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Connecting Mountain Islands and Desert Seas:

Biodiversity and Management of the Madrean Archipelago II

May 11-15, 2004
Tucson, Arizona

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Abstract—The Madrean Archipelago, or Sky Island, region of the southwestern United States and northern Mexico is recognized for its great biological diversity and natural beauty. This conference brought together scientists, managers, and other interested parties to share their knowledge about the region and to identify needs and possible solutions for existing and emerging problems. It provided a forum to update the state-of-knowledge acquired since the first conference in 1994. The proceedings contains over 100 articles and additional abstracts from the plenary sessions and from concurrent sessions covering biogeography, ecosystem monitoring, science-based management, cultural resources/history, invasive species, hydrology and biodiversity, conservation planning, ecology, fire, conservation practice, and global climatic change. Abstracts in Spanish are included. The summary of an open forum at the end of the conference provides additional thoughts about current and future needs for the Madrean Archipelago.

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Connecting Mountain Islands and Desert Seas:

Biodiversity and Management of the Madrean Archipelago II

and

5th Conference on Research and Resource Management in the Southwestern Deserts

May 11-15, 2004
Tucson, Arizona

Compilers:

Gerald J. Gottfried
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U.S. Department of Agriculture / Forest Service
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Preface

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David Hodges
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The Madrean Archipelago, or Sky Island region, of the Southwestern United States and Northern Mexico lies between the Sierra Madre Occidental and the Rocky Mountain Biogeographical Regions. The mountains, deserts, and grasslands of the region are known for their unique biodiversity and natural beauty. In 1994, Leonard DeBano and his associates organized the first conference to determine the state-of-knowledge and to focus management and scientific efforts on sustaining the Madrean Archipelago's ecosystems. The first conference was successful; however, research and management options are not static, and the 2004 conference has provided an opportunity to disseminate new information. The future health of the region was a concern in 1994, and concerns have grown as we enter the 21st century in spite of progress since the first conference. The 2004 conference combines two separate efforts (the "5th Conference on Research and Resource Management in the Southwestern Deserts" and "Biodiversity and Management of the Madrean Archipelago II") for ecosystems that are adjacent and often interconnected physically and philosophically and are under similar pressures from natural forces and human activities.

The Sky Island and Southwestern desert regions are the dubious beneficiary of too much love. More than 300,000 people have moved into the Sky Island region during the past 10 years. Rooftops have replaced open landscapes in some of our most remote valleys and hillsides. New and recent inhabitants view our public lands as their personal playgrounds, and the land often suffers because of overuse and public ignorance. However, people need to see themselves as an integral part of the ecosystem and attempt to understand the complexities in order to truly value biodiversity. Outreach to the general public should be an important component of our efforts. Humans are not the only problem; nature has not been kind to the region in recent years. Extended drought, wildfires, insects, diseases, non-native invasive species, and climate change are impacting, either alone or in combination, all of our major ecosystems from the low-elevation deserts to the mixed conifer and spruce-fir forests on the mountain tops. How can we protect the land while still availing ourselves of its numerous natural and esthetic resources? What must be done to make our ecosystems healthier and more sustainable?

In spite of these alarming changes, there is much hope for the Madrean Archipelago's future. The Forest Service, National Park Service, and other governmental agencies are working with private conservation groups to protect the region. Collaboration among groups will multiply the ability to protect and improve the land and its resources. Private organizations can mobilize their memberships and financial resources for conservation projects. Private land owners, such as members of the Malpai Borderlands Group and the Sonoita Valley Planning Partnership, have joined forces with State and Federal agencies, universities, and non-governmental organizations to protect their own lands with innovative strategies and successful models. An increasingly collaborative approach is needed as we attempt to tackle the region's problems and provide for the future.

Managers need science and particularly current science to accomplish their missions as stewards of the lands. Maintaining the viability of ecosystems and the connectivity among landforms requires sharing science and creative management among all groups.

Science cannot be truly useful if conducted in a vacuum. The 2004 conference, with more than 350 participants and almost 160 oral and poster presentations, was designed to increase communications and collaboration to achieve a common purpose and direction for the Madrean Archipelago and Southwestern deserts. Conferences such as this one provide a forum for the interchange of information, ideas, and views. The full articles and additional abstracts in these proceedings document the diverse research and management activities in the region. Each manuscript (except the abstracts listed at the end of the book) was reviewed for technical merit by at least two peers. Although this increased the time it took to publish the proceedings, it increased the quality of the content. The publication will also be available at **http://www.fs.fed.us/rm/main/pubs/electronic/rmrs_proc.html.**

Clear evidence of the spirit of cooperation and collaboration to achieve a common goal for the Madrean Archipelago is apparent by the members of the conference organizing committee and the diverse mix of agencies and private organizations that they represent:

- **Gerald Gottfried, Co-chair, USDA Forest Service, Rocky Mountain Research Station**
- **David Hodges, Co-chair, Sky Island Alliance**
- **Dale Turner, Program Chair, The Nature Conservancy**
- **Acasia Berry, Logistics Chair, Sky Island Alliance**
- **Brooke Gebow, Program Editor, University of Arizona, School of Natural Resources**
- **Alejandro Castellanos, Universidad de Sonora, Hermosillo**
- **Nina Chambers, Sonoran Institute**
- **Doug Duncan, U.S. Fish and Wildlife Service**
- **Peter Ffolliott, University of Arizona, School of Natural Resources**
- **Bill Halvorson, U.S. Geological Survey, Sonoran Desert Research Station**
- **Andy Hubbard, USDI National Park Service, Southern Desert Network**
- **Sue Kozacek, USDA Forest Service, Coronado National Forest**
- **Larry Laing, USDI National Park Service, Southern Arizona Office**
- **Dean Martens, USDA Agricultural Research Service, Southwest Watershed Research Center**
- **Joan Scott, Arizona Game and Fish Department**
- **Frank Toupal, USDA Natural Resources Conservation Service**
- **Tom Van Devender, Arizona-Sonora Desert Museum.**

Among this group of dedicated individuals we recognize the truly exceptional efforts of the committee chairs: Dale Turner, Acasia Berry, and Brooke Gebow (now with The Nature Conservancy) whose contributions to the success of the conference were far more than can be adequately described. We also acknowledge the assistance of Peter Ffolliott who was influential in the 1994 conference and who aided us with his active participation and insights and Tom Van Devender who accepted numerous extra duties. The activities of Nina Chambers and Andy Hubbard who organized the special ecosystem monitoring program are appreciated.

Three field trips to the deserts and mountains of the southern Arizona put the finishing touches on the conference, and we thank the leaders for organizing and leading the tours. The efforts of the session moderators, numerous student volunteers, art show coordinators, and the team that translated abstracts into Spanish are greatly appreciated. The conference would not have been successful without their efforts. The Rocky Mountain Research Station, Sonoran Institute, International Arid Lands Consortium of Tucson, the School of Natural Resources, University of Arizona, and the Sky Island Alliance provided additional support for the conference. We would like to thank Connie Lemos of the Rocky Mountain Research Station for her expert preparation of these proceedings for publication and Lillie Thomas of RMRS for her editorial assistance.

The comments in this Preface are partially developed from the opening remarks of Alison Hill, Assistant Director for Research, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO; David Hodges, Executive Director, Sky Island Alliance, Tucson; Jeanine Derby, Forest Supervisor, Coronado National Forest, Tucson; and Dale Turner, Conservation Planner, The Nature Conservancy, Tucson.

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Peter B. Stacey and Zach Perry. Coping with fragmented habitats on mountain islands: dispersal and metapopulation structure in the Mexican spotted owl.

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Keith Lombardo and John Kupfer. Landscape transformations: changes in biodiversity and ecosystem functioning following the Ryan Fire of 2002.

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Camille A. Holmgren, M. Cristina Peñalba, Kate Aasen Rylander, and Julio L. Betancourt. Late Quaternary vegetation history and paleoclimate of the U.S.A. – Mexico borderlands region from two new packrat midden series.

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Caren S. Goldberg, Kimberleigh J. Field, and Michael J. Sredl. Phylogenetic analysis of Chiricahua and Ramsey Canyon leopard frog populations in Arizona.

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Closing Remarks:

Biodiversity and Management of the Madrean Archipelago II: Summary of Discussions During the Concluding Session

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***Abstract**—The first Conference on Biodiversity and Management of the Madrean Archipelago brought together scientists, managers, and other interested parties from the United States and Mexico to share their knowledge about the region and to identify the needs and possible solutions for the future. The 1994 conference ended with an open discussion among the participants. The conference in 2004 had a similar goal and also concluded with an open forum. Participants discussed past and present accomplishments and the need for increased partnerships, especially among parties in the southwestern United States and northwestern Mexico, growing urban populations, and rural and American Indian communities. We recognized the gaps in our knowledge and major issues and opportunities for the future. All interested groups need to increase efforts to exchange information. Some of the major issues concerned the impacts of landscape fragmentation, management of water resources, and the role of fire in ecosystem management. Communications, cooperation, and technology transfers throughout the greater region should make the common goals of sustained biodiversity and ecosystem health more attainable in the Madrean Archipelago.*

***Resumen**—La primera Conferencia sobre Biodiversidad y manejo del Archipiélago Madrense reunió científicos, supervisores, y otros grupos interesados de Estados Unidos y México para compartir sus conocimientos sobre la región y para identificar las necesidades y las posibles soluciones en el futuro. La conferencia de 1994 terminó con una discusión abierta entre los participantes. La conferencia en el 2004 tenía una meta similar y también concluyó con un foro abierto. Los participantes discutieron sobre logros actuales y pasados y sobre la necesidad de incrementar el número de consorcios, especialmente entre grupos en el sudoeste de los Estados Unidos y en el noroeste de México, poblaciones urbanas y comunidades rurales y tribus Norteamericanas. Hemos Reconocido los huecos en nuestro conocimiento, los asuntos principales y oportunidades importantes en el futuro. Todos los grupos interesados necesitan aumentar sus esfuerzos para intercambiar información. Algunos de los temas principales se refirieron a los impactos de la fragmentación del paisaje, al manejo del agua y al papel de los incendios en la manejo de ecosistemas. La comunicación, la cooperación, y las transferencias de tecnología a través de la región mayor deben hacer que las metas comunes de biodiversidad sustentable y salud del ecosistema sean más alcanzables en el Archipiélago Madrense.*

Introduction

The Madrean Archipelago or Sky Island region of the Southwestern United States and Northwestern Mexico is recognized for its great biodiversity and natural beauty. The biological diversity of the region arises from its characteristic network of mountain ranges or "islands" separated by valley grassland or desertscrub and to its location between the main Sierra Madre Occidental and Rocky Mountain Biogeographical regions. The uniqueness of the region and the interest in its future has fostered numerous and diverse research projects throughout the years, and required land management to address the needs of maintaining biodiversity and healthy ecosystems. The same regional characteristics have fostered a number of advocacy organizations dedicated to protecting the region's natural and aesthetic resources.

One objective of the 1994 conference (DeBano and others 1995) was to bring together scientists, managers, and other interested individuals from the United States and Mexico to share their collective knowledge about the region, and to look ahead to the needs and possible solutions for the future. The conference, by assembling a large number of interested and dedicated people, helped shape research in the Madrean Archipelago for the past ten years. A general discussion at its conclusion considered the current state-of-knowledge and possible future directions of research and management in the Madrean Archipelago. These discussions were summarized by DeBano and Ffolliott (1995).

The 2004 conference represented a 10-year update on the Madrean Archipelago. Approximately 160 oral and poster presentations covered many of the critical issues for understanding and managing the region. Sessions covered biogeography, the role of fire, hydrology and water resources, ecology, invasive species, ecosystem monitoring, conservation planning and practice, and global climate change. The proceedings of the conference reflects the present status of knowledge on a large, but not necessarily all- inclusive, variety of relevant ecological and managerial topics.

The closing session in 2004 followed the same open discussion format that was used at the conclusion of the 1994 conference. The session was moderated by Thomas Van Devender and Laura Arriaga who presented overviews of the conference and changes in the state of regional knowledge since 1994. Daniel Neary then facilitated the open forum among the 90 plus attendees. Neary started the discussions by posing several questions including three suggested by Dale Turner of the The Nature Conservancy, Tucson, Arizona:

- "As a land manager, what knowledge would help you do your job better?"
- "As a researcher, what management questions can you help answer?"
- "As an activist, what can you contribute to improving conditions on the land?"

A summary of these discussions and comments is presented in this paper. The authors have rearranged the contents of the dialogue among participants to provide a logical flow to this paper. This summary is not all encompassing but rather largely reflects the opinions of the participants in the closing session.

Past and Present Accomplishments

The 1994 conference and the resulting proceedings inspired much of the research that was presented at the 2004 meeting. DeBano and Ffolliott (this proceedings) summarized many of the accomplishments during the past 10 years in the opening paper of this conference. A noticeable difference at the current conference was a greater emphasis on conservation in both the United States and Mexico and less on inventory and distribution information. Likewise, important studies concerning ecological phenomena over long temporal and large spatial scales were presented. Databases have developed and are continuing to grow as more information about the region becomes available. Examples of the evolving knowledge about the Madrean Archipelago region in southern Arizona include the floristic studies of Steven McLaughlin of the University of Arizona and Donald Pinkava and his students at Arizona State University, and the herpetological studies of Cecil Schwalbe and his associates from the U.S. Geological Survey and the University of Arizona. Several important books and publications printed since 1994 have contributed to the general knowledge of the region; the botanical and ecological works of Raymond Turner and others (1995, 2003), Felger and others (2000a, b), Paredes and others (2000), and Tellman (2002) are excellent examples. Russell and Monson (1998) have similarly contributed to our knowledge of the birds of Sonora. A number of conferences since 1994 have emphasized specific topics such as the future of arid grasslands and the effects of fire in Madrean ecosystems (DeBano and Ffolliott, this proceedings).

Much more baseline inventory information remains to be collected for Northwestern Mexico. The taxonomic databases compiled by the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) represent a noteworthy advance to achieve this baseline (Arriaga and others, this proceedings), but more local efforts are needed to complete regional biotas. Although a preliminary list of the flora of the Sierra de los Ajos in Sonora has been published, the distribution of plants and animals in many areas are very poorly known. Increased knowledge of species distributions will help revise the official lists of threatened, endangered, and sensitive (TES) species in Mexico. Collaboration between institutions and individuals in the United States and Mexico is increasing and should contribute to progress in filling information gaps related to the flora and fauna in Sonora. Additional investigation will ensure a larger regional effort for correcting the disparate state of knowledge found on the two sides of the border.

The impression ten years ago was that biodiversity in the Madrean Archipelago was rapidly eroding and that we had to act quickly to protect valuable resources. Regrettably, biodiversity is still declining as deforestation and landscape fragmentation continue. An issue arising during the past ten years is the concern about the spread of non-native invasive plants and animals and their impacts on the biological diversity of the region. Conservation and remediation of degraded or fragile ecosystems would be easier and more successful if adequate baseline information was available to managers in all areas.

Partnerships

It is important to build partnerships among the interested individuals and organizations to achieve the goals of sustained biodiversity in the Madrean Archipelago. An advantage of a conference is that it provides a vehicle for bringing people together for the interchange of ideas. Everyone and everything is tied to the environment, so we need to build bridges that connect all of us—ranchers and other private land owners, governmental agencies, universities, and environmental organizations. Improved and continuous communications among interested parties should result in less duplication of efforts and energy consumed in litigation among agencies, universities, and non-governmental organizations. Increased contacts between scientists and managers are vital so that new information is incorporated into management plans and the research community is aware of management's information needs. A more holistic viewpoint can alleviate the frequently encountered problems between urban and rural social-economic-political-institutional communications. We need to increase outreach and interpretation efforts to inform the growing and politically powerful urban populations in Arizona and elsewhere in the region about the values of maintaining and protecting biodiversity in the region. This population has an obvious impact on the land because of its occupation of the valleys and the need for quality recreation in the nearby mountains.

Outreach activities directed at rural communities should be sensitive to the effects of management decisions on livelihoods and social structure. The American Indian's traditional perspective on land management, resource use, ecology, and historical conditions of the land should be included. Knowledge gained by centuries of observation by indigenous peoples and their cultural histories has much to offer to the discussion of our region's future. Long-time ranchers and rural residents also have insights about natural processes that can contribute to our knowledge of biodiversity. Advocates for the "Sky Islands" must learn to be effective storytellers to reach the diverse populations within the region.

Opportunities for partnerships exist in the Metropolitan Tucson area that could have wide implications throughout the region. Both the Coronado National Forest and the Saguaro National Park will revise their land management plans in the near future, and have invited the public to participate in the process and share their knowledge and concerns with the agencies. The public should take advantage of these opportunities to work within our political, social, and legal systems to protect important resources. The plans will build on the foundations created by the information provided by the 1994 and 2004 conferences. Pima County's Sonoran Desert Conservation Plan and the USDI Bureau of Land Management's planning for the new Ironwood Forest National Monument are other examples of partnerships for land management planning.

Partnerships between the United States and Mexico are particularly important and, indeed, critical for the sound management of the diverse ecosystems of the Madrean Archipelago. Our diverse ecosystems are not separated by fences. It is necessary to think on a regional and where appropriate, larger scale in planning management and scientific efforts. Excellent examples of cross-border cooperation are the partnership between The Nature Conservancy and the Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora to identify conservation priorities and strategies for the Apache Highlands Ecoregion (D. Turner and others, this proceedings) and the partnership between the Comisión Nacional de Áreas Naturales Protegidas and the Sonoran Institute to monitor changes in biodiversity in the Sonoran Desert on both sides of the border. The Desert Southwest Cooperative Ecosystem Studies Unit is another example of a cooperative effort. The Unit was established to facilitate collaborative research, education, and technical assistance to address desert resource issues, and includes representatives from several Federal agencies with land management or research responsibilities, seven universities from the United States and northern Mexico, and nongovernmental organizations.

Increased information and technology transfers and exchanges among scientists and managers in both countries would benefit all parties. A recurring problem is the expense for Mexican colleagues to travel to meetings in the United States; holding a future conference at the Universidad de Sonora in Hermosillo would benefit the exchange process.

This conference brought to light much of the work that is underway on both sides of the border. However, workers in both countries remain unaware of research being conducted in their own backyards. A directory of people working on both sides of the international border and their areas of interest would facilitate cooperation. Scientists should also be more aggressive in identifying funding opportunities and in submitting proposals for joint U.S./Mexico research endeavors. We could work together to complete the inventories of the fauna and flora of Sonora and adjacent Chihuahua that can be used in making wise management decisions. Data and other information about TES species in Mexico would aid the understanding of species habitat requirements, the consequences of land management practices, and formulating of management decisions in the United States and Mexico.

Participants from the United States expressed concerns about the process of acquiring permits for research in Mexico and interest in the feasibility of developing a structure to make the permit process easier. However, others viewed the permit process as a way to enhance cooperation since required data sharing and collaboration may make the project results worthwhile for everyone. The permit issue is a legal question, not a scientific one. A booklet on Mexican laws, regulations, and permit procedures could provide guidelines for success. Participants must be sensitive to the fact that conservation and research must consider culture; the framework for working in Mexico is different from that in the United States. Science should be holistic, considering people and their institutions clearly within an ecosystem framework. Technologies developed in the United States cannot be blindly transferred to Mexico without considering the biophysical and socioeconomic environment of Mexico (DeBano and Ffolliott 1995).

There are 20 Sky Island complexes that occur on every continent throughout the world except Australia (Warshall 1995). Ecosystems in the Sky Islands of the adjacent Great

Basin in the Western United States, for example, have been impacted by other sets of dynamics over time. Scientists and managers who work in similar regions throughout the world might have insights and knowledge that could benefit their colleagues working in the Madrean Archipelago. Hence, an international Sky Island conference would bring interested parties together to compare and contrast their respective knowledge and perspectives.

Gaps in Knowledge

Information Technology

While the knowledge about the many faceted resources of the Madrean Archipelago has increased over the past ten years (DeBano and Ffolliott, this proceedings), many gaps still remain. Conference participants identified many concerns about improving access to information relevant to the Madrean Archipelago. A suggestion was made to develop a web site for those working in the region that includes a link to existing Sky Island literature. The Rocky Mountain Research Station developed an annotated bibliography for the Madrean Archipelago (Ffolliott and others 1999) that is posted on one of the Station's Web sites (www.rmrs.nau.edu/publications/madrean/). However, the bibliography requires regular updating with current literature, and its existence should be advertised to potential users. A common framework for inventory and monitoring activities and data acquisition and storage protocols would enhance research and management across agency and university entities. Such a clearinghouse could prevent expensive duplications of efforts within the region. Another method to reduce duplication and to enhance cooperation is to develop an atlas of sites where researchers are conducting projects or where research has been conducted in the past with the appropriate literature citations. A "chat room" to exchange information and to discuss questions and answers also would help facilitate contacts among interested parties.

While the availability and technology of computerized databases have improved over the past ten years, more needs to be done. These databases still lack information about keystone subject matter areas. An important example is the scarcity of general ecological information about indigenous and invasive herpetofauna. It is difficult to manage for ecosystem diversity without baseline information (DeBano and Ffolliott 1995). Current databases are also incomplete with respect to expressions of ecosystem degradation and fragmentation, conservation of key genetic flows, structural gap analyses, large-scale watershed conditions and hydrologic changes attributed to land use, market and non-market resource responses, and ecosystem management actions. Improved computerized databases containing information from well-studied sites in the United States can be transferred to facilitate cost-effective efforts to solve problems on less studied sites in both the United States and Mexico, although such transfers must recognize the inherent differences and similarities among sites.

Major Issues and Opportunities for the Future

The forest, woodland, and grassland vegetation on the mountains and plateaus throughout the Western United States and Northwestern Mexico are at risk because of the combined forces of extended drought and climate change, insects, fire, diseases, and non-native invasive species, and the impacts of past management and human development. Major ecosystem shifts will result if the current conditions persist, with the possible regional extinctions of some species and communities (Lynch, this proceedings; Swetnam, this proceedings). How should managers respond to the situation? What is the balance between management for natural resource commodities and sustaining ecosystem health? Can the scientific community provide ecological and climatological data for necessary adaptive management? Will adaptive management practices work? What are the effects of changes on adjacent regions and how do they affect the Madrean Archipelago? Can we extrapolate regionally from how people respond to local changes or vice versa? We need to summarize and analyze the historical weather and hydrological records in the region to establish a baseline for evaluating the current changes and predicting future changes. Historic information on vegetation changes during similar periods of drought and insects could help us plan for the current challenges.

The population of the region is growing and spreading into the valleys and mountains. These developments fragment open landscapes, provide conduits for non-native invasive species, block traditional animal migration routes, influence the diversity of animals on the land, increase the demands on often limited water resources, and influence the socio-economic patterns of rural communities. What can be done to mitigate this undermining of so many of the region's desirable attributes? It can be difficult for ranchers to refuse to sell their land when their economic sustainability is in question. There is a need for research to evaluate the impacts of fragmentation on the region's resources and to evaluate potential ecological and political compromises that would reduce its impacts.

Watershed hydrology and condition, riparian ecosystems, and water resources are critical issues in the region and will grow in importance as the population continues to increase in the face of periodic and often prolonged droughts. The climate in the region is variable and extended periods of drought have occurred over pre-historic and historic times (Betancourt, this proceedings). Some critical questions are:

- How will the scientific community respond and contribute to issues related to global climatic change in the region?
- How will possible water diversions and aquifer mining affect the fauna and flora, especially in important riparian communities?
- Is the reuse of water feasible on a large scale and how will this affect native ecosystems?
- How many people can the region support?
- Can scientists assist government with the related political and economic considerations?
- Should there be active management areas (AMA) or compatible delineations for water resources in rural areas?

- How will human activities and the climate variability modify our natural environment?
- What are the trade-offs in ecosystem management and how can the system be modified to adjust to change?

Fire was a natural force in many of the forest, woodland, and grassland communities of the Madrean Archipelago prior to Euro-American settlement (Swetnam, this proceedings). However, fire frequencies and characteristics have been altered because of past livestock grazing practices that removed a significant portion of the fire-carrying herbaceous vegetation and by past aggressive fire suppression policies of governmental agencies. Moratoriums on harvesting and thinning in the mountain forests and fire suppression activities have resulted in overcrowded stands of trees that are susceptible to insects and diseases and to stand-replacing wildfires. Mountain communities, which are at risk during wildfires, have expanded as the regional population continues to grow. Managers are faced with problems of protecting the growing wildland-urban-interface areas around these communities and the limited access routes to them. Agencies, often with support of private organizations, are attempting to reintroduce fire into many of the ecosystems in the Madrean Archipelago. We need to refine the knowledge of how to use fire wisely, how to speed up the approval process, and how the reintroduction of fire affects the ecosystems. A related issue is how should the region's forests and woodlands be managed to reduce the threats of destructive natural forces and still maintain biological diversity and healthy conditions within the ecosystems?

More collaboration with evolutionary biologists and managers will improve restoration efforts. We need to take a longer term view relative to genetic diversity, gene flows, and effective population size and their dynamics. There should be a greater emphasis on species interactions with their environments and less on the study of single species.

Additional information from the Mexican portion of the region will fill gaps in our knowledge of the floras and faunas of the Madrean Archipelago. The classic work by Marshall (1957) provided valuable information about the bird species and plant community composition in the pine-oak woodlands of southern Arizona and adjacent Mexico. Similar research is needed to increase the understanding of vertebrate and invertebrate community structures. Migration dynamics of indigenous and non-native species throughout the region have not been thoroughly studied.

Conclusions

A wide range of new and relevant information on the biodiversity and management of the Madrean Archipelago of the Southwestern United States and northern Mexico was presented at this conference. The conference has the potential of playing a similar role as the 1994 conference by providing a basis for planning future research and management agendas in the region. The conference provided a medium for communications among a diverse group of interested individuals, representing a variety of institutions from within the Southwest United States and neighboring Mexico. A follow-up conference on common ecological and managerial issues held in Mexico would enhance the opportunities for a wider group of stakeholders to participate in the established dialogue.

The Madrean Archipelago faces problems that are linked to natural events related to climate variability and some that are related to the consequences of past and present human activities. In 1995, DeBano and Ffolliott stated that building a consensus on the central goals and priorities of research and management will be necessary to confront region's challenges. The need for consensus holds today. Communications, cooperation, and technology transfers throughout the greater region should make the common goals of sustained biodiversity and ecosystem health more attainable in the Madrean Archipelago.

Acknowledgments

The helpful comments and suggestions of Leonard F. DeBano of the School of Natural Resources, University of Arizona, Tucson, and Carleton B. Edminster of the USDA Forest Service, Rocky Mountain Research Station, Flagstaff, are greatly appreciated.

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Plenary Sessions

Ecosystem Management in the Madrean Archipelago: A 10-Year (1994-2004) Historical Perspective

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Abstract—*The USDA Forest Service implemented a more holistic form of ecosystem management than previously practiced in the early 1990s through several ecosystem programs implemented in the Western United States. The ecosystem program that concerns this conference was a collaboration on "Achieving Ecosystem Management in the Borderlands of the Southwestern United States through Research and Management Partnerships" among researchers, managers, conservationists, and local landowners. Concurrent with initiation of this program was the first conference on "Sky Islands of the Madrean Archipelago," which brought together stakeholders and other interested parties from government agencies, universities, and private organizations. This paper describes the evolution of this ecosystem management program from a historical perspective and discusses some of the resulting activities.*

Introduction

The concept of ecosystem management is not new, but its role as a central theme of natural resources management gained renewed interest and greater emphasis in the early 1990s. In response to this increased interest and emphasis, the USDA Forest Service and others initiated a variety of ecosystem programs throughout the Western United States. The program that concerns this conference was collaboration on "Achieving Ecosystem Management in the Borderlands of the Southwestern United States through Research and Management Partnerships" among researchers, managers, conservationists, and private landowners. Concurrent with initiation of this program was the first conference on "Sky Islands of the Madrean Archipelago," which brought together interested stakeholders and other interested parties from government agencies, regional universities, and private organizations. This paper describes the implementation of ecosystem principles in the management of the Southwestern Borderlands of the United States and Mexico. Several milestone activities in the 10 years since the first conference are also described in the paper.

Background Perspective

The "ecosystem" concept has evolved from one representing a relatively stable biological-physical entity into a more dynamic form representing constantly interacting biological and physical processes in both time and space. Incorporation of the biological-physical processes of the ecosystem into a management-oriented perspective has led to still more complex landscape systems consisting of social, political, and economic dimensions. The term "ecosystem management" was coined in the early 1990s when ecosystem theory was implemented by managers in response to increasingly complex real-world management issues. It has since become embedded in the decision-making of managers, policy-makers, and the general public (Grumbine 1994). However, the term has also been used to describe a vague concept of land stewardship and, unfortunately, lacks a consistent definition among its users. It has been used interchangeably with terms such as "ecosystem health," "ecosystem integrity," and "ecosystem sustainability" adding to the confusion. In matter of fact, no single or unifying definition of ecosystem management has been universally accepted by researchers, managers, or decision-makers. Nevertheless, there are some common principles and concepts that are present in most definitions including:

- Ecosystem management represents a balance between the physical and biological features of ecosystems and people's needs for ecosystem resources. Ecosystem management, therefore, requires a balancing of the natural system with anthropogenic effects and other external influences impacting of the system.
- Ecosystem management requires that the functions and processes of biodiversity and productive capacity of the ecosystem be considered together in decision-making. Implementation of ecosystem management also requires that the levels of degradation below which ecosystems cannot be sustained without losing vital attributes be identified and that these thresholds be known to decision-makers.
- An appreciation and acceptance of "losses" is an essential part of ecosystem management. It is inevitable that some losses in ecosystem resources will occur in meeting societal demands. Choices and trade-offs are required and, therefore, the costs and benefits of making these choices and trade-offs must be fully assessed.
- The scale of ecosystem management implementation varies widely in time and space and must be flexible enough to respond to changing management goals and objectives. No single temporal or spatial scale is adequate for managing all ecosystems.
- Adaptive management is an essential part of ecosystem management. The criteria and rules for this management

must be flexible enough to adapt to changing biophysical conditions, human behavior, and scientific advances.

Applying Ecosystem Management in the Madrean Archipelago Region

The USDA Forest Service became interested in implementing the "more contemporary" concept of ecosystem management in the early 1990s to insure diverse, healthy, productive, and sustainable ecosystems and to protect or, if necessary, restore the integrity of the soil, air, and water resources, biological diversity, and ecological processes on National Forests and Grasslands (Vogt and others 1997). This approach was viewed by the USDA Forest Service as a means to manage ecosystem resources for present and future generations as a continuous flow of multiple benefits in a manner that was largely harmonious with ecosystem sustainability. As a result of this interest, 19 ecosystem management research projects were initiated by USDA Forest Service Research throughout the United States in 1994, one of which was the Southwestern Borderlands Project.

Initiation of the Southwestern Borderlands Project

The Rocky Mountain Research Station became actively involved in the program when it was awarded an ecosystem management grant to conduct research within the Southwestern Borderlands area and the Colorado Front Range, the Great Basin, the Bitterroot, and the Middle Rio Grande. The main objective the Southwestern Borderlands Project was to achieve responsible ecosystem management in the region through coordinated research and management partnerships involving both the public and private sectors. Much of the information to be gained from the project could then be extended to management of the larger Madrean Archipelago region of mostly isolated mountains known as "Sky Islands" separated from each other by "seas" of desert shrubs and grasslands. The project's plan of action included the preparation of appropriate strategies for restoring natural processes; improving the productivity of grasslands, woodlands, and forests, providing critical wildlife habitats; and sustaining open landscapes, viable rural economies, and social structures (Edminster and Gottfried 1999). The two initial problem areas for the research effort were to:

- Provide the scientific basis to establish the desired future conditions for the region based on the integration of the highest quality biological-physical science with desired future social and economic conditions in the context of public and private partnerships.
- Combine a long-term program of basic and applied research and coordinated monitoring efforts with ongoing activities of other management agencies and not-for-profit private organizations to integrate past and future research findings into management and contribute to developing guidelines for sustaining a variable rural economy and open landscapes.

Assembling and comprehensively reviewing the existing body of scientific knowledge pertaining to the Madrean Archipelago was the first major assignment of the newly created project. A large amount of research-based information on the biological, physical, and social dimensions of the region had been generated in the past, but this information had not been thoroughly collated for the necessary integrative analysis. The two approaches posed to bring this information together and make it available to the project's participants and others were:

- Organizing a conference where local and regional experts were asked to present materials relating to all aspects of the Madrean Archipelago region.
- Entering into partnerships with knowledgeable investigators to synthesize information on topical areas having significant research and management planning applications.

The first approach led to the first conference of the Madrean Archipelago region entitled "Biodiversity and Management of the Madrean Archipelago: The Sky Islands of Southwestern United States and Northwestern Mexico," held in Tucson, Arizona, on September 19-23, 1994. Many of the contributions achieved in undertaking the partnerships to bring known information together resulted in a series of milestone activities, some of which are described in this paper.

Implementation of the Long-Term Research Program

Concurrent with the initial information-collecting phase of the Southwestern Borderlands Project was the planning and implementation of a long-term, systematic program of both basic and applied research endeavors to enhance ecosystem management in the Madrean Archipelago region. The Rocky Mountain Research Station initiated numerous studies on its own but, more importantly, developed effective investigative partnerships with researchers and managers from other Federal and State agencies, universities, conservation organizations, and independent investigators. These partnerships provided the expertise necessary to address the wide array of questions that were considered fundamental to the level of "good ecosystem management" required to create and sustain healthy and productive landscapes. The willing exchange of ideas and information among the collaborators in these efforts has been one of the major forces in the 10-year success of the project. Of particular note has been the close collaboration with the Coronado National Forest, the Natural Resources Conservation Service, the Bureau of Land Management, the Universities of Arizona, New Mexico, and Oklahoma and other organizations in the public sector; and the Malpai Borderlands Group, the Animas Foundation, The Nature Conservancy, the Hadley Associates, the Desert Botanical Garden, and other not-for-profit organizations in the private sector. Many of the accomplishments and contributions that have evolved from these partnerships are presented in these proceedings.

Milestone Activities

There have been a large number of activities that have resulted in significant contributions to the level of knowledge relative to ecosystem management in the Madrean Archipelago region since publication of the proceedings of the first conference (DeBano and others 1995). While not intended to be complete, some of the more significant of these milestone collaborative activities are summarized below.

Symposia, Conferences, and Meetings

A symposium on the "Desired Future Conditions of Southwestern Riparian Ecosystems: Bringing Interest and Concerns Together" provided another forum for researchers, managers, conservationists, and representatives from the private sector to come together and share their findings, ideas, and visions for managing, conserving, and restoring degraded riparian ecosystems in the Southwestern United States including the Madrean Archipelago region (Shaw and Finch 1996). This symposium, held in Albuquerque, New Mexico, from September 18-22, 1995, addressed a variety of topics on hydrology and ecology; human history, values, and needs; and desired future conditions for these fragile ecosystems. It became evident that people were acknowledging and managing the region's landscapes in the context of humans being integral and influential components of riparian ecosystems by incorporating their needs, effects, and conflicts into more comprehensive management endeavors.

Researchers, managers, and resource specialists from government agencies, universities, and the private sector came together in a second conference (symposium) focusing specifically on the Madrean Archipelago ecosystems, entitled "Effects of Fire on Madrean Province Ecosystems," to learn about the effects of fire on ecosystem resources and how fire might be incorporated into a more holistic ecosystem approach to both research and management of these resources (Ffolliott and others 1996). Oral and poster papers on the management implications of the effects of fire on the ecosystems' resources; the varying socio-political perspectives of fire; and fire management issues of interest to different stakeholders were presented at the conference held in Tucson, Arizona, on March 11-15, 1996. The concluding presentation considered the benefits, concerns, and constraints relative to the future use of fire in the region.

The National Park Service and its cooperators continue to organize biannual conferences on "Research and Resource Management in Southern Arizona Parks and Neighboring Lands," with this conference on "Connecting the Mountain Islands and Desert Seas" in the Madrean Archipelago representing the fifth in the series. These conferences, all of which have been held in Tucson, Arizona, allow a diversity of attendees to learn about asking the right questions on research and resource management issues; gathering and processing relevant data sets and other information; effectively communicating findings; and guiding the application of results. The first conference, held May 15-17, 1996, sought to highlight and explore the relationships between National Park Service resources and those on neighboring lands and between researchers, resource managers, and the public (Tibbitts and Maender 1998). The following conferences had more specific themes. The second conference, held May 5-7, 1998, focused mostly on a century of research and resource management in the parks of Arizona and neighboring lands (Benson and Gebow 1999); the third conference, held May 16-18, 2000, reviewed the creativeness of cooperation and collaboration in research endeavors and resources management of these lands (Halverson and Gebow 2000), and the fourth conference, held May 15-17, 2002, addressed the research and resource management information needs of these lands (Halverson and Gebow 2002).

The fragile grassland ecosystems of the Madrean Archipelago region face continuing threats from spreading urbanization; habitat fragmentation resulting from development of rural housing; ecological impacts of invasive plant species; and conflicts over livestock grazing policies. Therefore, a conference on the "Future of Arid Grasslands: Identifying Issues, Seeking Solutions," was held in Tucson, Arizona, October 9-13, 1996, to provided a platform for private and public stakeholders to thoroughly discuss these problems and their possible resolutions in a non-confrontational manner (Tellman and others 1998). The targeted groups of attendees were ranchers and other private landowners, not-or-profit private organizations; representatives of government agencies with responsibilities for land stewardship in the region; and environmental advocates, researchers, and students.

More than 150 researchers, managers, and food producers were brought together in a symposium on the "Utilization and Conservation of Wild Flora in the Arid Zones of Northwestern Mexico and the Southwestern United States" to review utilization and conservation strategies for the often fragile flora inhabiting the arid and semiarid ecosystems of Northwestern Mexico and the Southwestern United States region (Vasquez del Castillo and others 1999). This symposium was organized by the University of Sonora and held in Hermosillo, March 4-6, 1998. Formal presentations and informal discussions allowed the diverse group of attendees to review and evaluate the status-of-knowledge (at the time) relative to the symposium's theme and, in doing so, provide a basis to plan for future collaborative efforts that will benefit both countries. Ecosystem conservation, sustainable use of resources, and proper management of the indigenous flora were stressed throughout the symposium.

A conference on "Cross Border Waters: Fragile Treasures for the 21st Century" held in Tucson, Arizona, June 3-6, 1998, represented the continuation of earlier forums on the exchange of scientific information, sharing of common concerns, and bilateral cooperation between Mexico and the United States for environmentally sound natural and cultural resource management (Gottfried and others 1998). Attendees identified issues affecting the management of wildlife and recreation areas; increased awareness of issues facing the border States on protection of the environment and utilization of valued cultural resources; and developed networks among resource managers, educational institutions, and policy-makers to better manage the binational resources.

A meeting entitled "Toward Integrated Research, Land Management, and Ecosystem Protection in the Malpai Borderlands," was held in Douglas, Arizona, January 6-8, 1999, to inform scientific communities, land management agencies, and local stakeholders of the progress made in the research studies and resources inventories of the Rocky Mountain Research Station's partnerships with researchers and managers from universities, public agencies, not-for-profit conservation organizations, and independent investigators in the mentioned "Southwestern Borderlands Ecosystem Management Project" in developing the necessary science base for this purpose (Gottfried and others 1999). Among the topics considered were species ecology and management, resource inventories, landscape changes, and anticipated future directions in the sciences and resource programs Southwestern Borderlands Project and, more generally, the Madrean Archipelago.

The accomplishments and contributions of the Santa Rita Experimental Range, the longest continuously operated research area dedicated to the sustainable management of North American rangelands, were celebrated in a conference held in Tucson, Arizona, October 30-November 1, 2003. The conference proceedings, entitled the "Santa Rita Experimental Range: 100 Years (1903 to 2003) of Accomplishments and Contributions," consist of a series of synthesis papers on significant research findings relative to vegetation and livestock management practices, wildlife ecology and management, hydrology and soil erosion, and historical trends and recent flora on the Santa Rita Experimental Range (McClaran and others 2003). These syntheses were expanded by reporting on recently completed or ongoing research on Santa Rita.

Publications

Ecologically fragile desert grasslands are found in the basins and valleys that skirt the mountain ranges and hills of the Madrean Archipelago. A comprehensive book appropriately entitled "The Desert Grassland" tells the story of the closely tied but also surprisingly independent soil features, landforms, and plants and animals that inhabit this often threatened ecosystem (McClaran and Van Devender 1995). How the frequency and intensity of fire can influence the present flora and fauna and how humans from Amerindians to contemporary ranchers, public land managers, and real estate developers have changed the relative abundance of indigenous species are described. A review of attempts to re-establish native forage plants where overgrazing, drought, farm abandonment, and increased densities of invasive plants have occurred concludes the book.

Interest in the holistic philosophy of ecosystem management led the USDA Forest Service to supported a study of past land use in the San Rafael Valley on the southern slopes of the Huachuca Mountains in southeastern Arizona. To better understand the cumulative impacts of people on the general area, a historical chronology of human occupation of the valley has been presented in a publication on the "Land Use History of the San Rafael Valley, Arizona (1540-1960)." A focus of this publication by Hadley and Sheridan (1995) is placed on natural resources use and an analysis of the impacts of historic land-use practices from Euroamerican contact to the twentieth century. The USDA Forest Service simultaneously sponsored a series of studies on the climatic patterns, soils and hydrology, and vegetation and wildlife in the area to obtain a more complete ecological picture of this unique setting (see Morrison and others 1997; Ffolliott and others 1996, 1999; McPherson and Weltzin 2000; and others).

While violent thunderstorms often sweep over the mountains of the Madrean Archipelago, no storm has ever been as fierce as that expressed by the opposition to the telescope installations on Mr. Graham. These installations roused little interest when first proposed in the early 1980s, but they came to represent a threat to many environmentalists and the desecration of sacred land to some Native Americans. Controversy aside, a book entitled "Storm Over a Mountain: Conservation Biology and the Mt. Graham Affair," represents a significant contribution to the knowledge of conservation biology on Mt. Graham and, more generally, throughout the Pinaleno Mountains (Istock and Hoffmann 1995). Contributors in the fields of astronomy, botany, biogeography, and genetics examined the purpose and promise of the ground-based observatories; the forest structure of the Pinalenos and its history; the past and present biogeographical basis for conservation of the Pinalenos; and the vulnerability to extinction of isolated species such as the Mt. Graham red squirrel.

Information on the taxonomic affiliations, geographic distributions, natural history and ecology, conservation and management, and ongoing studies on birds, mammals, and amphibians and reptiles is presented in a review of the "Literature on Wildlife Research in the Madrean Archipelago: 1800s-1994" by Morrison and others (1997). The references contained in this comprehensive literature search have furnished a key input to the development and subsequent prioritization of research plans that integrate the environmental factors that influence wildlife resources in the region. Early investigative works (1800s to 1960) concentrated on determining what species occurred in the borderlands. The majority of more current literature concerns varying aspects of ecology without particular emphasis on any specific topic. Abstracts and comments by the compilers are included with the cited references.

A literature base for planning broadly structured, ecosystem-based research and management activities in the Madrean Archipelago has been compiled online in "A Bibliography for the Northern Madrean Biogeographic Province" by Ffolliott and others (1999). Citations in the bibliography are listed by author(s) in the subject-matter headings of conservation and management, fire and fire effects, history of land use, human impacts, hydrology and watershed management, range management and livestock grazing, recreation and tourism, and plant, vertebrate, and invertebrate ecology. A listing of the over 5,000 items is available on the Web site http://ag.arizona.edu/OALS/watershed/index.html maintained by the Office of Arid Land Studies at the University of Arizona and the USDA Forest Service.

Contributors to a book on the "Ecology and Management of Forests, Woodlands, and Shrublands in the Dry Regions of the United States and Mexico: Perspectives for the 21st Century" examined the ecological relationships, historical and present-day land-use patterns, and natural resources management practices in the forests, woodlands, and shrublands of this arid and semiarid region (Ffolliott and Ortega-Rubio 1999). Many of the ecosystems of interest and concern to people on both sides of the border area are considered in this review, including montane forests, pinyon-juniper and encinal (oak) woodlands, sclerophyllous communities, and mesquite ecosystems. This book presents the available knowledge (at the time) in a perspective that furnishes a basis for the conservation and sustainable use of the natural resources in the region into the 21st century.

The main effects of disturbance factors and climate change on plant communities in the borderlands region have been evaluated in a literature review by McPherson and Weltzin (2000) entitled "Disturbance and Climate Change in United States-Mexico Borderland Plant Communities." A focus of this review is placed on the physiognomic-level changes of the woodlands and grasslands of southeastern Arizona and southwestern New Mexico. It is apparent that the observed changes in vegetation physiognomy have broad implications for management and land use in the borderlands. Much of this knowledge is derived from descriptive research having value for documenting changes in vegetation and identifying explanations for these changes.

As a follow-up to the keystone book on "The Changing Mile" by Hastings and Turner (1965), Turner and others (2003) have recently authored a sequel entitled "The Changing Mile Revisited" that contains repeat photography of earlier reference sites and accompanying descriptions. The sub-title of this book, "an ecological study of vegetation change with time in the lower mile of an arid and semi-arid region," is indicative of its main contribution to the status of ecological knowledge on both sides of the border of the Madrean Archipelago region. Both of these books contain baseline information to further people's understanding of desert ecology and their appreciation of vegetation dynamics of the Arizona-Mexico borderlands.

Conclusions

Much of what has been accomplished relative to ecosystem management in the Madrean Archipelago region in the past 10 years forms a sound basis for continuing the collaborative investigations necessary to achieve effective, efficient, and responsible ecosystem management. The partnerships and other relationships that have been forged among researchers, managers, ranchers, and environmentalists in tackling the challenges put forth in the early 1990s to ensure that diverse, healthy, and productive ecosystems are largely responsible for the successes achieved to date. There is every reason to believe that these partnerships and other collaborative efforts will also be sustained in the future to the benefit of the people of the region.

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Landholding Systems and Resource Management in the Sky Island Borderlands

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***Abstract**—The Borderlands region of the Madrean Sky Island Archipelago provides an excellent opportunity to compare a variety of landholding systems. During the past four centuries, landholding has been regulated by diverse systems that vary from the customary land distribution practices of native peoples to formalized written land laws imposed by the nation states that currently regulate land ownership and use. The following very informal review of landholding systems is intended to provide historical context for current scientific studies. Hopefully it will initiate a discussion of the relationship between land tenure, custom, and the management and consumption of natural resources.*

This discussion focuses on three "Borderland" valleys that extend across the present boundary between the United States and Mexico. Two of the valleys, the San Pedro River Valley and the San Simon/San Bernardino Valley, connect Arizona and Sonora, while the Animas/Playas Valley crosses between New Mexico and Chihuahua. With roughly south-north orientations, these montane valley systems have served as corridors for the movement of flora and fauna for many millennia, resulting in exceptional biological diversity.

Throughout the Borderlands, "Sky Island" mountain ranges abruptly emerge from "desert grassland seas." The vast, treeless expanses of grass, in turn, contain occasional watercourses, where riparian corridors provide a greater abundance of water, shelter, and biodiversity than can be found on the surrounding plains. These corridors proved to be the most attractive locations for human residence during the area's approximate 14 millennia of human settlement. During this lengthy prehistory, a remarkable variety of customs and practices must have been used to regulate settlement patterns and access to resources, and most of them will remain unknown. For the past four centuries, however, we are fortunate to have specific observations and recorded regulations for the systems that determined landholding and resource allocation in the Borderlands.

Today, the Borderland valleys contain a patchwork of landholding arrangements, demarcated by multiple jurisdictional and political borders. National, state, and county or *municipio* borders, as well as borders between private and public lands, communal and individually owned properties, wilderness areas and those with multiple-uses cut across the valleys. The four-century development of this geographical, political patchwork provides an unusual opportunity to consider the relationship between different land tenure systems, land use practices, cultures, and their consequent ecological impacts. Since the 1600s, diverse Native American groups, the Spanish Empire, the nation of Mexico, and the United States in its territorial and statehood phases have established landholding systems and resource regulations. Compliance with regulations occurred to a greater or lesser degree, according to the customs of the time and place. Impacts from the wide range of landholding regulations have been as diverse as the systems themselves. Impacts associated with particular landholdings can be separated into those that are intensive in restricted locations and extensive throughout the entire region. During the past four centuries, the most extensive land uses in the Borderlands have been associated with livestock, and much of the following discussion focuses on landholding associated with this use.

Native Landholding Systems at Contact

During the 17th century, Spanish military and church personnel recorded their perceptions of the native groups who resided in the Borderlands. Settled, agricultural peoples were found only on the San Pedro River, living in reed and pole houses in *barrio* settlements (so small they could not be called villages) scattered at irregular intervals along the river, each barrio having a system of irrigation canals. Inhabitants wore cotton clothing, *gamusas* (dressed buckskin), and decorated themselves with feathers and semi-precious stones. Archaeological excavations support the Spanish assumption that the river settlements were semi-independent and relatively peaceful. Cultural remains indicate that residents produced manufactured items and traded with distant peoples. Spaniards identified these natives as Sobaipuris, speakers of a Piman dialect. They lived on the eastern boundary of the region known to the Spaniards as the *Pimería Alta*, the land of the upper Pimas.

The orderly farm plots of the Sobaipuris produced a surplus of beans, maize, and squash. Farmers cooperated in the construction of irrigation canals, and shared the waters from the river's perennial flow, indicating that residents and leaders of the settlements had developed an organized method for determining rights to the fields, delivery of water, and proprietorship of the produce. The Sobaipuris apparently occupied their farm communities on a yearlong basis, although a community-based system for occasional relocation of entire agricultural settlements for safety or resource management was also in place.

East of the San Pedro more mobile native groups occupied the uplands. These largely non-agricultural groups hunted, gathered, sent out raiding parties, and lived seasonally in *rancherías* (encampments). Initial Spanish military reports give prominent mention to the Janos and Jacome, but with time, Apaches emerge the dominant group, and their territory came to be called the *Apachería*. The Borderlands portion of the *Apachería* was home to three bands of Athabascan-speaking Chiricahua Apaches. Each band occupied a separate territory and bore a separate name. The bands were in turn divided into several independent local groups – the units that had the greatest social and economic significance for Apaches.

Local groups recognized non-hereditary leaders, who determined movements and resource allocation in conjunction with other group members. They established headquarter encampments in mountain strongholds or in locations with good resources throughout the Chiricahua, Huachuca, Sierra San Luis, Sierra de la Hacha, Animas, and other ranges. The headquarter encampments might be abandoned in the event of an epidemic, enemy encroachment, depletion of the water, grass, fuel, or food supply, or degradation of the site through lengthy occupation. The local groups remained in their *rancherías* or revisited them on a regular basis and considered them home. These resource management practices, which provided for recovery through non-use, formed a rational, if less visible, form of landholding than that employed by the Sobaipuri.

Although occupation and ownership are not coterminous, it is clear that in a cultural system that does not incorporate written regulations, customary usufruct rights can be equivalent to property rights. Occupation, albeit seasonal, bore the implications of ownership.

Spanish Missions, Presidios, and Land Grants

Spanish presence in the Borderlands began during the late 17th century, with the establishment of missions, *visitas* (mission visiting stations), and *presidios* (military garrisons) in the San Pedro Valley portion of the *Pimería Alta*. Penetration into the *Apachería* consisted largely of military expeditions, the distribution of range cattle, and the establishment of a ranch and short-lived presidio at the *cienega* of San Bernardino. During the entire period of Spanish control (1680s-1821) the Borderlands region remained a sparsely populated frontier of shifting alliances and changing settlement patterns, dominated by Native American groups. Nevertheless, Spaniards imposed new forms of spatial reorganization on the indigenous populations that had lasting consequences.

The major Spanish imperial institutions, the church and the military, cooperated in accomplishing overlapping objectives. Members of religious orders staffed presidios and provided consolation to soldiers on military expeditions and army personnel accompanied missionaries when they established new missions. Jesuits supervised the Borderland missions until the order was expelled from the new world in 1767, after which time the missions were taken over by Franciscans. Each mission district had a *cabecera*, an administrative headquarters usually located at the largest native village. In addition, the religious order set up several *visitas* at smaller villages, where missionaries periodically said Mass. After conversion to Catholicism, the mission system's second most important goal was the incorporation of native peoples into the imperial economy. This was accomplished by concentrating dispersed native settlements into compact Spanish-style villages, where natives could be acculturated and their labor could produce a marketable surplus. These nucleated mission communities were called *congregaciónes* when they were established for Indians who already resided in villages. *Reducciónes* were nucleated communities established for Indians who lived in dispersed settlements. Both community forms radically changed native settlement patterns and concentrated population far more than was customary for any native group in the Borderlands region. Indian *governadores* acted as agents for the missionaries, and were invested with Spanish civil authority.

Missionaries acted as agricultural extension agents, distributing livestock, seeds, rootstocks, and farming implements to their charges. In the artificially created pueblos, missionary and military personnel attempted to restrict seasonal migrations for gathering and hunting and to extract extra labor for commodity production, exactions that proved to be unpopular, and, more importantly, unhealthy. Despite repeated importations of additional native residents to the mission settlements, native populations continually declined, a result of vulnerability to malaria and other European diseases to which natives had no immunity. As a consequence of declining population and increased Apache raiding, in 1762-63, the Sobaipuri relocated from the San Pedro Valley to the Santa Cruz Valley, after which time there were no nucleated Piman settlements along the San Pedro River, although a few Sobaipuri may have continued to reside in the area.

Presidios (military garrisons) were intended to provide dual services – military protection and settlement of the initial Spanish *vecinos* (citizens) in frontier areas. As an inducement to settle in dangerous or otherwise undesirable locations, presidio captains were authorized to issue soldiers small grants of land, house lots, and garden plots, and soldiers were encouraged to bring families with them. Although the dual scheme of protection and settlement proved effective elsewhere, the Borderland presidios failed to meet either military or settlement objectives. The garrison on the San Pedro moved three times, seeking an unexposed, healthful location that would effectively block Apache incursions. The garrison finally retreated to Santa Cruz, Sonora, where the small farming village still bears the name of the presidio today. The ranch at the San Bernardino cienega functioned as a presidio from 1775 to 1780, after which time the garrison was recalled to its original site at Fronteras. Immediately south of the present international boundary, the Spanish army constructed massive adobe buildings and a walled compound, subsequently used as ranch buildings. The removal of the presidios from the Borderlands coupled with relocation of the Sobaipuri Indians left this portion of the frontier even more open to Apache control.

Locations of the Presidio on the San Pedro

San Felipe de Jesús Gracia Real de Terrenate	San Mateo Canyon, near the plains of Terrenate, south of present international border near the San Pedro River	1741-1775
Santa Cruz de Terrenate	San Pedro River, near the visita of Santa Cruz de Gaybanipitea, near Faribank	1775-1780
Santa Cruz de Terrenate	Las Nutrias, south of present international border	1780-1787
Santa Cruz de Terrenate	Santa María Suamca, present Santa Cruz, Sonora	1787-

The third landholding scheme employed by Spaniards to populate the frontier was the distribution of large grants to persons with the financial capability to make the land productive. The distribution of land grants followed a set procedure. The individual desirous of receiving the grant petitioned the King of Spain for a specific parcel of land in the public domain – the King's land. After a formal survey, an auction was held, and the grant was issued to the successful bidder, usually the individual who requested the land be granted. Formal title to the land followed at a future date, a process that often took up to a decade. Grantees were expected to introduce agriculture, import livestock, and increase frontier population by settling farmers and *vaqueros* on the grant. A grant for *ganado mayor* (large livestock, such as cattle, horses, or mules) consisted of four *sitios*. Equal to a square league (one league is equivalent to 2.6 miles), one sitio contained approximately 4316.32 acres, and a grant for a four-sitio *estancia*, or cattle ranch, contained nearly 17,000 acres. All grants were, of course, unfenced.

During the Spanish period, the Borderlands had few significant *estancias*. José Romo de Vivar, *teniente alcalde mayor* (highest district official) of the Bacanuchi district, operated two of the first big ranches in the Borderlands, one near Cananea in the San Pedro watershed and the other at San Lazaro on the Santa Cruz River. Rancho San Bernardino at the cienega of that name has more obscure origins, although it was considered to be an *estancia* and cattle had been distributed on the ranch before it was converted into a presidio.

During the Spanish period, land grants in the Borderlands failed to extend the limits of the frontier or increase its population, but they did meet Spanish imperial goals for increasing resource production. Even though it became too dangerous for the grantees or their workers to reside on the grants, the livestock they distributed on them multiplied. By the mid 18th-century, various *estancias* in Sonora had 20,000 to 40,000 head of cattle and up to 100,000 head of sheep. Father Ignaz Pfefferkorn reported that herds expanded to such an extent that livestock flooded local markets and devaluated prices. In addition, the Spanish land grant model, followed by the independent nation of Mexico, had lasting impacts for both Mexico and for the portions of northern Mexico that became part of the United States.

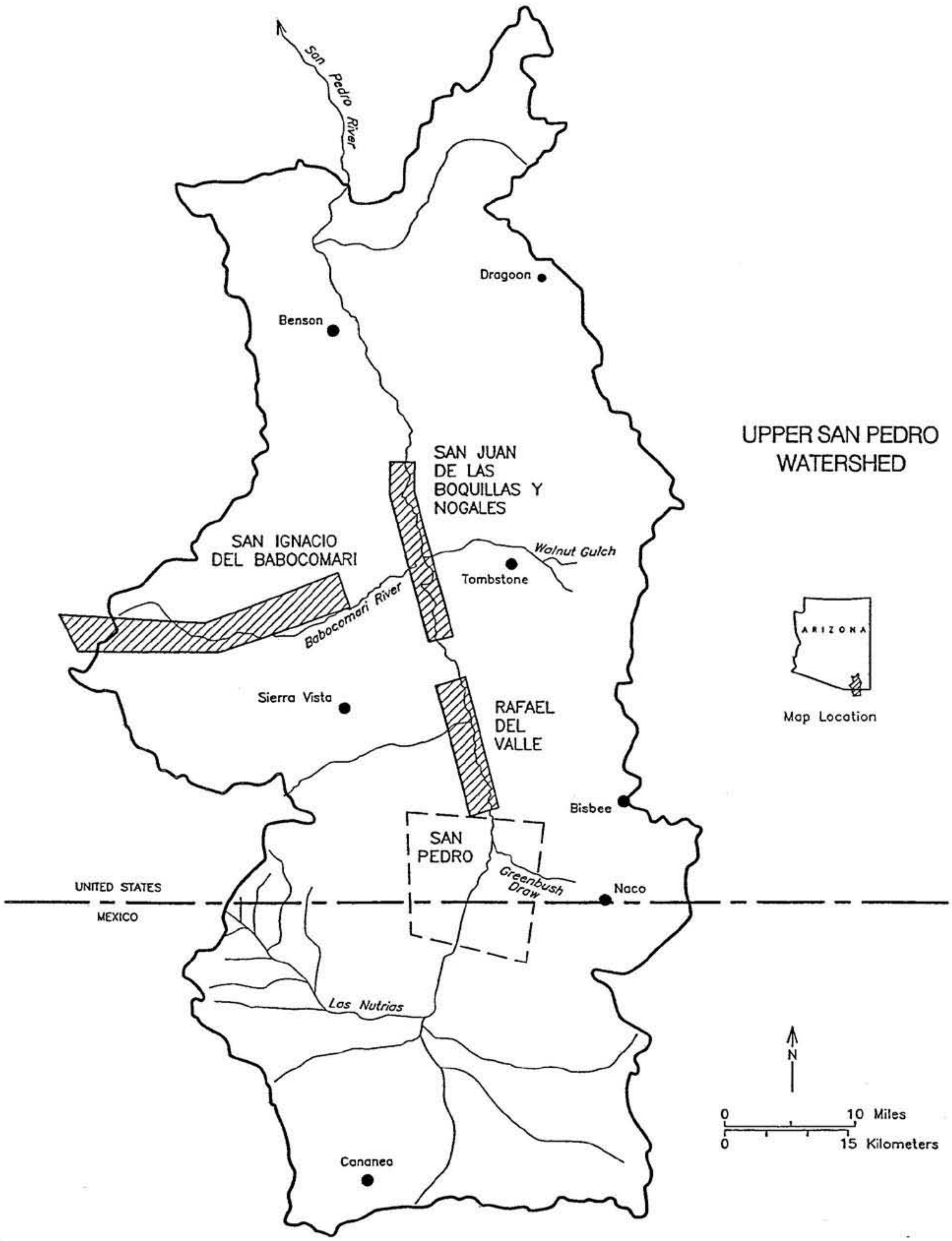
Mexican National Period: Land Grants

Following Mexican independence in 1821, the new government continued the Spanish land grant system with few alterations. In the San Bernardino Valley, the land grant at the San Bernardino cienega was initiated during the Spanish period but issued during the Mexican period. In December 1820 First Lieutenant Ignacio Pérez of the *compañía volante* (flying company or mobile squadron) of Nueva Vizcaya (later Chihuahua) applied to the King of Spain for four sitios of land in the "depopulated place" of San Bernardino. The survey, ordered in February 1821 and conducted in April 1821, was carried out while 20 soldiers from the Fronteras presidio protected the survey party from Chiricahua Apache raids. In March 1822 Pérez bought the grant at auction for 90 pesos per sitio. During the process of the application, survey, and auction, Mexico had become an independent nation.

Pérez was a member of the family that owned the valuable mines at Cananea and was married to an Elías, one of the most important and powerful landowning families in Sonora. To stock the Rancho San Bernardino, Pérez purchased 4,000 head of cattle from the missionary at Tumacacori Mission on the Santa Cruz River, but neglected to pay for the livestock, a debt that was later made good by a relative in the Elías family. After 32 years of ranch operation in the Perez family, the Gadsden Purchase incorporated approximately one-third of it into U. S. territory. The new international boundary cut directly across the property, which later became famous as the ranch owned by Cochise County Sheriff John Slaughter.

The San Bernardino watershed contained a second land grant. In July 1831, Juan, Rafael, and Ignacio Elías González, relatives of Ignacio Pérez's wife, petitioned for the Agua Prieta grant (18 sitios and 12.5 *caballerias*), land that incorporated the spring of that name on the international boundary. The petitioners justified the unusually large request, saying that their cattle strayed to the "four points of the compass," were already grazing as far as the Chiricahua Mountains and required additional forage. When the international boundary was established following the Gadsden Purchase, most of this grant remained in Sonora.

The majority of the Borderland grants were in the San Pedro watershed. On the Sonoran side of the present boundary, a number of powerful wealthy Sonoran families held grants to some of the most fertile, well-watered grasslands in northern Mexico. Several of the grants extended into the adjacent Santa Cruz River watershed. José Romo de Vivar and his descendants owned the La Cananea, El Alamo de Sevilla, and Cuitaca grants. José María Arvallo and his family held title to grants at Los Nogales and Ojo de Agua de Arvallo, the headwaters of the Sonora River and the main water supply for the Cananea mines. Vicente Mariscal, Guillermo Andrade, and Doña Ignacio Pérez de Urrea held title to the *demasías* de San Bernardino (the "over-plus" lands or lands into which it was assumed the livestock would spread). J. Jesús Merino



LAND GRANTS IN THE SAN PEDRO VALLEY, later became largest area ranches held title to the hacienda de la Sauceda and Filomeno Suárez to Las Nutrias, one of the sites of the former Spanish presidio. Members of the Elías family held title to the demasías de San José de Heredia. William C. Greene, developer of the Cananea mines, later incorporated many of these grants into his Sonoran ranch holdings.

When the Gadsden Purchase boundary was established, five of the San Pedro land grants fell on the U. S. side of the border, all on a major watercourse, either the San Pedro or the Babocómari. The Court of Private Land Claims, a special court established in 1891 to adjudicate the complicated titles, approved three of the five grants. Moving downstream along the San Pedro, the first of the grants, the San Pedro grant, straddling the international boundary, was property of the Elías González family, whose claim was recognized in Mexico but not in the United States. Moving downstream, the next grant, the San Rafael del Valle, was issued to Rafael Elías González, whose descendants sold it to members of the Camou family of Hermosillo, who in turn sold it to William C. Greene. The next grant downstream, the San Juan de las Boquillas y Nogales (Saint John of the Little Springs and Walnut Trees), had an irregular configuration, five-and-a-half leagues long and three-quarters of a league wide, extending along both sides of the San Pedro River from present Charleston to four miles south of Saint David. The grant was issued in 1833 to Captain Ignacio Elías González, former commander of the Tubac presidio and a cousin of Rafael Elías, owner of the San Rafael del Valle and San Pedro grants, immediately upstream.

The San Ignacio del Babocómari grant, west of the Boquillas grant, was surveyed in 1827 and granted in 1832 to two petitioners, Ignacio Elías González and his sister Eulalia Elías González, a woman rancher who actually resided on the grant and ran the ranch. Together they received eight sitios, approximately 35,000 acres. Six of the sitios had running water and two were dry. The grant contract included a three-year abandonment clause and stipulated that the boundaries be marked. The Elías family constructed a fortress-like adobe compound over an acre in size, surrounded by a high adobe wall with round lookout towers. According to information later given to boundary surveyor John Russell Bartlett while traveling through Sonora, this grant was stocked with 40,000 head of cattle that grazed throughout the unfenced valley. Within two decades the ranch buildings became romantic ruins that, along with the cottonwood-lined creek and the sacaton stands at the cienega, impressed many later visitors.

The Tres Alamos communal land grant, the farthest downstream, was proposed twice but never issued. Yet it may be the most interesting of all the grants. Had it been issued, headquarters would have been at Tres Alamos (north of Benson) and the grant would have contained 58 sitios extending from the Boquillas grant on the San Pedro northward to the Gila River, east to the Cobre Grande mines in New Mexico (near present Silver City) and west to the common lands of the Tucson Presidio. Settled in prehistoric times, the wide floodplain at Tres Alamos was farmed by Spaniards and Mexicans. While the Spanish peace program was in place, Manso Apaches, " tame" Apaches from Aravaipa who had settled at the Tucson Presidio, worked fields at Tres Alamos, protected by presidio soldiers. In 1831 Leonardo Escalante submitted the first application for the Tres Alamos grant on behalf of eight *empresarios* (promoters). The Congress of Sonora authorized the grant, but settlers never materialized and no title was issued. A second application, in September 1852 – after the Mexican War ended but before the Gadsden Purchase – also failed to produce the 100 Catholic families in residence within eight years. Three decades later, the fact that title had never been issued, did not deter California land agents from spending large sums of money in an effort to validate the grant and uproot numerous American homesteaders and "squatters" who had settled there in the interim.

The land grant system was designed to transfer *terrenos baldíos* (vacant lands) belonging to the government – originally the King's land and later Mexico's unoccupied public domain – to private landowners. Grantees were expected to have experience, financial capacity, and political power, and to be able to stock the grant with livestock, settle it with farmers and vaqueros, create the necessary infrastructure, provide protection from hostile Indians, and render the land productive. The system concentrated property in the hands of a few powerful families. Land grants fulfilled the goals of the system in part. Grantees promptly distributed livestock on the grants, often a full decade before receiving title – a lengthy process that took place in distant Spain or Mexico City. The livestock thrived and rendered some profit to grant owners. Settling the land, however, failed almost entirely in this portion of the northern frontier. By the 1830s, when the Mexican government could no longer provide funding for frontier military protection or the Apache peace program, raiding became so intense that most land grants were abandoned.

After the Gadsden Purchase

Indian Reservations

The incorporation of the northern portions of Sonora and Chihuahua into the United States through the 1854 Gadsden Purchase initiated the present checkerboard pattern of multiple boundaries. It also introduced new forms of landholding. During the first two decades of United States control, Apaches maintained strongholds throughout the Borderland region and prevented significant new settlement. In Sonora, population in beleaguered villages near the new border dwindled. In the previously unpopulated portion of Arizona Territory a few adventurous individuals, many of them rustlers or outlaws, took up informal land claims largely without legal sanction. These non-Indian intrusions into their homeland infuriated Chiricahua Apaches. Between 1854 and 1872 hundreds of skirmishes took place between Apaches, the military, and non-Indian settlers and travelers, both north and south of the border. The boundary remained a largely unmarked political line, particularly invisible to the region's native inhabitants.

In 1872, a treaty negotiated by the Chiricahua Apache leader Cochise and Brigadier General Oliver O. Howard ended some of the worst fighting and led to the establishment of the Chiricahua Reservation. The reservation included much of the homeland of the Chokonen band of the Chiricahua Apache nation and incorporated the entire southeastern corner of Arizona

Territory, extending from the New Mexico border to the Dragoon Mountains and from the international boundary north to the Overland Mail route, near present Interstate 10. Agent Thomas J. Jeffords, a trusted friend of Cochise, moved reservation headquarters three times – from the Sulphur Springs, to the San Simon Cienega, to Turkey Creek on the west side of the Chiricahua Mountains – seeking a healthy location free from malaria and distant from rapacious white traders who dealt in illegal liquor and arms. In June 1876 shortly after Cochise's death, a presidential order terminated the reservation, and soldiers from Fort Bowie marched its residents to the hated San Carlos Reservation. Hostilities continued until the 1886 surrender of Geronimo and his small group of renegades, who refused to stay at San Carlos.

The Chiricahua Reservation briefly extended the Apache traditional form of landholding, a system that allowed greater seasonal movement and the maintenance of a more communal economy. Temporary continuance of that system, however, depended on management by U. S. government agencies. The termination of the Chiricahua Reservation opened the way for the first big influx of non-Indian settlers.

Public Land: Preemption and Homesteading

During the nineteenth century, the federal government attempted to achieve a number of democratic objectives through its administration of the public domain. Elements of public land law were designed to populate the frontier, encourage westward movement, and distribute inexpensive land to *bona fide* settlers. The General Land Office (GLO), the administrative agency for public lands, oversaw the survey of the public domain into a pattern of rectangular townships, each containing 36 sections (square miles). As restless Americans moved west, the GLO followed, opening branch offices and conducting surveys as requests for surveys came in.

The transfer of land out of the public domain was accomplished by a variety of means. Public lands could be purchased through cash sale, after the nearest land office had conducted a township survey, determined the price per acre, and established the size of the parcels to be sold. Land could also be acquired through purchase of public land "scrip," transferable land certificates issued in lieu of land as payment for government or military service. Payments in land scrip were frequently issued to veterans or their widows, who sold them to land speculators. Railroad "lieu lands," larger parcels of land issued to railroad companies to support the construction of railroads across the continent, could also be purchased from railroad companies or speculators. States and territories also had land available for sale or lease, land that had been transferred from the public domain through the GLO. Territories received two sections in each township to be used for support of institutions and education. When the territory became a state, two more sections per township were granted for the same purposes.

The majority of the first wave of Borderlands settlers "squatted" on public land, intending to acquire property through "squatters rights," entitlements specified in a series of preemption laws designed to legalize existing illegal land occupation. Throughout frontier America, thousands of pioneer settlers had developed farms and built homes on land they did not own. First codified in the Preemption Act of 1841, the acts underwent many reforms because speculators often used preemption as a means to acquire large tracts of land. The preemption system never fully accomplished its goal of legitimizing existing, informal occupation of unsurveyed public domain land by bona fide settlers.

The homestead acts allowed settlers to claim homesteads and acquire title to land in surveyed townships. Between 1862 and 1916, a series of acts and amendments to existing homestead acts attempted to stimulate legal settlement on the unoccupied public domain. Patenting the claim, or acquiring title to the property, depended on compliance with a set of regulations. Some homestead acts required that the claimant pay fees, or "prove up," at the end of period of residence, others required an inspection to verify that claimants had fulfilled the requirements of the act. The Homestead Act of 1862, the first act in the series, accounted for the majority of claims in the Borderlands. It allowed individuals 21 years of age to claim up to 160 acres of public land, after payment of a filing fee. To acquire title, a homesteader had to establish residency within six months of filing the claim, reside continuously on the land for five years, and cultivate a portion of the land during the final four years. The act was amended several times, increasing the acreage allowance, easing residence requirements, and generally making it easier to acquire a homestead.

In the Borderlands, successful patents began after the 1870s. Homesteading peaked during the "dry farming craze" of the 1910s. The most common homestead entries were made under the Homestead Act of 1862, the Stock Raising Homestead Act of 1916, and the Dry Farming Homestead Act of 1909--in that order. The Forest Homestead Act of 1906 was used less frequently because it only applied to arable acreage within national forests. The Enlarged Homestead Act, commonly known as the "Dry Farming Act," doubled the maximum size of claims to 320 acres, required the cultivation of non-native grasses, and allowed claimants to be absent for up to five months per year. The Stock Raising Homestead Act allowed claims of up to one section (640 acres) of non-irrigable land. This act recognized the need for larger acreage in arid areas and was designed to promote settlement of "remnant" land, valuable chiefly for forage. It required that the claimant construct improvements in the form of fences and wells, equivalent to an investment of $1.25 an acre.

The homestead laws reflect the American philosophy that each citizen has a natural right to a share of the country. The first Homestead Act facilitated acquisition of the mythical quarter section (160-acre) farm, the ideal acreage to create a Jeffersonian utopia of small farmers. Although the homestead laws reflected fine ideals, they were based on an inaccurate understanding of climate. As settlement proceeded westward, it became evident that the 160-acre farm was not viable in more arid regions. Ambiguities in the regulations permitted unintended uses and gross abuses of the laws. Adjustments to existing acts and several entirely new homestead acts attempted to remedy flaws in previous regulations. But none of the adjustments made the system work entirely as it was intended.

Considerable “bending of the law,” if not outright fraud, accompanied the acquisition of homesteads, as well as the maintenance and use of homesteads. Complicated land laws gave shrewd businessmen distinct advantages over simple homesteaders. Land speculators often used “dummy entrymen” to file homesteads on their behalf, then acquired the homesteads through default on mortgages. Homesteaders themselves abused the homestead laws. They employed loopholes in the laws that allowed them to benefit from use of the land, without intending to secure title. Applicants could use (or abuse) the water, soil, and forage on the land from the time they filed their application until the time they were supposed to “prove up” (five years under the Homestead Act) then walk away from the homestead, without any costs other than the filing fees. In other situations, claimants could continue to use the land and its resources on a homestead for which the application had expired unnoticed.

Promotion of settlement and the distribution of inexpensive land appeared to uphold democratic principles, but unintended applications of homestead laws could have decidedly undemocratic consequences. Along the Arizona/New Mexico boundary, the most common unanticipated use of homestead laws was the creation of large ranches by amassing multiple small homestead parcels. Large landowners, often ranching corporations that owned land in the region, made arrangements with cowboys or ranch workers to file homestead claims. As soon as the properties went to patent, the ranch corporation would purchase the titles through pre-arranged agreements. In addition, large landowners could surreptitiously sponsor township surveys to hasten the opening of an area to homesteading. Legally, actual residents of an area could request that the township in which they lived be surveyed so they could homestead and acquire title to the land. In such cases, requestors were responsible for paying surveyor fees. During the 1880s, township surveys cost between $600 and $800, approximately three to four times the average annual salary of most homesteaders, cowboys, or farm workers. Sponsors of many township surveys at the southern end of the Animas Valley, for example, have Hispanic names, which do not appear on subsequent homestead applications. The requestors in this case may have been cowboys in the employ of one of the area’s large corporate ranches. If so, they could not have paid for the surveys, and payments must have been supported by their employers.

In the arid Southwest, the fundamental flaw of the homestead regulations was the inadequate size of homesteads. The Enlarged Homestead Act of 1909, designed to encourage non-irrigated farming, had particularly unfortunate results. Passage of this act coincided with the promotion of scientific dry farming methods by local agricultural extension agencies and the onset of two decades of heavier than normal rainfall. Although many dry farmers produced surprisingly high yields of forage crops and pinto beans without irrigation, when drought returned to the Borderlands area in the early 1930s, the majority of the dry farms collapsed. Even the Stock-Raising Homestead Act, which provided the largest amount of land, one full section per claimant, was insufficient for raising livestock. In the Borderlands, one section of non-irrigated grazing range might support 10 to 16 head of mother cows with calves yearlong, without damage to native grasses and other range resources. Stocking rates depended on the type and condition of the forage. To support a family of four, a homesteader needed a minimum of 150 head (requiring some 15 sections of land) making it necessary for settlers to utilize the public grazing lands to accommodate adequate herds.

In the Borderlands, homesteading did not fully accomplish the democratic or demographic goals inherent in the acts. Approximately one quarter of the land claimed under the homestead laws was returned to government ownership, after claimants either relinquished their claims or failed to “prove-up.” Yet, despite the fact that most settlers could not make a living from homesteading alone, the acts succeeded in bringing population to the Borderlands and created dispersed rural settlements that lasted for several decades. These settlements were composed of several agricultural homesteads, not enough to constitute a village, but with enough population to warrant a school and/or post office, within walking distance. In New Mexico these existed at Cloverdale, Middle Animas, Walnut Wells, Guadalupe Canyon, and near the Box Schoolhouse, and in Arizona at Babocomari, Bean, Hereford, and Palomas. By the end of World War II many rural residents had become dissatisfied with the hardships and isolation of rural life. During the next decade, rural out-migration led to the gradual death of most dispersed agricultural settlements.

The legacy of Borderlands homesteading is still visible. In the Animas Valley, for example, outlines of former dry farms are still noticeable, for their scanty clumps of invasive grasses and patches of bare ground. Crumbling adobe houses along the creek near Middle Animas attest to failed homesteads. Settlements that grew into vigorous Borderland towns were those with sources of income in addition to agriculture, most often mining or transportation, as was the case with Bisbee, Animas, Hachita, or Rodeo. Third and fourth generation descendants of some of the Borderlands’ most energetic, persistent homesteaders still live on family farms in the Animas or San Simon valleys, and others run family cattle ranches. A significant, unanticipated outcome of the homestead movement was the concentration of land among fewer, larger landholders. Within four or five decades, the majority of successfully patented homesteads had been sold to larger landowners.

Corporate Ranching

Although homesteaders began arriving in the Borderlands at approximately the same time as land agents and wealthy cattle ranchers, smallholders were at a clear disadvantage. During the late 1870s, agents of large cattle operations began purchasing titles and quitclaim deeds to the area’s land grants and initiated litigation to clear the titles. Like their Spanish and Mexican land grant predecessors, the new investors began stocking their properties with cattle long before the titles had cleared the courts.

By the late-1880s, the big ranches that came to dominate the valleys of the Borderlands for decades were all in place. On the San Pedro River, copper magnate William C. Greene bought most of the land grants near Cananea, as well as the San Pedro and San Rafael del Valle grants in Arizona. The Boquillas Land and Cattle Company, a subsidiary of California’s powerful Kern County Land and Cattle Company, bought the Boquillas grant. The Perrin family, owners of other land grant ranches in Arizona, bought the Babocomari grant. In the San Bernardino Valley, former sheriff John Slaughter bought the San Bernardino grant on both sides of the border. In the San Simon Valley, the San Simon Canal and Cattle Company held title to the cienega and most of the other water sources in the San Simon and the northern San Bernardino valleys. In the Animas and Playas valleys, the Victorio Land and Cattle Company, a subsidiary of Kern County like the Boquillas, owned the majority of the best rangeland.

Investors in the land grant properties included several of the wealthiest, most influential "capitalists" in America. George Hearst, James Ben Ali Haggin, and Lloyd Tevis had investments in the Boquillas and Victorio companies, and Lloyd Tevis's son was an initial investor in the Babocomari. The three elder men came to California as Forty-niners, made fortunes during the Gold Rush, and were neighbors in one of San Francisco's most elegant sections. Hearst, a legendary mining tycoon considered to be a "natural prospector" and fine practical geologist, walked alongside his ox team from a small Missouri farm to California. He created a mining empire that included the Silver City and Butte copper mines. Hearst served as U. S. senator from California, ran unsuccessfully for governor of California, and leveraged his ownership of the San Francisco Daily Examiner into the Hearst Newspaper conglomerate. Haggin and Tevis were attorneys from Kentucky, brothers-in-law, and partners in a California land law practice. Haggin, the second largest landowner in California with 450,000 acres of range and farmland in the state's central valleys, was founder of the Kern County Land and Cattle Company and developer of dozens of irrigation districts. He owned over a hundred mining properties, scattered from Alaska to South America, among them Grant County, New Mexico's tiny Victorio mine, which rendered little ore but gave its name to the Victorio Land and Cattle Company. Lloyd Tevis, in addition to founding and owning Wells Fargo, was a principal in the California Steam Navigation Company and the Western Union Telegraph Company, and served as president of the southern Pacific Railroad.

The other large ranching investors, although perhaps less famous, were nonetheless knowledgeable cattle growers. The Perrin family owned other land grant ranches. The Paramores and Mercants were famous cattlemen in Texas. John Slaughter gained fame as the sheriff who ran the outlaws out of Cochise County. Investments by such influential men, no doubt, spurred Congress to streamline the inefficient system for validating land grant titles, a process initially conducted by the surveyor general of the territory in which the grant was located, who made recommendations to the U. S. Secretary of Interior, who in turn made recommendations to Congress, where final determination was reached. In 1891, Congress created the Court of Private Land Claims, with an Arizona district headquartered in Tucson. Despite the streamlining, the adjudication process for Arizona land grants lasted until 1904. During the interim, the new land grant claimants stocked their ranches to capacity. Their persistent importation of cattle, first by trail drive and later by railroad, spurred the cattle boom of the 1880s and 1890s and the competitive overstocking that contributed to severe range deterioration.

The land management philosophies of the large ranchers varied considerably. William C. Greene was considered to be one of the most progressive range managers of his time and his descendants continued his management practices. When Greene died accidentally in 1911, his descendents retained ownership of the land grant ranches in Sonora, and the Boquillas Land and Cattle Company bought his ranches on the San Pedro in Arizona. The Boquillas and the Victorio Land and Cattle Company in the Animas and Playas valleys were both subsidiaries of the Kern County Land and Cattle Company. Kern County followed a policy of acquiring large tracts of contiguous private land and eliminating intermediary in-holdings whenever possible. Although the Boquillas and the Victorio operated under separate management, both followed the land ownership policies and management practices of the parent company. By the 1940s, both the Boquillas and the Victorio had adopted more progressive range management practices. Although they employed standard predator control and introduced non-native forage species, both ranches steadily reduced stocking rates. Grasslands in the valleys benefited from Kern County's ability to implement fast off-take strategies during droughts, when cattle were promptly relocated to the company's irrigated pasture in California. As a result, when the Boquillas and Victorio ranches were sold during the 1950s, they consisted of large continuous tracts of land that were in relatively good condition.

In contrast, the San Simon Canal and Cattle Company concentrated on buying water sources, made no attempt to purchase tracts of land that connected the waters, and followed a policy of maximizing forage consumption on the intermediate public domain, or "open range." The result was a checkerboard pattern, in which private property alternated with public land. San Simon Company owners, members of the Merchant and the Parramore families of Abilene, Texas, had stronger attachments to their ranch properties in Texas and eastern New Mexico. James Parramore actively supported the development of the townsite at the Rodeo, New Mexico, a cattle shipping station on the El Paso and Southwestern Railroad, through the sale of lots and donation of property for community buildings, churches, and schools. In the early-1920s, when his son "Doc" Parramore sold off the dispersed private parcels of the ranch, many smallholders and medium-sized ranchers bought land.

A comparison of the ownership and management policies of the Kern County subsidiaries and the San Simon Canal and Cattle Company provides some insight into the lasting effects of land policies enacted between five and eight decades ago. Kern County, through its subsidiary ranch companies, purchased as much private land as possible in the San Pedro, the Animas and Playas valleys. In both areas, the company's large uninterrupted tracts of private land benefited from range management practices that were better than average for the time. Acquisition strategies of the San Simon Land and Cattle Company left large areas or rangeland available for lease through the Bureau of Land Management, or sale and/or lease through the Arizona State Land Department. Ultimately, the reluctance of the company to purchase large contiguous tracts of land increased the parcelization in the valley and eventually facilitated sub-division of open space for residential sale. In addition, the land management policies followed by the company, particularly on open range, did little to further resource conservation.

Protecting the Public Domain

Between the 1880s and 1930s, three factors coalesced to create a situation in which Borderlands rangeland resources were abused: the federal government failed to implement regulations for livestock access on the public domain; livestock owners had unrealistic expectations concerning climate variability and the ability of arid land grasses to recuperate from overgrazing or drought; and materials, in the form fencing and other ranch hardware, were unavailable or economically inaccessible to many settlers and ranchers. A system of competitive overstocking on public lands quickly developed. The individual who controlled a water source attempted to fully stock the range surrounding it to prevent access by his neighbors' cattle. Within three decades of their arrival in the territory, American cattle growers and range specialists recognized that a disaster was unfolding on the Borderlands public domain. In the 1890s, Dean Robert H. Forbes of the University of Arizona's College of Agriculture and other range experts pointed to the San Simon Valley as one of the worst examples of degraded rangeland, erosion, and arroyo cutting in the Southwest.

Contrary to what many individuals in the present livestock industry believe, state and local cattle growers associations in Arizona and New Mexico were among the first to pressure the federal government for stocking limitations and seasonal access to public lands. Demands for better regulation began during the 1890s and continued through the 1920s. Large ranchers were the most vocal advocates for regulation. Henry Hooker, William Bayless and other pioneer ranchers attributed range degradation to unregulated overgrazing. The inability to control livestock movement was a significant source of the problem. Barbed wire became available during the 1880s, but fencing was so uncommon that even portions of the international boundary remained unfenced until the 1930s. On the public domain, it was illegal to erect unpermitted fences, including short stretches of "drift" fence intended to prevent cattle from drifting through mountain passes, crossing territorial boundaries, or moving into locations where they would be difficult to gather.

To address widespread natural resource abuses, Congress passed the General Land Law Revision Act in 1891, giving the president authority to set aside portions of the public domain as timber reserves. For decades, the reserves offered the only form of protection for public lands. Initially, the Department of the Interior managed the reserves, without allowing multiple uses. After 1905, when the Department of Agriculture (USDA) took over the reserves, grazing and other limited uses were allowed. In 1907, "forest reserves" were renamed "national forests," reflecting a philosophical difference in the policies of the two agencies.

The Peloncillo and Huachuca reserves are of particular importance in the Borderlands. In July 1902, the first seven reserves in southern Arizona were created. Four years later, the Peloncillo Forest Reserve was among the next group established. Created in November 1906, the reserve encompassed the Peloncillo and Animas mountain ranges. It contained approximately 320 square miles, extended across the territorial boundary between Arizona and New Mexico, and was divided into two geographically separate divisions – the Animas Creek District with approximately 55,700 acres and the Peloncillo District with approximately 88,000 acres. Newspapers reported that the reserve was created in order to protect watersheds that were becoming denuded. The Huachuca Forest Reserve, also established in November 1906, had the curtailment of unregulated logging and fuelwood cutting as a primary objective, although grazing regulation was quickly implement there as well.

During the next 50 years, the southern Arizona/New Mexico reserves underwent a series of consolidations and eliminations that incorporated 14 small reserves into the Coronado National Forest. In 1908, the Peloncillo Reserve became the Peloncillo-Animas District of the Chiricahua National Forest, which was incorporated into the Coronado National Forest in 1916. The forest supervisor's office for the Peloncillo Reserve had been located in Rodeo, New Mexico, a major cattle shipping station in the San Simon Valley directly between the Peloncillo and the Chiricahua ranges, an indication of the importance of grazing in that national forest. When the forest was incorporated into the Coronado, the supervisor's office moved to Tucson. Ranger stations for the Peloncillo-Animas District relocated several times, with locations in Skeleton Canyon (1908-1920), the small homestead settlement at Cloverdale, New Mexico (1920-1933), and finally Douglas, Arizona (1933 to the present). The Animas Creek Division underwent a reduction in 1910, when President Taft eliminated its southern portion along the Mexican boundary. In 1948, the remaining 50,000 acres of the division were privatized in an exchange for forested land in west-central New Mexico. After privatization, most of the acreage in the Animas District was sold to the former allottees. The Huachuca Reserve became a district of the Garcés National Forest in 1908, along with the Baboquivari and Tumacacori reserves, which were also demoted to district status. With headquarters in Nogales, the Garcés was called the "Border Forest," or the "Sneeze-Cough Forest," because the names of its three districts were difficult to pronounce. In 1911 the Baboquivari District was eliminated, and the remaining divisions were incorporated into the Coronado.

When the forest reserves were set up, they offered the only land holding designation that provided a legal means to control natural resource consumption on public lands. Yet several early regulations proved to be contrary to agency goals. In 1906, Congress passed the Forest Homestead Act, which provided for the elimination of non-forested, arable land thought not to be appropriate to a forest reserve. The law permitted claims of up to 40 acres in the ponderosa pine belt, or up to 80 acres in the piñon-juniper zone, after the land had been classified as agricultural and surveyed by Forest Service personnel. Claims did not have to be rectangular and could follow the configurations of the floodplain. The act was intended to support farm production, yet the majority of forest homesteaders wanted forest homesteads for ranching rather than farming. Since forest claims were normally surrounded by national forest, the homesteader qualified for a Class A Grazing Permit, the most desirable type of permit reserved for private land adjacent to national forests. Inadvertently, the law increased the number of landowners who could apply for grazing permits, contributing to occasional conflict between the agency and permit holders and between permittees themselves. Dozens of grazing permits associated with forest homesteads were issued in the Peloncillo and Huachuca mountains.

The passage of the Taylor Grazing Act on June 28, 1934, ended the open range system of cattle ranching. The act established grazing districts, charged with leasing grazing allotments on the public domain. Preference was to be given to owners of private land or water rights contiguous to the land requested in the lease application. The General Land Office (GLO) in conjunction with the Grazing Service (after 1946, the Bureau of Land Management) administered the allotment system, issuing ten-year leases and setting lease fees according to a formula based on estimated carrying capacity. Twenty-five percent of the lease fees were to be expended on range improvements (fences, wells, windmills, pipelines, tanques) on the leased allotments. To expedite the leasing system, the GLO held public hearings and interviewed ranchers who had previously grazed their cattle on the public domain free of charge. In some areas heated controversies arose between neighbors or between ranchers and agency representatives. In other areas, the allocation of leases went smoothly.

At the time of the Taylor Act, state land commissions in Arizona and New Mexico increased regulation and tightened up leasing systems. Like the GLO, state land commissions gave priority to previous lessees and honored improvements installed on state land at the cattle owners' expense. By the 1940s, state grazing leases were extended from five to ten years. State land departments soon developed the reputation for imposing less rigorous scrutiny than the Taylor Grazing Service, requiring no time limits on the installation of fencing, but providing no monetary or physical assistance for such improvements.

Many ranchers who participated in the transition from open range to regulated grazing stated that resource management improved noticeably. They observed, however, that larger ranches received preference in the distribution of leases and that smallholders were often unable to obtain leases and were frequently forced out of the cattle business.

Sonora After the Revolution

Latifundia and Ejido

William C. Greene, Cananea's copper mining magnate, initially operated his Sonoran ranches through a Mexican company, incorporated in 1901 in Nogales, Sonora. His ranches were estimated to extended for approximately 68 miles east and west along the international boundary and approximately 48 miles southward from the border. After Greene's 1911 death, family members retained his progressive range management policies. The Mexican Revolution (1910-1920), however, altered the legality and the structure of the Greene landholdings. In 1923, Article 27 of the newly adopted Mexican Constitution codified a major land reform, the primary goal of the ten-year revolution. Under the new Agrarian Code the vast rural properties common throughout Mexico prior to the revolution became illegal. Mexico's *latifundia* (the Latin word describing the great estates of ancient Rome) could now be expropriated for conversion into *ejidos*, (communal or cooperatively held farm and ranch properties) for distribution to the *campesinos* (rural peasants) who worked them. Ejidos were to be held in trust as unalienable common property belonging to *ejidatarios* (members of the ejido) and their descendants. Management policies were to be determined by a governing council elected by ejido members.

Under the new constitution individual landholdings in excess of 10,000 hectares and foreign ownership of property adjacent to international borders became illegal. To comply with the new regulations, Greene family members organized the Ranchos de Cananea, a set of separate but interconnected Mexican companies that held multiple titles to the ranch holdings. It was common knowledge, however, that the vast landholdings were illegal. For three decades, political connections and respect for the Greene family delayed expropriation, but during the early 1950s a federation of Sonoran laborers, peasants, and veterans of the revolution began pressuring for confiscation. After several years of negotiations, a price for the seven ranch divisions and a separate price for the livestock were determined and the properties were nationalized.

The expropriation was so politically significant, that President Adolfo López Mateos came to Sonora in February 1959 to personally deliver the deeds to the seven divisions to the Ejidos de Cananea, a conglomerate of ejidos with a membership of 585 new *ejidatarios*. More than 250,000 hectares of former Greene lands were redistributed, comprising over 50 percent of the Sonoran portion of the San Pedro basin. Initially, the Ejidos de Cananea followed management policies similar to those of the former ranch, despite the new form of land tenure. The size and boundaries of the seven new ejidos corresponded roughly to the former divisions. Livestock remained the major economic activity although the ejidos increased the acreage devoted to farming, introduced dairying, and initiated several small industries. The Banco Nacional de Crédito Ejidal, an agency of the Mexican Department of Agriculture, administered credit, provided technical advice, and required adherence to stocking rates based on the estimated carrying capacity of the land. With time, however, the overall number of ejidatarios and the consequent numbers of permitted livestock multiplied. Members increasingly failed to comply with stocking regulations and range conditions generally deteriorated. The supplemental economic activities attempted on the ejidos proved unprofitable. With time, overall political support throughout Mexico for the ejido system diminished.

In 1992, the Mexican Congress abrogated Article 27 of the constitution, with profound consequences for property rights, productions systems, and the organization of the rural sector. The new Agrarian Code put an end to land redistribution, and offered ejidos federally recognized ownership rights to ejidal land and the structures upon it. It became possible for an *asamblea ejidal*, the governing body of an ejido, to modify its property status. With appropriate authorization, an entire ejido could be sold or leased as a unit, or individual *derechos*, rights to parcels of ejidal land, could be sold or leased by individual ejido members, after the parcels have been surveyed and distributed to members. Ejidatarios could also lease their usufruct rights to common lands, for grazing, forestry, or water supply. In addition, the new code ended the prohibition of foreign ownership of land and water rights along international borders.

By the year 2000, approximately 30 percent of the ejidatarios in the San Pedro basin had sold their derechos, resulting in the proliferation of undersized parcels of private land among smallholders, whose economic needs dictated that they graze as many animals as possible. Additionally, the parcel owners were no longer subjected to the level of scrutiny previously imposed by the Agriculture Department. The construction of fencing around the small parcels contributed to intense overgrazing in limited areas as well as to the obstruction of wildlife movement through this portion of the watershed. Some researchers state that the results of privatization have been ecologically disastrous.

Observations on Borderland Landholdings

Research for this three-century segment of Borderlands land use history gives rise to several tentative general observations, which relate only to this region. They are presented here in the hopes of stimulating discussion and further study of the wider relationship between landholding, culture, and resource use. First, the region's native peoples appear to have worked out relatively efficient land use systems, the impacts of their occupations limited to specific locations in which intensive use occurred. Second, government landholding policies often failed to achieve the specific goals for which they were intended. Regulations--whether enacted by the government of Spain, Mexico, or the United States--were frequently used to accomplish ulterior ends, producing situations in which well-intended policies had unanticipated, even perverse, consequences. Third, private property, with security of tenure, received better treatment than public land, particularly during the period prior to implementation of public land regulation. Fourth, in the arid ecological conditions of the Borderlands, small agricultural landholdings were not economically viable, and consequently were subjected to more intensive use and harsher resource consumption.

The fifth observation relates to land use on large private landholdings, which, of course, were subject to the predilections of the owners. In the Borderlands, the proprietors of four of the largest landholdings followed management practices considered at the time to be progressive. Yet, despite the owners' diligence in acquiring large, uninterrupted tracts of private land both for economic motives and for preservation of open space, unforeseen circumstances determined different outcomes for the various properties. At the present time, one of the large landholdings (Victorio Land and Cattle Company, later known as Gray Ranch) continues to be a private, protected working landscape. On another large landholding (Boquillas Land and Cattle Company), the riparian areas are protected and are currently under restoration as the San Pedro Riparian National Conservation Area, while the grassland portions of the same property were mostly sold for development as platted residential sub-divisions near the booming town of Sierra Vista, Arizona. Significant portions of another large property (Babocomari Ranch) are currently being developed as "wildcat," or informal, subdivisions, subject to lot splits on 40-acre parcels. The remaining extensive but non-contiguous landholding on the U. S. side of the border (San Simon Land and Cattle Company) was sold in parcels decades ago. The largest well-managed landholding in Sonora (Ranchos de Cananea) underwent conversion from private to communal to private property, with unfortunate consequences for its resources.

A final observation is that external forces, often in the form of large infusions of outside capital, have overwhelmed local goals, particularly those related to the land. The interweaving of economic forces with climate variability has had an adverse influence on the retention of family landholdings. Other external forces, however, in the form of national conservation groups, have become surprising allies for some local goals, particularly for the preservation of Borderland landholdings. Local culture and land ethics have occasionally come together to influence property economics, as can be seen in the case of the Malpai Borderlands Group or the region's grassland associations.

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Ghostly Grazers and Sky Islands

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Abstract—*The evolution of the western range involves millions of years of coexistence of herbaceous plants with a great many kinds of large herbivores, most of the latter suddenly removed around 13,000 years ago. The fossil record indicates more diversity of large herbivores before this time, not less, and with more taxa of large herbivores consuming more forage than livestock eat at present. With extinction of megafauna coinciding with Clovis colonization around 13,000 years ago, large herbivores and their herbivory decreased. Most of our large native herbivores vanished when these prehistoric people invaded. In addition the invaders triggered a considerable surge in fire frequency, declining historically with the introduction of domestic livestock. As archaeologists and geographers have long realized, environmentalists must not overlook or ignore but embrace prehistory.*

Fenceline Mirage

New to Arizona in 1956, I glanced down a fenceline. The fence separated pastures between two ranches in eastern Cochise County. I was near the foot of a Sky Island, the Chiricahua Mountains. The grass on one side of the fence was close-cropped and short; the other was ungrazed with knee-high heads of native grasses, probably including species of *Aristida* (three-awn), *Bouteloua* (grama), and/or *Muhlenbergia* (muhly), all important range grasses with many species in Arizona and New Mexico and many more species across the border in northern Mexico. There was no doubt on which side of the fence the grasses were flourishing and "natural" and therefore more desirable, and which side was eaten down or "overgrazed."

"Viva biomass! Hug the grass! Damn the cows," I thought. That summer was unusually hot and dry. One well-to-do rancher in the Animas Valley in New Mexico loaded his cattle onto trucks to transport them to greener pastures he leased in eastern Colorado. In the fall another couple I had befriended, Alden Hayes and his wife Gretchen, who provided informative answers to all my questions about a region totally new to me, lost their ranch just east of Portal. The spotty summer rains missed the Hayes' pastures; there would be no increase in their herd and the bank foreclosed the mortgage.

Alden had degrees in anthropology from the University of New Mexico and he soon found employment with the National Park Service south of Phoenix at Casa Grande National Monument.

In recent years the "shoot-from-the-hip" environmental judgment of grass huggers who oppose grazing has been gaining traction. Nevertheless, as a starting point for sharpening insight, one could do worse than consider differences through time in the biomass one sees across fencelines. The longest fenceline, to my knowledge, runs along the border separating the grassland and oak woodland of southeastern Arizona from the grassland and oak woodland of northern Sonora. Differences in grazing intensity are clearly visible in the reflectivity seen in satellite images. Pastures on the Mexican side have a distinctly lighter tone than on the Arizona side, where grazing is less intense. Not bothered by the heavier grazing on the Mexican side, those in search of extra diversity in this region must cross the border and head south to find an environment increasingly richer in endemic species.

Census data on grass populations across fencelines are available in southeastern Arizona at the Appleton-Whittell Research Ranch (TRR), 7,800 acres ungrazed since 1969. Carl and Jane Bock compared the biota of moderately grazed pastures adjoining the ungrazed grassland within TRR (Bock and Bock 2000). The results are less alarming than cow cursers might have us believe. Still, in the 1950s, I bought the party line: "cows eat grass and that favors the weeds; cows destroy riparian plants when they trample springs and wet ground; cows are bad and livestock ranching should be eliminated." Is this interpretation invariably sound?

Extinctions in "Near Time"

Through radiocarbon dating, I learned of the dramatic extinctions in "*near time,*" the last 50,000 years. Sweeping extinctions eliminated two-thirds of the large terrestrial mammals native to America around 13,000 years ago. Similar extinctions of large mammals, reptiles, huge flightless birds, and even some trees of the rainforest struck in Australia 50,000 years ago. In the last 3,000 years many species of flightless endemic birds, especially flightless rails, vanished from the islands in the Pacific and Indian Oceans. These and other prehistoric extinctions around the globe march in step to prehistoric human colonizations (Martin and Steadman 1999, Martin 2005).

Before 13,000 years ago America was wonderfully rich in large mammals (Lange 2002). In the Pleistocene, America was far richer in diversity of large mammals than those found by Lewis and Clark. Before the extinctions American diversity of large mammals was much more like that of Africa or tropical Asia. Then around 13,000 years ago people entered the

Americas, very likely from over the Bering Bridge. Coinciding with human arrival of Paleolithic people in the New World, about 100 genera of large mammals disappeared.

What does the prehistoric past have to do with fencelines? When we look down a fenceline on the western range we need to keep in mind the fossil record of the Cenozoic, the last 65 million years and the age of mammals, ending in the ice ages, the last two million years, punctuated, as we have seen, by sweeping extinction of large mammals in America just 13,000 years ago. Some paleontologists have interpreted the megafaunal extinctions in near time as the result of ice age climatic change. But the extinctions strike at the end, not the beginning of the Quaternary ice age, making it unlikely that they were forced by some unique continent-wide climatic change. The human invasion of America is a close chronological fit.

Before the extinctions of 13,000 years ago North America supported at least six species of proboscideans, more than six species of equids and many artiodactyls, such as camelids, stag moose, and brush-oxen, soon to join the ranks of the extinct. There were giant edentates, both ground sloths and glyptodonts; the largest ground sloths equaled an African elephant in size. There were giant tayassuids (javelina) and giant beaver the size of a black bear. In the extinction process all large American mammals mentioned above and even some smaller ones became extinct, as did all the glyptodonts and all American proboscidea.

In the pampas Charles Darwin was among the first to collect the strange bones of what Sir Richard Owen later described as two new orders of South American endemic mammals, the litopterns and the notoungulates. They too vanished late in the Pleistocene when extinctions swept through the Americas. Only in the West Indies did sloths (suborder Phyllophaga) disappear in the mid postglacial rather than around 13,000 years ago, coinciding with the age of the earliest archaeological sites in the Greater Antilles.

Extinction of the largest mammals of the West Indies, the ground sloths, and arrival of prehistoric people lagged similar extinction and human colonization on the mainland by about 7,000 years. Had climatic change been responsible for the extinctions, the West Indian ground sloths would not be expected to postdate extinction of continental ground sloths.

Such a mighty menagerie of giant Pleistocene herbivores was accompanied, not surprisingly, by a retinue of large carnivores, the American lion, a giant short-faced bear, saber-tooth and dirk-tooth cats, cheetah, and a variety of New World avian scavengers to match the largest vultures and storks found now in Africa. In brief, most of the native fauna of America vanished long before ranching of livestock began.

Confined by the trivial timescale of the written word, the history of America available to historians is limited to the last 500 years. Our familiar historic figures, with Columbus, Cortez, and Coronado, also include Alvar Nuñez Cabeza de Vaca who, following shipwreck, found himself and his three surviving shipmates no longer conquerors but captives at the mercy of the natives. They managed to escape, then became venerated as shamans, and traversed an unknown route of over a thousand miles from the Texas coast west through the Chihuahuan Desert and over the Continental Divide to Sinaloa on the Pacific slope of Mexico where they found their countrymen.

Figure 1—Bison on the Armendaris Ranch, June 1996.

Had they traveled in a straight line, which they did not, Cabeza de Vaca and his three companions would have walked at least a thousand miles through the interior of America. They may or may not have journeyed past the Chiricahuas and other Sky Islands. One of them, the slave Estevan, guided Fray Marcos ahead of Coronado north to Zuni where he was killed. He and Coronado may have traveled close to if not through the Sky Islands.

Of interest for our purpose here is the fact that while on his trek from the Texas Coast west to Sinaloa, Álvar Nuñez Cabeza de Vaca often mentioned bison (Adorno and Pautz 1999). Nevertheless, he mentioned no vast herds of tame animals comparable to those seen by Lewis and Clark in Montana.

"Spanish and American explorers in the Southwest failed to find bison in desert grassland west of the Pecos River in eastern New Mexico. … However, the archaeological record indicates their presence in southern Arizona" (Parmenter and Van Devender 1995: 214). According to range scientists Tom Waddell and Joe Truett both bison (figure 1) and prairie dogs are doing very well following introduction on the Armendaris Ranch of Ted Turner, east of the Río Grande in southern New Mexico (personal communication, February 21, 2005).

Vertebrate fossils add insight to what took place. After tens of millions of years, America ceased to be the land of dozens of species of large mammals just 13,000 years ago. If not a full-blown mass extinction like dinosaur extinction at the K/T boundary, the magnitude of loss at least qualifies as the first wave of the planet's sixth mass extinction, the one we find ourselves in now (Leakey and Lewin 1995, Martin 2005). The first wave is not only marked by disappearance of animals but also by virtual disappearance of the dung fungus, *Sporormiella*, which reappears historically in pond sediments accumulating after the arrival of large herds of domestic livestock (Davis 1987, Davis and others 2002). There is no doubt that the first wave of the sixth mass extinction struck a terrible blow, a loss of megafauna whose consequences are all too often ignored and whose significance remains underestimated.

Trauma in Near Time

Those with an eye for prehistory appreciate the many changes initiated by early people. In the beginning some 13,000 years ago Clovis hunters with Clovis Points killed mammoth and bison. In southern Arizona both Clovis hunters and mammoths soon vanished, to be replaced by a different economy, the Cochise Culture, foragers of flood plains and adjacent bajadas. Beyond harvesting wild plants and small mammals, the desert dwellers learned to cultivate corn and stored surplus crops in the ground in pits while living in pit houses. Occasionally bison bones turn up in remains of the Cochise Culture and of the Sobaipuri, farmers of the San Pedro River into the time of Father Kino.

Occasional sub-fossil records (Mead and Johnson 2004) not withstanding, Spanish explorers and military parties did not report bison in Arizona or New Mexico. Some view the scarcity of bison as an indication of an unfavorable environment. Nevertheless, with native societies thriving on both cultivated and wild plants, and hunting whatever they could obtain, absence of bison and scarcity of mountain sheep in archaeofaunal samples might not mean the absence of a climate and environment favorable to both. Instead, it might reflect the presence of too many humans, including many would-be big game hunters, reduced to foraging for small game, gathering wild plants, and cultivating corn (maize), beans, and squash. Arizona's first cornfields are thousands of years old. Very likely corn cultivation and wild, free ranging bison did not mix well in the view of prehistoric agriculturalists. It is no surprise that when introduced historically in three parts of Arizona, bison thrived.

War Zones in Wild America

Early explorers such as Lewis and Clark, to name one famous example, did not see bison throughout the west. They found none on the Columbia River or the Clearwater. Zoogeographers had yet to map, much less to speculate on, what the range of bison might mean. Early travelers and explorers discovered that despite local abundance in one region, bison might be absent elsewhere. Understandably, bison were absent from places that they were not well adapted to occupy, such as tropical rain forest along with the rest of the tropics south of Nicaragua, their southernmost locality (McDonald 1981).

That does not explain absence of bison in certain North American grasslands. Had bison ranged where livestock can thrive, at least in small numbers, they would have inhabited all prairies, the High Plains, the Palouse loess, California's coastal grasslands, the desert grasslands of Arizona and New Mexico, and the rich grasslands of northern Mexico on the high, summer-wet plateau above the Chihuahuan Desert and between the Sierra Madre Oriental, the Sierra Madre Occidental, and the Valley of Mexico (map in McClaran and Van Devender 1995, page 2). Yet we know that only some of these grasslands held bison historically. Why was that?

In a long neglected entry in his trip log 200 years ago William Clark provided a possible answer: "*I have observed that in the country between the nations which are at war with each other the greatest numbers of wild animals are to be found*" (William Clark, Friday, 29th August 1806). Lewis and Clark were a month out of St. Louis and near to the end of their expedition. It took many months of experience over parts of two years on the Upper Missouri, the Clearwater, and the Columbia, with Clark rafting down the Yellowstone River and thereby seeing significantly more country rich in buffalo than his co-captain, Meriwether Lewis, before William Clark entered that one sentence in his journal.

What Lewis and Clark reported was a West in flux as far as bison hunters and bison hunting were concerned. Introduced diseases and the uneven distribution of trade goods, among many other traumas of contact, drastically altered the numbers and even the presence of native people. More than climate and the environment, Indians played a crucial role in determining where bison would be found along the route followed by Lewis and Clark and other early travelers (Martin and Szuter 1999, Martin and Szuter 2004).

Until recently, few historians have mentioned that in Montana between the upper Missouri River and the Yellowstone, regions where Native Americans were largely absent, Lewis and Clark were in a war zone. The abundant bison, elk, deer, beaver, and, locally, grizzly bear that we venerate as part of our national heritage thrived when Native Americans were largely absent, as Lewis and Clark noted when they traveled through Montana.

In the Upper Missouri River in Montana Lewis and Clark and other early observers found all wild species to be surprisingly tame and fearless, or truculent in the case of the grizzlies. It is an old story. But are we ready to accept the evidence that the game rich "wild America" of our dreams was in fact an intertribal war zone, a faunal refuge developing between cultures in conflict? In this "top-down" interpretation, carrying capacity alone did not enable bison to swarm over the state of Montana in the first decade of the 19th Century. It was the absence of any resident bison hunters.

West of the Continental Divide most and at times all of the Columbia River drainage lacked bison, as it did in the days of Lewis and Clark. Is this because the natural vegetation is unsuitable for any large ruminant, cattle included? Those who advocate suppressing both cattle and ranching seem to think so (Wuerthner and Matteson 2002). Should such a policy be accepted without question throughout the West, including southern Arizona? Fifty years ago I thought along those lines, until I learned more about the fossil record of large mammals.

Some vertebrate paleontologists regard the loss of large mammals as climatically driven, but nothing in the proxy data of ice age climatic change, whether fossil pollen, fossil content of pack rat middens (Martin 1999), or chemical and geochemical signatures in ice core or marine core records reveals a unique pulse that might explain a unique extinction event (Martin 2005). More than that, if there was a severe climatic shock, why did mostly large animals succumb, those most mobile and best buffered against climatic insult by virtue of their large size, enabling them to emigrate to more suitable climates while weathering extremes?

Given the intensity of prehistoric cultural activity in Arizona and adjacent states, with hunting unregulated, we need not be surprised that recently with hunting focused on deer and other big game, smaller mammals like opossum and coati have spread north from Mexico into Arizona, New Mexico, and Texas while javelina (*Peccari tajacu*), raccoons, and elk, despite hunting pressure, are increasing in numbers. Increase in javelina may possibly be involved in the increase in prickly pear in southern Arizona, as the increase in mesquite is partly attributed to distribution of mesquite seeds in sweet pods attractive to livestock and javelina (for matched photos showing mesquite and prickly pear increase see Turner and others 2003). Javelina, whose bones do not appear in zoo-archaeological collections, now range north to and beyond Interstate 40 in both north-central Arizona and New Mexico. Javelina are popular prey and if zoo-archaeologist Christine Szuter and I read the fossil record right (Martin and Szuter 1999, Martin and Szuter 2004) the spread of javelina in the 19th and 20th Century reflects relaxation of a hunting pressure that was heavier in prehistoric times for some of our larger mammals than it is now.

As hunting pressure is reduced on large carnivores and management favors them, it is no surprise to learn that more than the accidental jaguar ranges into Arizona from Mexico. If tapir were not dependant on heavy tropical forest to escape hunters, they too might be returning to Arizona along with the javelina. Fossil tapir bones were excavated in the Clovis archaeological site at Lehner Ranch on the San Pedro, at Ventana Cave on the O'Odham Reservation, and on the Colorado Plateau in northern Arizona. Certainly Arizona is not any colder now than it was over 13,000 years ago and if temperature rather than predation limits tapir range, the animals should have returned to Arizona from the tropics.

Fencelines and Fossils

The late Pleistocene fossil record of the Southwest, unknown to me when I made my fenceline judgment call almost 50 years ago, is attracting the interest of ecologists and naturalists. Judging by radiocarbon dates, until 13,000 years ago the Americas were rich in proboscidea, both mammoths and mastodons, with a third family, the gomphotheres, in Mexico and Florida south to Argentina and Chile. Native equids, horses of many species, evolved in America along with the camelids.

In addition, there were extinct tayassuid pigs, *Platygonus* and *Mylohyus,* much larger than our native javelina. There were ground sloths, especially the Shasta ground sloth and occasionally Jefferson's ground sloth. The pronghorn included not only the living species but also a dwarf genus, *Stockoceros*.

Carnivores included dire wolves, lions twice the mass of African lions, and especially at Rancho la Brea the famous saber-tooth cat. Fossils of the dirk-tooth cat are found in Texas in Friesenhan Cave, associated with bones of probable prey, juvenile mastodonts (Martin 2005). A giant short-faced bear (*Arctodus simus*), larger than a grizzly, fell victim to the Hot Springs, South Dakota, Mammoth Site, very likely attracted to rotting carcasses of sub-adult young male mammoths caught in the slippery sink. Young males, no longer under the guardianship of the matriarch in the matriarchal mammoth herd, were especially at risk when first out on their own. At Huntington Canyon at 9,000 feet in the Wasatch Mountains above Salt Lake City a giant bear died close to the remains of an aged and moribund mammoth (Madsen 2000), perhaps its actual or intended prey.

Dry caves in the Grand Canyon harbor extinct animals including a surface made by the trampling of the Shasta ground sloth (figure 2). In a Grand Canyon cave rich in the remains of late Pleistocene condors I found a bone of a much larger avian scavenger, *Titanis* (Martin 2005). In addition, in various parts of Arizona there were extinct bloodsuckers, vampire bats, *Desmodus.* There was an extinct skunk, *Brachyprotoma*, along with extinct species of pack rats, *Neotoma.* The best dietary record of an extinct mammal comes from the analysis of a meter deep dung deposit of the extinct Shasta ground sloth (Hansen 1978).

On the Mexican border in Cochise County at Naco archaeologist and Arizona State Museum Director Emil Haury reported a Columbian elephant (Haury 1953) that had been speared before death. Local residents, the Navarettes, father and son, found the carcass; it was an adult female that was not butchered and, some suspect, may have escaped the Clovis hunters whose sites would be excavated downstream on the San Pedro at Lehner Ranch and Murray Springs (figure 3). The Naco mammoth yielded a total of eight unbroken Clovis points, an extraordinary number (Haury 1953). The Naco discovery remains one of the most unusual finds in the fossil record of American mammoths. The artifacts found at Murray Springs were more likely to be broken (figure 4), presumably because any unbroken points or shaft-straightening tools would be used again and were removed from the kill sites.

One obvious result of near time extinctions is impoverishment of the megafauna of America, including the mountains and valleys of the Sky Island archipelago—the land in southern Arizona and southern New Mexico between the Colorado Plateau and the Mexican Plateau. To repeat the litany, based on near time records, the missing (and all too rarely missed} animals that are known or might be expected in this region include mammoths, mastodonts, camelids, equids, tapir, Shasta ground sloths, dwarf antelope, dire wolves, saber-tooth cats, an extinct skunk, marmots, California condors, and vampire bats. They appear in the fossil record until the end of the last ice age, 13,000 years ago; perhaps a few may have lasted longer (Martin 2005).

Camelids, equids, and dwarf pronghorn evolved in North America during the tens of millions of years of the Cenozoic; others invaded from other continents or regions, the proboscideans beginning over 10 million years ago. All are undeniably native and only missed inclusion in our national songs such as "Home on the Range" by virtue of their end-Pleistocene extinction. Otherwise we might well sing: "*Give me a home, where mastodonts roam, where ground sloths and glyptodonts play*…"

Can we rule out climatic change as part of the story? Ice core records of the Pleistocene reveal details of climatic changes that occurred repeatedly over hundreds of thousands of years (Alley 2000). Those of the various glacial stages were

Figure 2—Ground sloth dung on trampled surface, Rampart Cave. Photo by Charles Kepner.

remarkably similar in magnitude, involving major change in mean temperature. The paleoclimatic record indicates a great many pulses; most of them appear to be comparable in amplitude. Beyond the fact of megafaunal extinction, nothing unique occurred around the end of the Pleistocene, around 13,000 radiocarbon years ago. The cold climate of the time was about to warm rapidly, just as it had many times before, as can be read in the ice core and marine core records. Suddenly, with no warning, something eliminated America's elephants, horses, camelids, ground sloths, and many other large mammals mentioned previously.

In the spirit of *The Eyes of Discovery* (Bakeless 1961) zoologists turn to historians for written records when they evaluate competing strategies of management. To these they now need to add the record of fossils provided by paleontologists. The previously mentioned mammoths, mastodonts, ground sloths, tapir, native species of horses, camels, bison, dire wolves, and vampire bats once lived in or around the Chiricahuas, Huachucas, and other Sky Islands. They vanished without triggering any extinction among the native plants of the region. In fact riparian plants may have increased considerably in biomass, after the extinctions, judging by the number of riparian species found in the dung of extinct mammoth (Davis 1987, Davis and others 2002). In the presence of proboscideans riparian growth may have suffered serious attrition, far more than we see in the case of livestock.

In the past conservationists and field ecologists have paid scant attention to monumental changes in near time. That no longer works. The late Quaternary arrival of humans in America, revealed in stratigraphic detail from excavations of the mammoth kill sites on the San Pedro River in Cochise County and at the Clovis type site near the town of Clovis in eastern New Mexico, allows us to speculate on events 13,000 years ago when anthropogenic fires became a new force on the landscape. For whatever reason, that is when the native large mammals of Arizona, New Mexico, Sonora, and Chihuahua vanished. Conservationists, wildlife managers, and ecologists can no longer ignore that loss and the profound meaning it conveys for those who would design with nature.

Figure 3—Tracks at Murray Springs.

What about bison? The animal is often considered to favor tall grassland in the mid-continent, where Coronado finally found the bison he had heard about, far to the east of Santa Fe, supposedly in Kansas. Pleistocene fossils of bison occur in parts of Arizona and New Mexico, in floodplains of the

Figure 4—Clovis artifacts from Murray Springs.

desert grassland, and occasionally in the Holocene. Neither Alvar Nuñez Cabeza de Vaca, nor Fray Marcos, nor Coronado reported bison in Arizona and New Mexico. Some managers or advocates for a return to "wildness" have argued that the absence of historic or Holocene fossil records indicates the unsuitability of a region for livestock. Do those who think this way have their history right? The success of bison on Ted Turner's Armendaris Ranch near Truth or Consequences in southern New Mexico suggests that bison are better adapted to droughty pastures of desert grassland than are cattle.

The postglacial fossil range of bison, mapped by Graham and Lundelius (1994: 460-461), does not extend east of the midcontinent, ending 100 miles west of the Mississippi River. The entire southeast of the United States harbors few if any Holocene fossil records of bison. Then, historically, there is a remarkable expansion. In the last few hundred years, after the time of Hernando De Soto and before European settlement west of the Atlantic coast, bison made their move. They swept east across the Mississippi into the abandoned fields of the American Indians from New York State south to Florida (Rostlund 1960). Diseases, including small pox, unwittingly introduced by De Soto and other conquistadors may account for the collapse of large Indian settlements. For whatever reason bison suddenly found lebensraum to the *east* of the Mississippi.

To understand the last thousand years we need come to grips with the Cenozoic, the last 60 million years, including the evolution of American horses, camelids, and ground sloths. Beginning over 10 million years ago proboscideans (gomphotheres, mastodonts, and mammoths) invaded from Eurasia and speciated. As a consequence American vegetation coevolved with large herbivores to match those found now in African Parks such as Kruger in South Africa or the Serengeti in Tanzania.

With extinction of megafauna coinciding with Clovis colonization around 13,000 years ago large herbivores and their herbivory decreased. Perhaps some of the native plant species lost some of their resistance to grazing. The increase in fire frequency by anthropogenic ignitions of the human newcomers may have reduced plant biomass in season as effectively as pre-extinction grazing and browsing. I am thinking of ground sloths, extinct equids, extinct camelids, extinct bovids, and extinct proboscideans. The historic arrival of livestock in a land largely lacking large herbivores since prehistoric extinction over 10,000 years earlier, restarted a trophic function (energy exchange) that had evolved in North and South America over tens of millions of years.

Wildfires

In the 10,000 years between the end of grass consumption by native megaherbivores and before the arrival of their domestic proxies (cattle, horses, sheep, goats) another catastrophic consumer of vegetation deserves consideration: wildfire. In the 10,000 years of the Holocene and with the possible exception of occasional transient bison, the grasslands of the borderlands were consumed by nothing larger than insects, especially orthoptera (grasshoppers, crickets, roaches). After the Ryan Fire of April 30, 2002, the Research Ranch might have looked like what one would have seen in Cochise County during the millennia after megafaunal extinction and before ranching began, when the prehistoric Cochise Culture and its Hohokam successors controlled fire frequency. Warfare and fire are reflected in the four corners archaeological record to a greater degree than some pre-historians have indicated (LeBlanc 2003).

Soon after the Ryan Fire, Manager Bill Brannon of the Research Ranch noted something he had not seen before: a large number of both raptorial birds and ravens coursing over the burned ground, attracted by the windfall. They were preying on the native mice and packrats searching for suitable cover in their newly exposed runways.

Northeast of the Research Ranch is the Babocomari Ranch. On heavy flood plain soils the Babocomari supports a tall dense stand of sacaton grass that can attain two meters in height, a rich habitat for Botteri sparrows, pack rats, and javelina. In spring the dry sacaton is burned to provide new green grass for cattle. I suspect that the practice was familiar to the Sobaipuri, the Apache, and their predecessors hunting small game. What are the dynamic biotic changes that can be expected following wildfire treatments compared with grazed and ungrazed control sites?

Perhaps it is time to establish a third experimental site, a "fire ranch" in which the summer-rain grass crop will be allowed to mature, dry out, and then be burned off at the end of winter. Would this favor a different suite of grass species from what occupies Research Ranch now? Might such an assemblage be more representative of the grassland communities found prehistorically? At the very least an increased fire frequency would appear to favor avian predators.

Over the years my fenceline interpretation of 1956 has changed. Now when I look down a fenceline separating heavily grazed from ungrazed pastures I find challenging questions to ponder. For example, aside from overgrazing, what about under-browsing? Or under-burning? Or seed dispersal by livestock (figure 5) suggesting cattle substituting for what bison might have done?

Figure 5—Cow patty with seedling cholla, suggesting what bison might have done.

Those that denigrate livestock on public and private ranges—both cattle and horses, along with sheep in northern Arizona, and, increasingly, camelids (vicuna, alpaca or dromedary) plus the best-adapted large herbivore escaped into American arid lands and thriving in southern New Mexico, the gemsbok (*Oryx gazella*)—might be surprised to learn of the *Oostvaardersplassen*. This nature reserve of 6,000 hectares in the Netherlands, almost twice the size of the Research Ranch, tests the impact of wild-living Heck cattle, wild-living konik horses (*Equus przewalski*), and roe deer. Will the cattle, horses, and deer living in what Vera calls "the wild" facilitate the establishment of various species of wild flora and fauna, including thorny bushes and trees (F. W. M. Vera 2000: 383)? Reflecting a wet climate and favorable soil to facilitate biomass in the Netherlands, in 1999 there were about 500 Heck cattle, 450 konik horses and 400 red deer in the *Oostvaardersplassen*.

Finally, if plant lovers want to see many more species of vascular plants than occur in southern Arizona and New Mexico, I recommend the land where Sky Islands coalesce into the Sierra Madre in northern Mexico (Martin and others 1998). There, new records and occasionally new species of vascular plants continue to turn up, never mind heavy grazing, lumbering, and frequent fires in mountains attaining 2,700 meters, and roughly as far south of the border as the White Mountains are to the north (figure 6). Richest of all are the gigantic incisions in the Sierra Madre known as barrancas (figure 7) where 10 square kilometers will harbor at least 823 species of vascular plants and at least 17 species of oaks (*Quercus*) plus two hybrids (Spellenberg and others 1996). This species richness greatly exceeds anything found north of the border where the entire range of the Pinalenos, Mt. Graham included, has 786 species of vascular plants and the Rincons with Saguaro National Park has 986. These ranges have 1,800 meters or more of relative relief. No hot spot north of the border can match the Cascada de Candameña.

Yes, there are major downsides to the spread of livestock in Mexico and magnificent thorn forest and tropical deciduous forest is being sacrificed to the cattle industry. Surely some other species, adapted to aridity, capable of good meat

Figure 6—*Tigridia pavonia,* Iridaceae, Sierra de Obscura, Chihuahua.

production, and leaving a lighter footprint on the land is worth considering as an alternative. New Mexico may already have a solution in its gemsbok, the Kalahari oryx. Are experiments with aliens still totally taboo? Will we fiddle while dry tropical forest is torn down for cattle?

As archaeologists and geographers have long realized, environmentalists must not overlook or ignore but embrace prehistory, including the fire stick foragers and the extinct animals that vanished at the start of our watch in America. If not a place for domestic grazers such as cattle, horses, sheep, and goats, wild America known to Lewis and Clark harbored deer, elk, and buffalo, along with wolves and grizzly bear, all of which did or might have lived around the Chiricahuas, just like they lived in Montana, if Native Americans foraging

Figure 7—Basaseachic Falls, a waterfall of over 245 meters.

on wild plants and cultivating corn in the Southwest had not suppressed javelina, elk, and buffalo.

Introduced buffalo appear to do very well on Ted Turner's Armendaris Ranch in southern New Mexico. If my suggestion that the lack of large herds of native bison throughout the southwest, in the Chihuahuan Desert and in the desert grassland of northern Mexico, prehistorically reflects predation by native people, and not the unsuitability of desert grassland for bison, the success of Turner's Armendaris Ranch is no surprise.

For both ranchers and preservationists the take home message is that the evolution of the western range involves tens of millions of years of coexistence of herbaceous plants with a great many kinds of large herbivores, most of the latter suddenly removed around 13,000 years ago for reasons that remain controversial. Most of our large native herbivores vanished when prehistoric people invaded. In addition the invaders triggered a considerable surge in fire frequency, declining historically with the introduction of domestic livestock (Davis and others 2002).

In this thumbnail sketch for fenceline philosophers, grazing differences can certainly change the dynamics of what species of grasses thrive on one side of the fence compared with another, as the Bocks' book, *The View from Bald Hill* (2000), reveals. There are more comparisons to consider and few ecologists, least of all the Bocks, will claim that all ranching is ecologically "wrong" and that blanket protection of the range from all large domestic herbivores is invariably "right." In the evolution of the desert grasslands, the fossil record indicates more diversity of large herbivores in the past, not less, and with more taxa of large herbivores presumably consuming more forage than is eaten by livestock at present. It is not only the fossil record that needs to be considered, it is also the experiments in the Netherlands to recreate wild lands in the *Oostvaardersplassen* with free ranging cattle, Przewalski's horses, and roe deer. It is time to experiment with more fire and more taxa of large mammals in American ranges and browse-lands. In monitoring the experiment we may find that fencelines have a great deal to teach, far more than fenceline photographers may realize . . .

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Fire Histories From Pine-Dominant Forest in the Madrean Archipelago

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Abstract—*The pine-dominated woodlands and forests of the Sky Islands typically sustained surface burns about once per decade until the turn of the 19th to the 20th centuries, when livestock grazing and organized fire suppression effectively ended this centuries-long pattern. Fire scar chronologies from 31 sites in 10 mountain ranges illustrate this history. By combining elevational transects of fire scar chronologies in three of the mountain ranges it is possible to visualize the temporal changes in widespread fire occurrence. Combining all 31 chronologies for the region, it is evident that there was a high degree of synchrony in fire occurrence that must have been related to broad-scale climate variations. Comparisons of synchronous fire years with a regional tree-ring reconstruction of precipitation confirm the importance of wet/dry seasonal and inter-annual climate patterns in promoting widspread burning.*

Introduction

For many centuries fire and smoke were as regular in the Sky Islands as the Southwest monsoon. Indeed, fiery columns of smoke rising from the mountains were as normal a sight in May and early June as watery cumulous clouds in late June and July. Then in the late nineteenth century, large numbers of American settlers arrived with their enormous herds of livestock. Thousands of sheep, goats, cows, and horses clipped the bunch grasses and pounded trails and driveways across the landscape. This disruption of surface fuels effectively ended the centuries-long pattern of free spreading surface fires (Leopold 1924). Tree-ring studies from dozens of forests and woodland sites in the Sky Islands clearly show these patterns of change. The timing of the last widespread fire in any given mountain range closely coincides with the first arrival of large livestock herds in that particular range (Swetnam et al. 2001; Swetnam and Baisan 2003). At about the same time that livestock numbers decreased in the early 20th century, government foresters adopted fire suppression as a primary mission (Pyne 1982).

Although the human-caused changes to fire regimes in the late 19th century—from frequent, widespread surface fires to nearly total fire exclusion—is very obvious in tree-ring and documentary records, we are less certain about the causes and controls of fire regime changes before circa 1880. Undoubtedly, both climatic variability and human uses of fire were responsible for fire frequency changes, but what were their relative roles and importance? The answer depends upon the time and the place. In some places and times, American Indians greatly modified ecosystems, and in other places and times the role of humans in controlling past fire regimes was probably non-existent or negligible (Swetnam et al. 2001; Allen 2002). Even in those places and times where people were using fire frequently and extensively, it still is likely that climatic variations were important in controlling, to some degree, the variations in local to regional fire regimes. In fact, the fire scar record from the broader Southwest, as well as the Sky Islands, confirms this interpretation.

In this paper I illustrate three tree-ring based fire histories from elevational transects in ponderosa pine and mixed conifer forests of the Madrean Archipelago. These case studies exemplify the kinds of variations and changes that occurred in surface fire regimes over the past 300 to 500 years. I also summarize fire history patterns in a total of 31 sites in 10 Sky Island Mountain Ranges (figure 1), and the linkages of wet and drought years to fire occurrence from 1640 to 1900. Both human and climatic influences are evident in these fire chronologies.

Three Examples of Surface Fire Histories Along Elevational Transects

Over the past 20 years we have sampled hundreds of fire scarred trees in dozens of sites across the Sky Islands region. "Sites" in these cases are forest stands where fire scarred trees were collected over areas typically ranging from about 10 to 100 hectares. In some cases the fire scar records from multiple sites were combined at broader scales (100 to 2,000+ ha) to form a single, composite fire scar chronology for a watershed or for the forested area at the top of a Sky Island. Sites typically included 10 to 50 fire scarred trees. Broad composites of multiple sites distributed over large areas typically included 50 to 100+ fire scarred trees. The composite fire chronologies are useful for studying fires that occurred anywhere within the sampled area, as well as widespread fires. The period of time that is well represented by the fire scarred trees usually extends between about AD 1600 and the present, although some sampled trees extend back to AD 1400 or earlier.

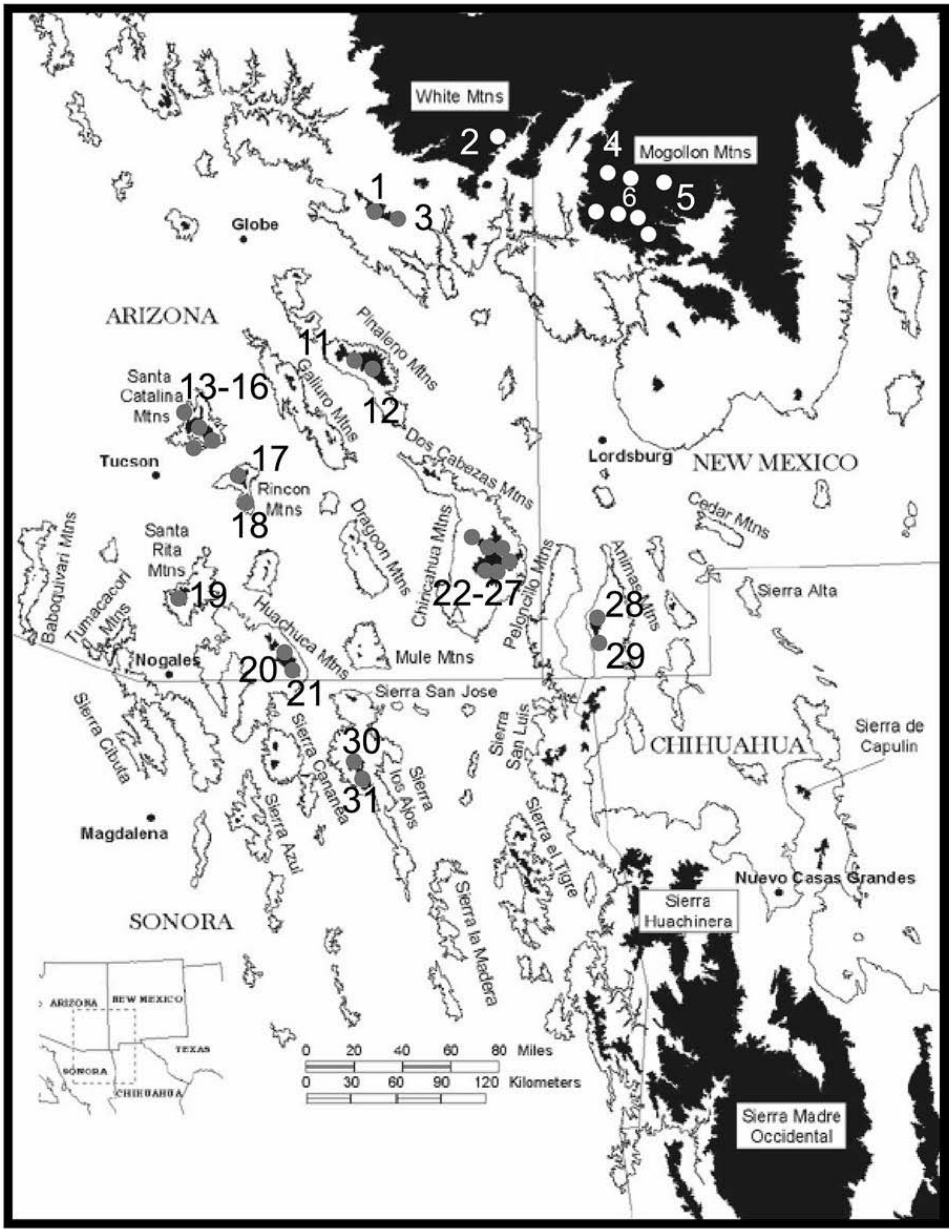

Figure 1—Map of the Madrean Archipelago region, with numbered locations of fire scar collection sites and chronologies.

The collection sites are generally within pine-dominated forests and woodlands. These include pine-oak mixtures at the lowest elevations, pure ponderosa pine stands at middle elevations, and mixed conifer at the highest elevation stands. Ponderosa pine (*Pinus ponderosa*) or Arizona pine (*Pinus arizonica*) was the most common, dominant over story species in these stands, and the most common fire scarred tree sample. Other pine species included Southwestern white pine (*Pinus strobiformis*), Chihuahua pine (*Pinus leiophylla*), and Apache pine (*Pinus engelmannii*). The mixed conifer stands sometimes contained pine species only as a minor component (Douglas-fir, [*Pseudotsuga menziesii*], and white fir, [*Abies concolor*], were typically dominant in these cases). In a few cases the uppermost elevation sites (e.g., the Gila [or Mogollon], and Piñaleno Mountains) were adjacent to spruce-fir stands.

The collection sites were selected based upon a broad range of considerations. Of course, the presence of fire scarred trees was a primary factor, which naturally limits these reconstructions to conifer forests. Evergreen oaks in the borderlands area are generally not suitable for tree-ring analyses because the rings are not annual, or are very difficult to identify. In general, the mountain ranges and watersheds where we sampled fire scarred trees were selected because they were of interest to fire management programs in Federal agencies and conservation organizations, and we had financial and logistical support from these agencies to carry out studies in these areas. Accessibility, travel routes, and permission to sample with chain saws or handsaws also partly determined our sampling strategies. Within the study areas we attempted to collect samples from spatially dispersed locations, and often from a range of elevations, aspects, and forest conditions. Although the sites and trees sampled were not randomly located, they were often systematically placed so that some general representation of the areas and conditions were likely to be captured (see Swetnam and Baisan [1996] for additional discussion of sampling strategies and rationale). One of the systematic sampling approaches we used was to collect fire scarred trees along elevational transects (figure 2).

Graphical depictions of the composite fire scar chronologies are very useful for visualizing the temporal and spatial changes in surface fire regimes (figure 2). When the individual tree records, and sites are arranged along an elevational transect on the y-axis, it is sometimes possible to discern fire frequency differences and similarities among sites. The three elevation transects illustrate several common patterns seen elsewhere in the Sky Islands and other pine-dominant forests of the Southwest (see also Barton et al. 2001 for another example of an elevational transect of fire scar chronologies in the Chiricahua Mountains).

The most obvious pattern is the disruption of the fire regime around the turn of the 19th to the 20th century. Note that the timing differs between the areas, with the last widespread fire in 1904 along the Gila transect, 1917 along the Chiricahua transect (but with a long interval preceding this back to 1894), and 1900 along the Santa Catalina transect (figure 2). As previously mentioned, the timing of the surface fire regime disruptions tends to correspond very well (usually to within a few years) with the first introduction of large numbers of sheep, goats, cows, and/or horses in these specific areas. The last widespread fires, as recorded by the fire scars, was confirmed in all three of these cases by independent documentary sources mentioning the fires (e.g., newspaper accounts and government documents; see Swetnam et al. 2001 for detailed historical references and examples).

The other most obvious pattern evident in these broad fire chronology comparisons is the high fire frequency before circa 1900, but highly variable intervals between fire events. In general, at the scales of these transects (see caption in figure 2), there was typically a fire burning somewhere within the general area about once every 2 to 4 years. However, it is important to bear in mind that this does not mean that all of these fires were widespread. In fact, many fires were not widespread. Between 1650 and 1900, 22% of fires were recorded as fire scars only on single trees on the Gila, 43% on the Chiricahua transect, and 36% on the Santa Catalina transect. This pattern is not surprising because lightning ignition rates within these mountain ranges can be quite high, but most fires typically do not spread beyond the tree that was struck, or a few hectares. A recent examination of lightning fire ignition rates over the 20th century in the Rincon Mountains, for example, indicates that the frequency of any fire occurring *anywhere* in the conifer forests on the mountain was at least 1 fire per year (Farris and others, unpublished manuscript).

Of greater interest, and perhaps greater ecological importance, are the relatively widespread fire events. These are visible along the fire scar/elevational transects as broadly synchronous events between trees and sites (figure 2). The actual extent of these events is unknown because many of these fires probably burned far beyond the areas we sampled, and they probably did not burn all areas between the sampled trees. Moreover, the spatial distribution of the trees we sampled was non-random and non-uniformly distributed. Likewise, the time coverage varied from location to location because of different spans of time, and quality (completeness) of the fire record as represented by the sampled trees. Hence, these records have various spatial and temporal biases that limit their direct interpretation or extrapolation to quantitative amounts of area burned, or for detailed mapping of the spatial patterns of fire events within sites. These limitations and uncertainties of fire scar records have been highlighted in recent papers (Minnich et al. 2000; Baker and Ehle 2001), but Fulé et al. (2003) and Stephens et al. (2003) present some countering evidence and perspectives. Falk (2004; Falk and Swetnam 2003) also evaluates the dependencies of fire frequency estimates upon sampled area and sample size (numbers of fire scarred trees included in chronologies).

Despite the uncertainties that exist in fire scar chronologies (whether sampled systematically or randomly), there is increasing evidence that relatively widespread fire events can be completely inventoried by fire scar collections (Fulé et al. 2003; Swetnam and Baisan 2003; Falk 2004; Farris and others, unpublished manuscript). In particular, "filtered" fire events, which are identified as those events recorded on a minimum number and/or percentage of fire scarred trees, can provide complete, or nearly complete, chronologies of relatively widespread fires within sampled areas. We have confirmed this interpretation in numerous instances where documented 20th century fires were well represented in the fire scar record. For example, the cases previously mentioned of the last widespread fires in the Gila, Chiricahua, and Santa Catalina Mountains (figure 2) correspond well with the historic records, including a few recent, large fires (and see examples described in Swetnam et al. 2001, the papers cited therein; and Farris and others, unpublished manuscript).

As mentioned above, even widespread fire events, as interpreted from broadly synchronous fire scar dates within sites, should not be interpreted to have burned all areas between fire-scarred trees. Fire intensity, severity, and completeness of burning of fuels tend to be highly variable at all spatial scales. Even in the most widespread, low intensity surface fire, or in the most widespread and high severity crown fire, there is almost always some degree of "patchiness," where fuels are left unburned or only partially burned. Furthermore, it should be recognized that fire histories of all kinds have some degree of bias and inaccuracy, including those based on mapped

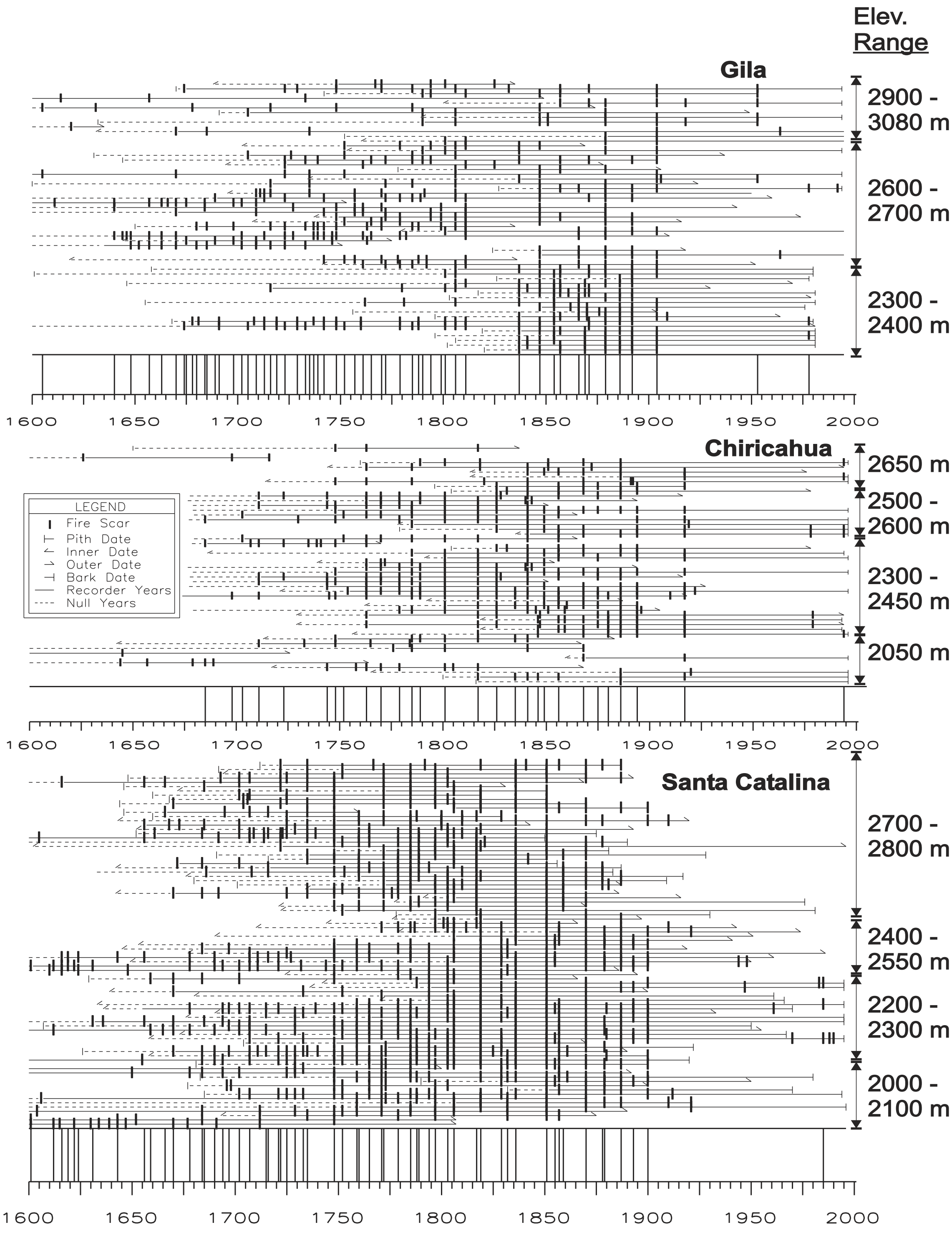

Figure 2—Fire scar chronologies from elevational transects in the Gila Wilderness, New Mexico (sites 7-10 in figure 1), the Chiricahua Mountains, Arizona (sites 24-27), and the Santa Catalina Mountains, Arizona (sites 13-16). The Gila transect sites are near the headwaters of the West Fork, extending from Langstroth Mesa to Snow Park. The Chiricahua transect sites are within the Mormon Canyon watershed, extending up to Anita Park. The Santa Catalina transect sites extend along the Mt. Lemmon Highway, from Bear Canyon to Mt. Lemmon. The Gila transect spans an elevation range of approximately 2,300 m to 3,080 meters and a linear distance of about 9 km. The Chiricahua transect spans an elevation range of approximately 2,050 m to 2,650 meters and a linear distance of about 5 km. The Santa Catalina transect spans an elevation range of approximately 2,100 m to 2,800 meters and a linear distance of about 13 km. The horizontal lines in each transect graph are the records represented by individual fire scarred trees, and the vertical tick marks are the fire dates recorded in those sites.

perimeters of fires from direct observations and documents (e.g., fire atlases, aerial photos, or satellites) or stand age structure evidence (Finney 1995; Rollins et al. 2001; Morgan et al. 2001). It is also likely that fire scar-based estimates of location and timing of past fires are, in some cases, more accurate than estimates based on other methods of fire history.

Synchronous fire scar dates on trees distributed across the elevational transects probably represent widespread fires, although it is possible that some of these events were multiple, separate fires that ignited (e.g., by lightning) and spread during the same year. The repeated occurrence of many different fire dates through time that are synchronous on the same trees (e.g., figure 2), however, logically argues that most of these dates were likely widespread fires, rather than separate ignitions.

In general, the widespread fire events along the fire scar transects can be estimated as those that were recorded by 25% or more of the trees (see the vertical lines at the bottom of each chronology chart). This particular percentage (25%) is somewhat arbitrary, but useful at this stage of our understanding and analyses to identify events that were probably widespread along the transects. The means of all intervals between the 25% filtered fire events (from 1650 to1900) were 10.7 years along the Gila transect, 9.9 years along the Chiricahua transect, and 9.0 years along the Santa Catalina transect.

Regional Fire History and Climate

In contrast to the elevational gradients, synchrony of fire events at the regional (or sub-regional) scale, such as the Madrean Archipelago (figure 1), most likely relates to broad-scale climate variability. This is confirmed in a comparison of the 30 most synchronous fire years between 1640 and 1900 (labeled years in figure 3) and an independently developed tree-ring width reconstruction of November to April precipitation for Arizona Climate Division 7 (figure 4) (Ni et al. 2002). This climate division encompasses the entire Arizona portion of the study area. Note that 23 of the 30 most synchronous fire events fall on dry years (below the mean line), while only 7 fire events fell on wet years (above the mean line). The November to April period compared here is the season proceeding the typical fire season, which usually extends from about April to August, and is the period when most fire scars were formed.

A superposed epoch analysis (SEA) (inset graph in figure 4) also confirms this pattern of the most synchronous fire years among the Sky Islands corresponding with dry preceding winters/springs. The SEA involves computing the mean seasonal (November to April) precipitation amounts during all 30 regional fire years (0 year lag in figure 4), and the mean precipitation during 5 years prior to and 5 years following the regional fire years. The SEA reveals a pattern commonly seen in these types of comparisons of fire occurrence time series and precipitation or drought indices—a correspondence of 1 to 3 wet prior years combined with dry current years is a typical wet/dry cycle that promotes fire synchrony (Baisan and Swetnam 1990; Swetnam and Betancourt 1998). This pattern probably reflects the role of prior year's moisture in promoting the growth of fine fuels (grasses and tree leaves) and appears to be particularly important in drier, lower elevation woodlands and forests where grass cover was an important factor in fire ignition and spread.

The importance of wet/dry patterns in fire occurrence has been common wisdom among knowledgeable fire managers in the Southwest for some time, but it seems to have been first identified systematically and statistically in our tree-ring fire history work (Baisan and Swetnam 1990; Swetnam and Betancourt 1992). Subsequently, a number of other tree-ring studies found similar patterns in the Southwest (e.g., Grissino-Mayer and Swetnam 2000; Brown et al. 2001; Fulé et al. 2003), and in Colorado (e.g., Veblen et al. 2000; Donnegan et al. 2001). Again, the wet/dry pattern seems to predominate in semi-arid forests and woodlands where grass cover was an important fuel. At higher elevations (e.g., mixed conifer) or higher latitudes the current year drought signal is often stronger, but the lagged, prior year wet conditions typically become unimportant (statistically insignificant) (e.g., Swetnam and Baisan 2003; Veblen et al. 2001; Heyerdahl et al. 2002).

Recent statistical studies of 20th century fire occurrence data (numbers of fires and areas burned) from the whole Western United States have confirmed the existence and statistical importance of lagged, prior year wet conditions to subsequent years increased fire occurrence in the modern period, especially in parts of the Southwest (Westerling et al. 2002, 2003; Westerling and Swetnam 2003; Crimmins and Comrie, in press). These lagged patterns offer useful opportunities for forecasting because statistical models can make use of prior seasons conditions for "predicting" the relative hazard of the up-coming fire season (Westerling et al. 2002; Kitzberger 2002). In fact, such models and forecasts are being used now as one of the tools for long-range fire management planning at regional and continental scales (e.g., see Seasonal Outlook Web pages of the Southwest Greater Area Coordination Center (GACC) at: http://www.fs.fed.us/r3/fire/swapredictive/swaoutlooks/swaoutlooks.htm and the Predictive Services group at the National Interagency Fire Center (NIFC) at: http://www.nifc.gov/news/intell_predserv_forms/season_outlook.html).

An important aspect of these wet/dry and synchronous fire occurrence patterns across the Southwest (widespread fire) is that they are fairly robust from the 17th through the 20th centuries, despite the major changes that have occurred in fire regimes, forest conditions and fuels. Westerling and Swetnam (2003) recently applied these wet/dry lagging relationships in a linear regression model, where 20th century area burned statistics (1916-1978) from all lands in the Southwest were "calibrated" with a time series of Palmer Drought Severity Indices (PDSI) for the Southwest over the same time period. The regression model was then applied to a 300 year long tree-ring reconstruction of PDSI (from hundreds of drought sensitive tree-ring width chronologies) for the entire Southwest (Cook et al. 1999) to estimate area burned (using PDSI as the predictor variable) back to AD 1700. The resulting estimates from the modeled area burned correlates well with a composite time series from 63 fire scarred tree chronologies from the Southwest (Spearman's $r = 0.61$, $p < 0.05$, 1700-1900 period).

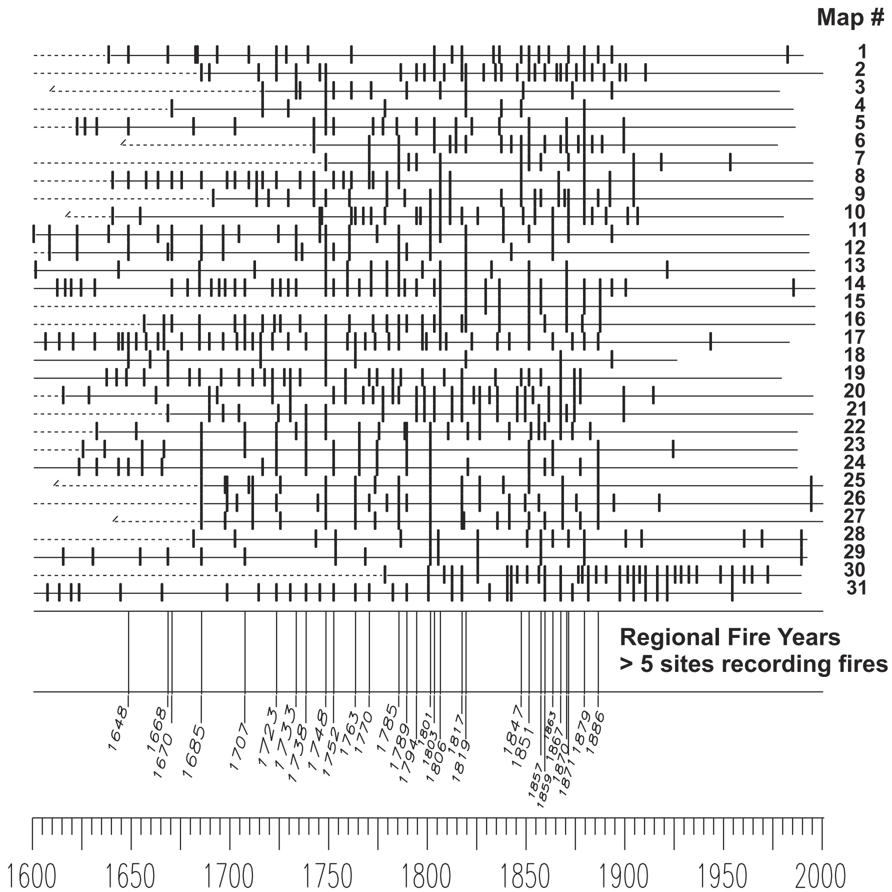

Figure 3—Regional composite fire scar chronology from 31 sites in the Madrean Archipelago (see numbered locations on map in figure 1). The horizontal lines are time spans represented by all fire scarred trees sampled within each site, and the vertical tick marks are fire events recorded by 25% or more of sampled trees (in that year) within each site. The composite vertical lines and dates at the bottom of the graph show the 30 most synchronous fire years among the 31 sites (6 or more sites recording an event).

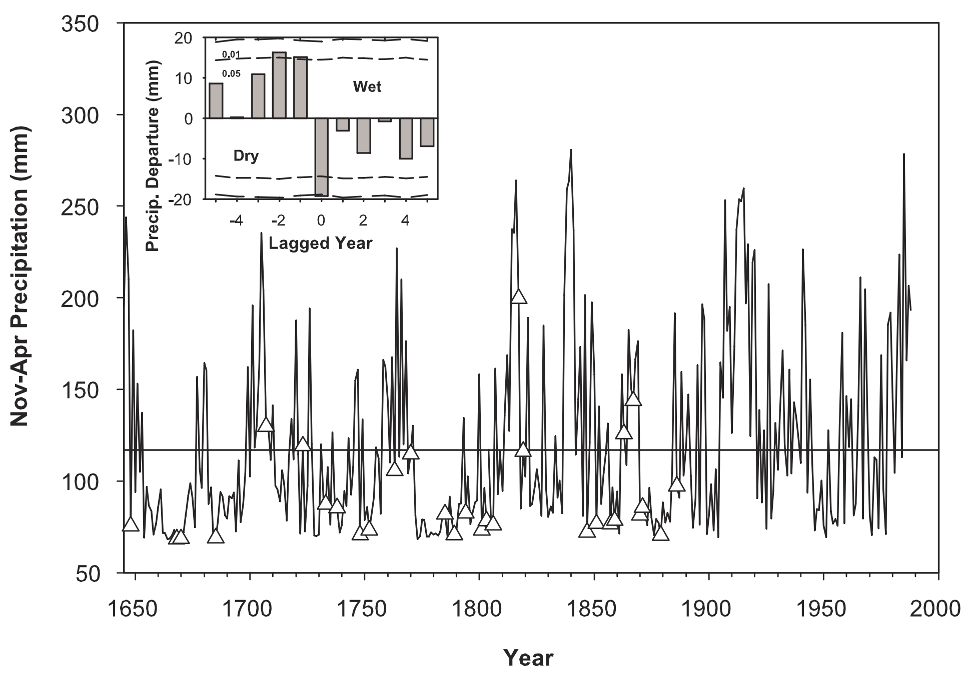

Figure 4—November to April precipitation (1650 to 1989) and the 30 most synchronous fire years among the Sky Islands (labeled dates from 1650 to 1900 in figure 3). The inset graph in upper left corner shows the results of the superposed epoch analysis, with average conditions significantly dry ($p < 0.01$) during the 30 synchronous fire years, and the previous two years significantly wet ($p < 0.05$) (see text for explanation).

These results indicate that inter-annual variations in climate, especially wet and dry patterns, have been important to fire activity in the Southwest and Sky Islands sub-region for hundreds of years. Moreover, expanded studies on these lagging patterns using modern fire occurrence data may provide useful fire hazard forecasting tools. Examples of the use of these kinds of tools are the Southwest GACC and NIFC Web sites listed above. Another example is the Wildfire Alternatives (WALTER) Web site at: http://walter.arizona.edu/

The WALTER model provides a set of spatial analytical tools, combining physical, ecological, and social factors, for assessment of relative fire hazard. The model also includes a sophisticated climate input that derives in part from and assessment of season to season lags in climate and fire responses (Crimmins and Comrie, in press).

One additional kind of climate-fire pattern that has occurred in the Southwest Sky Islands is worth pointing out. As shown in the SEA (figure 4) and the statistical modeling results (i.e., Westerling and Swetnam 2003) inter-annual climate-fire relations are important, but it is also evident that decadal scale patterns of climate and fire synchrony (and asynchrony) are also important. For example, it is possible to visually detect a change in fire frequency and synchrony during the 1700s and 1800s (figures 2 and 3). Notice that fires tended to be more frequent along the elevational transects during the 1700s, and then there is a change to decreased fire occurrence around 1800. This change is most obvious in the Gila and Santa Catalina transects. A "gap" in fire occurrence—i.e., a long interval between fires—appears in many of the sampled sites along the transects (and elsewhere in the Southwest) during the early 1800s. Note the long interval between synchronous events (>5 sites) in the Sky Islands composite between 1819 and 1847 (figure 3).

This hiatus, or gap in fire occurrence was first noted in fire scar chronologies developed in the Gila Wilderness (Swetnam and Dieterich 1985). Since that time, it has been found in numerous other fire scar chronologies in the Southwest (but not a majority of sites), and interestingly, in very far flung locations, such as Baja California (Stephens et al. 2003) and the Blue Mountains of Oregon (Heyerdahl et al. 2002). A marked decrease in correlation between fire occurrence and drought indices in the Southwest also occurs during this period (circa 1780-1840) (Swetnam and Betancourt 1998). Most remarkably, a decrease in fire frequency during this period also appears in fire scar chronologies from semi-arid *Austrocedrus chilensis* woodlands and forests in Patagonia, Argentina (Kitzberger et al. 2001). Based on comparisons between the Southwest and Patagonia fire scar chronologies, and climatic records, we hypothesized that these inter-hemispheric fire regime correlations must be driven by very broad-scale ocean-atmosphere patterns, such as decadal-scale changes in the frequency and amplitude of the El Niño-Southern Oscillation (ENSO) (Kitzberger et al. 2001). (Barton et al. [2001] also detect a gap in fire occurrence during the early 1800s within the Rhyolite Canyon watershed in Chiricahua National Monument. However, this long interval is restricted to only part of the Canyon, and appears to be a local-scale event, possibly related to a flood that disrupted fuel continuity within the Canyon for a period of time.)

Much more study is needed of both inter-annual and decadal scale patterns of climate and fire. In addition to ENSO, a variety of oscillatory, hemispheric to global scale ocean-atmosphere patterns that affect climate in the Western United States have been identified in recent years (e.g., Pacific Decadal Oscillation, Atlantic Multi-decadal Oscillation, others). Comparisons of fire occurrence time series (modern and paleo) with these ocean-atmosphere time series can reveal important insights on regional to continental fire climatology (e.g., Swetnam and Betancourt 1990, 1992; Veblen et al. 2000; Heyerdahl et al. 2002; Norman and Taylor 2003; Westerling and Swetnam 2003).

Conclusions

Fire climatology has the potential to provide new understanding of how climate variability and change affects fire regimes and ecosystems over long time scales and broad spatial scales. This understanding will be needed as we enter an increasingly warm and variable climatic period, which will likely result from increasing greenhouse gases. Recent assessments of possible climate change impacts on fire regimes indicate that the Southwestern United States is particularly vulnerable, with probable increases in areas burned (McKenzie et al. 2004; Brown et al. 2004). As the example of inter-annual lagging relations between climate and fire in semi-arid forests (wet/dry cycle) shows, the paleo-ecological record of fire and climate can be very useful in uncovering relationships, which can then be further tested and evaluated with modern data and modeling. Some of these relationships can lead to development of forecasting tools that will be an aid to fire management planning.

The fire scar record in the Sky Islands has been very useful in clearly documenting the fact that surface fires were once very frequent and widespread in the pine dominant forests, but that rather drastic changes took place when livestock grazing and organized fire suppression began. In addition to fire-climate studies, the existing chronologies are most useful for coarse-scale assessment of fire frequency within sampled areas, but are limited in their usefulness for examining more detailed spatial patterns within and between sites. Increased sampling intensity and extent in spatial grid designs or random sampling (e.g., Heyerdahl et al. 2001; Fulé et al. 2003; Falk and Swetnam 2003; Farris and others, unpublished manuscript) will undoubtedly improve our estimates of the spatial pattern of past fires, and also provide fire frequency estimates that are less biased by sampled area and sample size. These kinds of assessments will be particularly useful in wilderness areas and parks, as fire managers eventually move beyond the current phase of surface fire regime re-introduction, and into a phase of fire regime maintenance. In this latter phase of fire use and management at landscape scales, the importance of knowing and understanding spatially explicit fire regime patterns will be of increasing importance.

Acknowledgments

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Plenary Abstracts

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Ecological responses to climate variability in time and space: a Southwestern synopsis. Southwestern ecosystems bear the imprint of climate variability on Quaternary to interannual time scales. Unlike most desert regions in the world, the Southwest has experienced dramatic changes in the abundance, variance, and seasonality of precipitation with ~10º shifts in the average, winter position of the northern westerlies. Among the many imprints are floras rich in winter annuals, unusually high levels of granivory, and many presumed Pleistocene relicts on mountaintops and in streams. The great turnover began 13,000 years ago with increased temperatures and a "Clovis megadrought," which must have entailed massive tree dieoffs and stand-replacing fires. Rapid denudation readied the landscape for invasions from the lowlands and farther south. Drought-induced disturbances have routinely modulated the pace of Holocene invasions. Yet another spate of disturbance-driven invasions may be looming in the Southwest. Critical fuel thresholds have been exceeded, a warming North Atlantic and cooling tropical Pacific have shifted the climate from wet to dry, fires and insect outbreaks are consuming large patches of the landscape, and the last freeze now happens earlier. The next decade will pose many challenges for land managers, who may or may not be equipped to manage ecosystems undergoing dramatic change.

Respuestas ecológicas a la variabilidad del clima en tiempo y espacio: una sinopsis al suroeste. Los ecosistemas al suroeste llevan la impresión de la variabilidad climática en escalas desde el Cuaternario hasta tiempos interanuales. A diferencia de la mayoría de las regiones desérticas del mundo, el suroeste ha experimentado cambios dramáticos en la abundancia, la variación y la estacionalidad de la precipitación con los cambios de ~10º, en la posición promedio invernal de los vientos norteños del oeste. Entre las muchas impresiones están las floras ricas en plantas anuales de invierno, niveles inusualmente altos de granivoría y muchos, presumiblemente, relictos Pleistocenos en cimas montañosas y corrientes. El gran cambio comenzó hace 13,000 años con temperaturas crecientes y una "megasequía de Clovis," que debe haber sobrellevado mortandades masivas de árboles e incendios que substituyeron rodales. La denudación rápida alistó el paisaje para las invasiones provenientes de las tierras bajas y del sur más lejano. Los disturbios inducidos por la sequía, han modulado rutinariamente el paso de las invasiones del Holoceno. Más aun, otra disputa de invasiones provocadas por disturbios puede estar surgiendo en el suroeste. Se han excedido los umbrales críticos del combustible: un Atlántico Norte que se calentaba y un Pacífico tropical que se refrescaba, han cambiado el clima de húmedo a seco, los fuegos reemplazadores de rodales y los brotes de insectos están consumiendo grandes extensiones del paisaje, y las heladas tardías ahora suceden en la primavera temprana. La próxima década planteará muchos desafíos para los manejadores de las tierras, quienes pueden o no estar equipados para anticipar y manejar los ecosistemas que experimentan un cambio dramático.

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The dance between science, decision making, and public education for natural resource management. Decision makers and land managers are facing increasingly complex issues in natural resource management to meet competing demands of limited resources. In many instances, decision makers are taking the lead in integrating more sophisticated science and research in their overall decision process. If research scientists want their work to be used more rapidly, and directly, to aid decision making, they must take the lead in working closely with decision makers. They must not only publish in the peer-reviewed literature but, devote significant time to work with decision makers. Time is the key to building trust, and trust is an essential element for the dance to continue. Complex resource management decisions over large areas and watersheds must involve the public. If difficult decisions are to be made by elected officials, the public must understand why the decisions were made and the scientific and economic underpinnings supporting these decisions. Thus, public education must take its turn in leading the dance. The trust of the public must also be earned.

In this overall process (e.g. the dance) the lead will change many times but it must be balanced and fair. This presentation provides an overview of my experiences in the interplay between science, decision-making, and public education as part of on-going efforts of the Upper San Pedro Partnership (http://www.usppartnership.com/) in southeastern Arizona. It also reviews several research efforts presented at this conference which may provide a lead in identifying future important issues for decision makers and the public which are not currently front and center.

La danza entre ciencia, toma de decisiones y educación pública para el manejo de los recursos naturales. Los tomadores de decisiones y los manejadores de la tierra se encuentran cada vez más con aspectos complejos en el manejo de los recursos naturales para conciliar demandas competitivas sobre recursos limitados. En muchas instancias, los tomadores de decisiones han tomado el liderazgo al integrar ciencia e investigación sofisticada a los procesos de toma de decisiones. Si los investigadores quieren que su trabajo sea usado más rápidamente y directamente ayudar en la toma de decisiones, deben tomar el liderazgo para trabajar estrechamente con tomadores de decisiones. No sólo deben publicar en revistas arbitradas, sino también dedicar tiempo suficiente para trabajar con tomadores de decisiones. El tiempo es la clave para la construcción de confianza y la confianza es un elemento decisivo para que la danza continue. Las decisiones complejas sobre manejo de recursos en grandes áreas y cuencas, deben involucrar al público. Si se requieren decisiones difíciles por parte de las autoridades, el público debe entender porqué tales decisiones fueron hechas y las bases científicas y económicas que las soportan. Por eso, la educación pública debe tomar su turno en llevar la danza. La confianza del público se debe ganar. En el proceso en general (i.e. la danza) la trama cambiará muchas veces pero debe ser balanceada y justa. Esta presentación proveerá un bosquejo de mis experiencieas en la intersección entre ciencia, toma de decisiones y educación pública com parte de los esfuerzos actuales de la Sociedad del Alto Río San Pedro (http://www.usppartnership.com) en el sur de Arizona. Hace igualmente una revisión de varios esfuerzos de investigación presentados en esta conferencia y que pueda proveer de un hilo conductor para identificar futuros aspectos de importancia para los tomadores de decisiones y el público que no están muy involucrados actualmente.

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Insects as agents of change in the Sky Islands. Sky Island forests have been impacted by multiple, severe insect outbreaks. Southern Arizona and New Mexico have incurred, on average, 118,000 ac of insect-related mortality each year since 2000. Bark beetles have killed pine stressed by several years of drought, and spruce and fir stressed by winter storms, drought, and defoliation. Extensive and severe bark beetle disturbances are commonly associated with drought, but drought is not sufficient explanation for the multitude, extent, and severity of outbreaks. Other factors are the introduction of exotic species, especially spruce aphid, and climate warming. Though their impact has been minimal to date, both white pine blister rust and sudden oak death have been found in Arizona and New Mexico. Second, a small change in mean annual temperature has dramatically altered the seasonality of temperature limits associated with insect populations, which are sensitive to small changes in climate. Population dynamics that have changed with warmer temperature regimes are not likely to be reestablished once the drought ends. The exact nature of future insect disturbances is unpredictable, but degradation of these forests will continue, with or without drought. These degraded ecosystems are threatened by catastrophic wildfire, especially when multiple forest zones are degraded at the same time. The combined effects of drought, native and exotic pests, and wildfire will cause rapid changes to forest systems.

Insectos como agentes de cambio en las Islas del Cielo. Los bosques en las Islas del Cielo han sido impactados por multiples y severas plagas de insectos. En el sur de Arizona y New Mexico ha presentado mortalidad relacionada con insectos en 118,000 ac en promedio cada año desde el 2000. Descortezadores han provocado la muerte de pinos estresados por varios años de sequía, y oyamel y abetos estresados por tormentas de invierno, sequía y defoliación. La perturbación extensa y severa de los descortezadores esta comunmente asociada con sequía, pero la sequía no es explicación suficiente para la multitud, extención y severidad de las plagas. Otros factores son la introducción de especies exóticas, especialmente áfidos de oyamel y el calentamiento global. Aunque sus impactos han sido mínimos hasta la fecha, tanto la roya fusiforme del pino blanco y muerte súbita del encino se han encontrado en Arizona y New Mexico. Además, un pequeño cambio en la temperatura media anual ha alterado en forma dramática la estacionalidad de los límites de temperatura asociados con las poblaciones de insectos, que son muy sensibles a pequeños cambios en el clima. La dinámica de poblaciones que ha cambiado con regímenes de temperaturas más elevadas no se reestablecerán una vez que termine la sequía. La naturaleza exacta de las perturbaciones futuras de insectos son impredecibles, pero la degradación de esos bosques continuará, con o sin sequía. Esos ecosistemas degradados están amenazados por fuegos catastróficos, especialmente cuando múltiples zonas forestales son degradadas al mísmo tiempo. Los efectos combinados de sequía, plagas nativas y exóticas, y fuego, causarán cambios muy rápidos alos sistemas forestales.

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Biocultural diversity and its conservation in the Mother Mountains. For many millennia, the Sierra Madre Occidental has been the theater for the evolution, divergence, and adaptive radiation of many biological species and indigenous cultures. The importance of this cordilleran habitat complex is even evident in the name, Madro-Tertiary flora, whose descendants now dominate the surrounding ecoregions as well. But what has been most unique about this mountain and barranca ecoregion over the last three to five millennia is the active interplay between biological and cultural diversity that has led not merely to high species richness in native crops and land management practices, but cultural refugia for wild and semi-managed species as well. Like it or not, the Sierra Madre's current conservation value is not merely its wild species and wild places, but the traditional ecological knowledge of its inhabitants and the culturally-managed landscapes they inhabit as well. There is greater probability of creating broader partnerships for on-ground conservation through endorsing the paradigm of safeguarding biocultural diversity — heralded by Terralingua, Mexico North, Comunidad y Biodiversidad, Native Seeds/SEARCH, CONABIO, and the Center for Sustainable Environments — than by treating the Sierra Madre merely as one of the last great wild places and ignoring cultural connections.

Diversidad biocultural y su conservación en las Montañas Madre. Por muchos milenios, la Sierra Madre Occidental ha sido el teatro para la evolución, divergencia y radiación adaptativa de muchas especies biológicas y culturas indígenas. La importancia de este complejo hábitat cordillerano es aún evidente en el nombre, Flora Madroterciaria, cuyos descendientes ahora dominan las ecoregiones circundantes. Pero lo que ha sido mas único acerca de esta ecoregión de montaña y barranca en los últimos tres a cinco milenios es el juego interactivo entre la diversidad biológica y cultural que ha conducido no solamente a altas riquezas de especies en cultivos nativos y prácticas en el manejo de tierras, sino a el refugio cultural para especies semi-manejadas y silvestres. Quiérase o no, el valor actual de conservación de la Sierra Madre no se debe únicamente sus especies silvestres y sus lugares naturales, sino el conocimiento ecológico tradicional de sus habitantes y de los paisajes que ellos habitan y que son culturalmente manejados. Existe una gran probabilidad de crear asociaciones mas amplias para la conservación del suelo, a través de endosar el paradigma de salvaguardar la diversidad biocultural—proclamada por Terralingua, Mexico North, Comunidad y Biodiversidad, Native Seeds/SEARCH, CONABIO, y el Center for Sustainable Environments—en lugar de tratar a la Sierra Madre como uno de los últimos grandes lugares naturales e ignorando las conexiones culturales.

Biogeography

Sexual Differentiation in the Distribution Potential of Northern Jaguars (*Panthera onca*)

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Abstract—*We estimated the potential geographic distribution of jaguars in the southwestern United States and northwestern Mexico by modeling the jaguar ecological niche from occurrence records. We modeled separately the distributions of males and females, assuming records of females probably represented established home ranges while male records likely included dispersal movements. The predicted distribution for males was larger than that for females. Eastern Sonora appeared capable of supporting male and female jaguars with potential range expansion into southeastern Arizona. New Mexico and Chihuahua contained environmental characteristics primarily limited to the male niche and thus may be areas into which males occasionally disperse.*

Introduction

One source of the rich biodiversity found in North America's Madrean Archipelago is the meeting of temperate and sub-tropical zones (Felger and Wilson 1994), resulting in the unique overlap of some temperate and tropical species at the edges of their distributions. Among these species are large carnivores that may further contribute to the region's biodiversity through top-down effects and other ecological roles (Berger 1999; Estes et al. 1998; Terborgh et al. 1999). As is the case for large carnivores worldwide (Gittleman et al. 2001), however, predators have declined or disappeared from the Madrean Archipelago largely due to human pressures (Brown 1985; Brown and López González 2001; Phillips and Smith 1996).

The only Neotropical large carnivore with a distribution extending north into the Madrean Archipelago is the jaguar. Jaguars are distributed across parts of Mexico, Central America, and South America (Sanderson et al. 2002), but the rugged and extremely arid conditions at the northern limit of this distribution contrast sharply to lush tropical forests to the south. Currently the northernmost breeding population of jaguars is situated in Sonora, Mexico, about 220 km south of the junction of Arizona and New Mexico with the United States-Mexico border (López González and Brown 2002); how far north this population may have formerly extended is unknown. There are documented records of jaguars killed or photographed in Arizona and New Mexico during the 1900s, and these numbers declined from 51 individuals between 1900-1940 to 11 between 1946-1986 (Brown and López González 2001). No verified jaguars were documented in the United States from 1987 until 1996, and four documented observations during 1996-2003 (J. Childs, personal communication; Childs 1998; Glenn 1996) were presumably individuals that originated in Sonora.

Although it may never be possible to resolve debate about the existence of a breeding jaguar population in the United State, we sought to identify areas in the southwestern United States and northwestern Mexico that jaguars could occupy and that may be areas that jaguars formerly occupied. To estimate the potential distribution of "northern" jaguars (jaguars in the southwestern United States and northwestern Mexico) and identify possible dispersal routes, we employed Geographic Information Systems (GIS) technology and new spatial tools for modeling a species' fundamental ecological niche (Grinnell 1917) from records of occurrence (Stockwell and Peters 1999). Researchers have recently demonstrated powerful conservation biology applications for such predictive models of species' ecological niches (Peterson et al. 2002; Peterson and Robins 2002; Raxworthy et al. 2003), and such tools appear to be particularly useful when spatial and ecological data are limited, as is often the case with large elusive carnivores.

Although little is known about jaguars, knowledge and syntheses about other large carnivore species provide a strong theoretical background for making predictions about jaguars. Dispersal in carnivores is male-biased (Fuller et al. 1992; Rogers 1987; Smale et al. 1997), and male carnivores generally have much larger home ranges than females (Sandell 1989). Among solitary felids, males tend to occupy exclusive territories that may overlap with the home ranges of multiple females but generally do not overlap with other males (Sandell 1989; Sunquist and Sunquist 1989). Male felids can move long-distances in the process of dispersal (Logan et al. 1986; López González 1999), but when female dispersal does occur, distances are much shorter (Logan and Sweanor 2001). Finally, jaguars are sexually dimorphic, and such species tend to have different habitat and food requirements (Aunapuu and

Oksanen 2003). We expected that these sex differences would be important at the landscape scale and therefore considered them in our modeling exercise. We assumed that records of occurrence for jaguar males would include dispersing or non-territorial males in search of areas without male competitors, while records for females were more likely to be from animals with established home ranges in areas with adequate food and shelter resources for reproduction. We therefore predicted that males would show a broader ecological niche than females, and females would have a more restricted niche, as their distribution should be more closely tied to the distribution of resources (Emlen and Oring 1977; Sunquist and Sunquist 1989).

Materials and Methods

We delimited our study area as that encompassing a portion of the southwestern United States, namely the States of Arizona, New Mexico, and the panhandle of Texas, and the northwest Mexican States of Sonora and Chihuahua. The Madrean Archipelago is contained within this arid region, which extended from 25º26' and 36º56' N latitude, and 103º04' and 113º58' W longitude.

We assembled a database of jaguar occurrence records, including museum records, photographic records, and verified kills for the study area. We requested holdings information from North American institutions, including Arizona State University, California Academy of Science, CONABIO, Michigan State University, Museum of Comparative Zoology, Harvard University, Natural History Museum of Los Angeles County, University of Arizona, Southwestern Biology Museum-University of New Mexico, Texas Tech University, University of Kansas, and University of Texas. A complementary bibliographic search included records published in Hall (1981), Leopold (1977), and Brown and López González (2000; 2001). We obtained jaguar records for 2001-2003 in Sonora and Chihuahua through interviews with residents. All occurrence records were verified, ground-truthed, and the geographic location recorded using a Garmin 12XL GPS unit. We included only records with sufficient locality information to plot occurrence points within 25 km^2 accuracy and that included the sex of the individual.

We estimated the distribution of northern jaguars based on the Genetic Algorithm for Rule Set Production (GARP, Sachetti-Pereira 2002; Stockwell and Noble 1999; Stockwell and Peters 1999). The GARP algorithm models the fundamental ecological niche of species, utilizing environmental conditions (e.g., temperature, frost, soil) to predict the distribution of a species that would support a viable population (Anderson et al. 2002a). This algorithm associates points of known occurrence to digital environmental layers by searching for non-random association between the known points against the full extension of the study area for all the environmental characteristics. Through an iterative process of rule selection, rules with increasing predictive accuracy evolve until the algorithm has run 1,000 iterations or reached convergence. The results of these iterations are represented as maps of the predicted geographic distribution of the species in the experiment (Rice et al. 2003; Stockwell and Peters 1999).

We used GARP to model 3 jaguar distributions. One model included records for both males and females, another included only males, and the third included only females. There were 20 environmental layers representing abiotic characteristics for the climate and landscape, including temperature, wetness, vapor pressure, frost days, snow accumulation, radiation, soil type and other geologic features, elevation, aspect, slope, compound topographic index, water flow, and runoff. We derived these layers from raster and vector data from IPCC (http://www.ipcc.ch), USGS Hydro 1k (http://edcdaac.usgs.gov/gtopo3/hydro), and ESRI ArcAtlas (ESRI 1996). Layers were projected into geographic coordinates and resampled to 25 km^2 pixel size to match the resolution of the occurrence data.

The GARP program tested occurrence points for spatial independence and excluded redundant points. For each modeling exercise, we opted for 100 runs with a maximum of 1,000 iterations. We selected a convergence limit of 0.01 and restricted the analysis to an omission of 10% and a tolerance commission of 50%, and we selected the option "best subsets" (Anderson et al. 2003; Anderson et al. 2002b). We selected the 4 best models from each category (males, females, and males and females combined), choosing those with the closest precision value to one, the highest number of records present in the predicted area, and low omission errors for inclusion in analyses (Anderson et al. 2002b). We added these 4 models together as raster overlays in ArcView 3.3 (ESRI, Inc.) to generate a graduated distributional map for each category. We based area measurements and other analyses of the distributional outputs on the overlap among these models, which were essentially binary maps with each pixel or grid cell coded for either the predicted presence or absence of jaguars, with a map for males, females, and both males and females combined. For measurements of area (in km^2), we reprojected GIS data into meters in the Lambert Azimuthal Equal Area projection.

We made a composite grid by combining the binary maps of the predicted male and female distributions with the 20 environmental data grids that were used in building the GARP model, such that each grid cell (or pixel) could have one of 22 different attribute values (20 environmental values plus male presence/absence and female presence/absence). We exported the attribute data for the 22 data layers to a data spreadsheet to conduct ecological niche "visualization" (Rice et al. 2003). We z-standardized all of the environmental variables based on the mean of each, and examined differences between the data for cells that were included in the male and female distributions and cells that were not. We used multivariate discriminant analysis to explore niche specificity and examine if differences in the environmental data allowed grid cells to be classified according to whether or not they were from the predicted distributions.

Finally, we focused on females and compared the predicted female distribution to a land cover map from the USGS North America Landcover Database (http://edcdaac.usgs.gov/glcc) resampled to 25 m^2. Using the grid cell values for land cover and the female distribution, we performed a chi-square analysis to compare land cover types in the female distribution to the land cover types for the entire study area.

Results

We obtained 142 records of jaguar occurrence, 100 male and 42 female records (for a partial list of records with descriptions, see Brown and López González 2001). Records for males came from all 4 States: Arizona (n = 47), Chihuahua (n = 8), New Mexico (n = 6), and Sonora (n = 39), while records of females came only from Arizona (n = 6) and Sonora (n = 36) (figure 1a). We obtained no verifiable records with sufficient locality information from the Texas panhandle, although there are records of jaguars in other parts of Texas (Brown and López González 2001).

The total area of the predicted distribution for jaguars was 367,000 km^2, with an area of 391,000 km^2 predicted based on males only and 145,000 km^2 based only on females. Thus, as expected, male jaguars had a wider distribution than females (figure 1). That the model for both males and females combined yielded a more limited distribution than for males alone suggests that this difference was not simply a function of the sizes of the datasets. The amount of area where the male and female geographic distributions overlapped was 132,000 km^2. This amount was 91% of the predicted female distribution but was only 34% of the range predicted for males. Thus, very little area was uniquely predicted for females compared to males. The female distribution predicted with highest confidence included a 100,000 km^2 contiguous area contained mostly in Sonora's eastern half and some disjointed patches mostly in Arizona. Interestingly, although we obtained no records of females from New Mexico or Chihuahua, scattered areas predicted as parts of the female distribution in these States overlapped with the predicted male distribution (figure 1).

To assess whether values of grid cells from particular groups were readily identifiable, we conducted quadratic discriminant analysis (DA). We divided grid cells into 4 classification groups: (a) the predicted distribution (or "niche") of females, (b) areas not included in the female distribution,

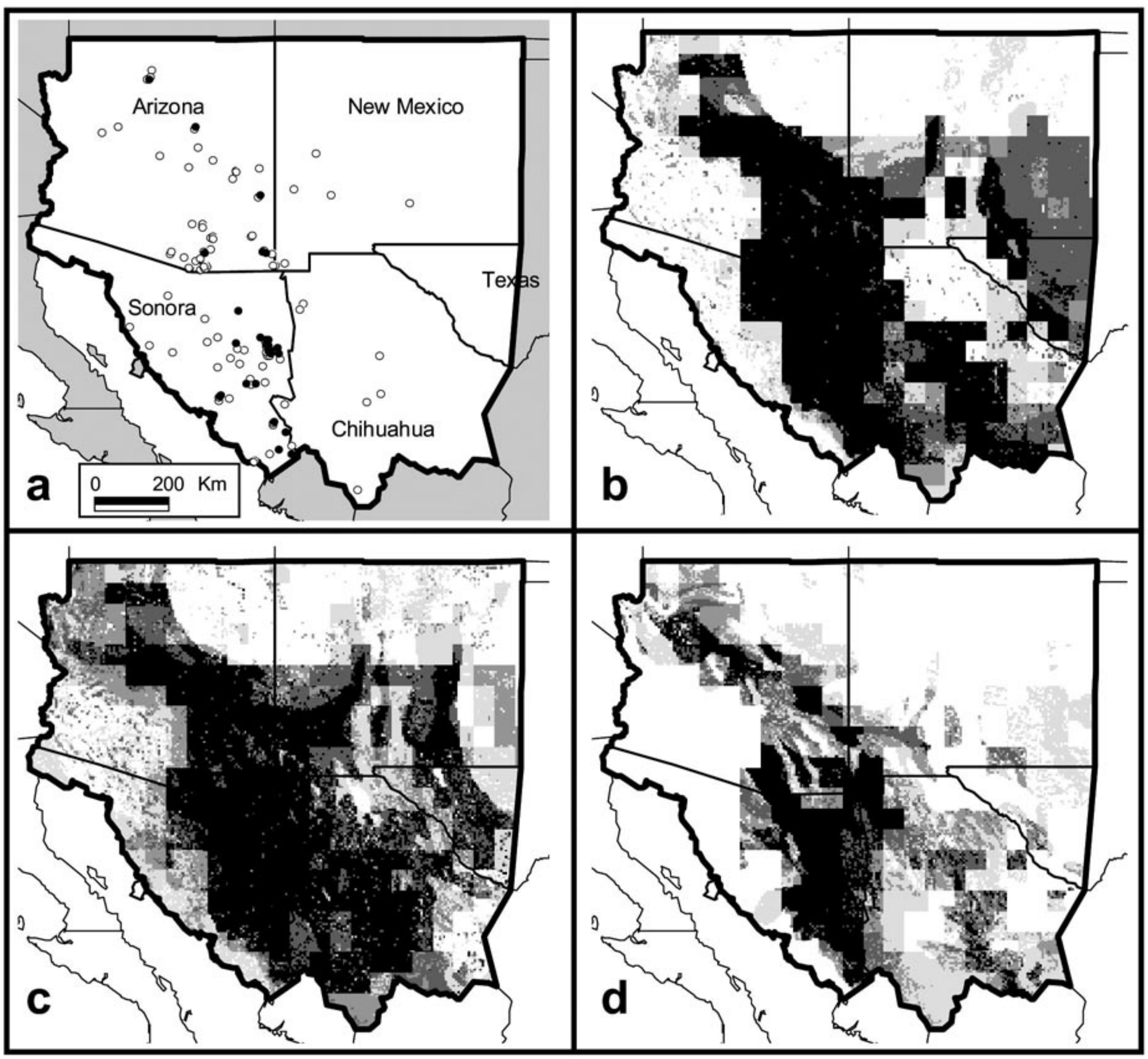

Figure 1—(a) Records of occurrence of male jaguars (open circles) and female jaguars (solid circles) in the study area which included all of Arizona, New Mexico, Sonora, Chihuahua, and the panhandle of Texas, shown in white with a bold outline. In (b), (c), and (d), the predicted distributions are shown in graduated shades representing confidence with black indicating where all 4 best subset models overlapped for distributions based on (b) all occurrence points, (c) male occurrence points only, and (d) female occurrence points only.

(c) the predicted male distribution, and (d) areas not included in the male distribution. DA to classify data for females (figure 1d) into groups a and b correctly assigned 95% of 5,227 cells from the female distribution to group a and correctly assigned 83% of the remaining 36,351 cells to group b. The overall proportion correct was 84%. Similarly, DA on data for males (figure 1c) correctly assigned 93% of 14,798 cells to group c, 78% of 26,780 cells to group d, and had an overall proportion correct of 83%. Thus, DA distinguished cells that were not predicted as part of the distributions from those that were, and it correctly assigned cells that were included in the distributions with a very high probability. In a DA to compare cells from the female distribution (group a) with cells from the male distribution (group c), the overall proportion correctly classified was lower at 68%. For group a, DA correctly classified 83% of cells while only 63% from group c were correctly classified, suggesting that the female ecological niche was narrower than the niche predicted for males.

We could not identify the variables that most contributed to group classification from the discriminant analysis. However, histograms and scatterplots revealed some of the differences for specific environmental variables, including precipitation, elevation, slope, and temperature that were normally distributed. Mean annual precipitation (± SD) averaged across all pixels for the study area was 291 ± 116 mm. For the male distribution, mean precipitation was 347 ± 116 mm; it was slightly higher for the female distribution at 379 ± 115 mm. Mean elevation of the predicted male distribution was 1,481 ± 510 m, similar to the mean of 1,414 ± 619 m for the study area as a whole. For females, mean elevation was lower at 1,216 ± 478 m, but the slopes of both the male (31 ± 31 degrees) and female distribution (31 ± 29 degrees) tended to be steeper than for the study area in general (20 ± 26 degrees). Other general differences were that the predicted jaguar distributions were on average warmer, sunnier, and had older soils than the study area as a whole. Jaguars were not predicted to occur on Sonora's coast, even though there was one male record from there. Jaguars were also not predicted in the very high elevation and cold areas of northern New Mexico and northeastern Arizona.

The primary land cover types in the study area landscape were shrubland (60%), grassland (22%), and forest (17% for all types combined) (figure 2). The remaining land cover types were 1% or less of the landscape. We found significant differences between land cover within the female distribution and the available landscape ($X^2 = 217.62$, df = 8, p = 0.05; figure 2). The predicted distribution of female jaguars was mainly across areas of shrubland, deciduous broadleaf forest, and grassland (figure 2), but deciduous broadleaf forest and mixed forest composed more of the female distribution than expected by chance when compared to the available land cover for the study area. Shrubland was a smaller proportion of the female distribution than expected, and grassland and needleleaf forest were present in proportion to their availability.

Discussion

We expected that differences between the sexes in resource use and competition would be apparent in the ecological niche distributions of jaguars and that female jaguars would have a smaller distribution. We also assumed that for a large carnivore in which males range more widely than females, female occurrence records would be a better indicator of the potential distribution of a viable population than records of males. Our GARP modeling showed that a predicted distribution based on males alone resulted in a broader geographic range and ecological niche than for females. Using the occurrence records for both males and females yielded a model that was intermediate between the males-only and females-only models and that was a blend of the more environmentally restricted females and more generalist males. We derived these distributions from records of occurrence that were mostly from hunted specimens. We do not know if a male and female jaguar in a given area

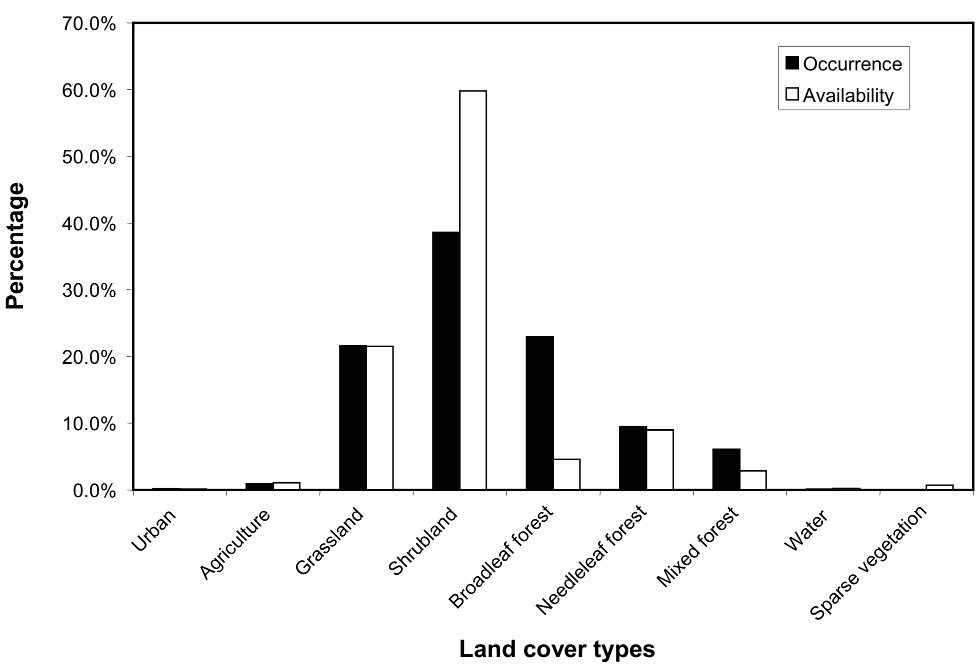

Figure 2—Comparison of female jaguar occurrence (solid bars) versus available land cover types within the study area (open bars). The broadleaf forest category was almost entirely deciduous, but we also grouped into this category the small percentage of evergreen broadleaf (<0.05%) in the landscape. Ranchlands were not included in the category of agriculture.

would have the same detection and capture probability by a hunter. However, the sex ratio of records from Sonora where jaguars are known to occur was almost 1:1, but elsewhere it was heavily skewed towards males.

Our results indicated that the availability of areas meeting females' environmental requirements may be an important factor limiting the distribution of northern jaguars. That jaguars formerly wandered as far north as the Grand Canyon (Brown and López González 2001) suggests that the leading edge of the northern jaguar range has likely retracted to the south, as reaching this location today from the center of the nearest jaguar population would require traveling 750 km. Whether the range of the jaguar is currently decreasing is unclear. However, even in the core population area in Sonora, jaguars are rare and there are conflicts between ranchers and jaguars (López González 2004). Additionally there are almost no protected areas in this area (Arriaga et al. 2000).

Although GARP has been used for a variety of taxa (Anderson et al. 2002a; Peterson et al. 2002; Peterson and Robins 2002; Raxworthy et al. 2003; Rice et al. 2003), this may be the first application to a large carnivore and the incorporation of sex differences using this tool. There are important limits to the interpretation of our results, but we hope this attempt will be just one of many by a wider community of scientists to better understand jaguar requirements and assist with prioritizing conservation efforts. The center of the existing jaguar population lies in the heart of the area that the GARP model predicted based on females, but potentially suitable areas that are currently unoccupied were also predicted within the female distribution. A future challenge for conservation biologists could be determining whether the existing jaguar population could naturally expand into these unoccupied areas and understanding the social, political, and biological requirements for this process to occur. Range expansion could help prevent genetic isolation and extinction of the northern jaguars and also increase chances for long-term survival of this species in the face of global anthropogenic changes. Furthermore, as top predators, jaguars can serve as indicators of the success of land management policies and practices that help maintain biological resources in the United States and Mexico. By maintaining connectivity across subtropical and temperate zones, conservation of jaguars would help conserve a number of other species and preserve the biological integrity of the unique Madrean region.

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Predicting Habitat Suitability for Wildlife in Southeastern Arizona Using Geographic Information Systems: Scaled Quail, a Case Study

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Abstract—*Studies have used Geographic Information Systems (GIS) to evaluate habitat suitability for wildlife on a landscape scale, yet few have established the accuracy of these models. Based on documented habitat selection patterns of scaled quail (*Callipepla squamata pallida*), we produced GIS covers for several habitat parameters to create a map of potential habitat in southeastern Arizona. We found scaled quail coveys on 36% of surveys conducted inside of potential scaled quail habitat, and 80% of the scaled quail coveys found occurred within the potential habitat map. We developed a logistic regression model that predicted 70% of used and unused sites. Potential causes for the low accuracy of GIS models are discussed.*

Introduction

Several authors have used Geographic Information Systems (GIS) to predict habitat suitability for wildlife on a landscape scale (Boyce and Waller 2003). Few such studies have validated their models by comparing classifications to actual habitat selection or abundance estimates. Mapping wildlife habitat suitability (availability and relative quality) is important because it provides information for long-term planning and can illustrate impacts of past and future land management activities (Roseberry and Sudkamp 1998).

Scaled quail (*Callipepla squamata pallida*) are a good species to test the efficacy of modeling habitat suitability using GIS in Arizona because they: are habitat specialists that are relatively widely distributed (Brown 1989), are relatively easy to survey (Brown et al. 1978), and are sensitive to habitat parameters available on GIS covers. In Arizona, scaled quail are mainly restricted to relatively flat, open grassland and desert areas with a summer rainfall regime (Brown 1970).

Objectives of our study were to: (1) identify landscape-scale availability of scaled quail habitat in Arizona, (2) develop a model to predict use, and estimate relative quality of scaled quail habitat across southeastern Arizona, and (3) test the efficacy of our GIS modeling efforts. Although habitat use patterns of scaled quail are well understood in other States, level of knowledge in Arizona is less than ideal (Rosenstock et al. 1996). General habitat preferences of a given species are likely consistent throughout their range, but site-specific habitat selection can be greatly affected by the quality of available habitat (Arthur et al. 1996). If adequate accuracy can be verified, GIS modeling may provide a valuable shortcut to more traditional intensive field surveys and field mapping.

Study Area

We conducted field surveys across the major portion of scaled quail distribution in southeastern Arizona. The vegetation associations within this area consisted primarily of semi- desert grasslands and Chihuahuan and Sonoran desert scrub. Brown (1994) provides a thorough description of the dominant grasses, shrubs, cacti, and trees within these vegetative associations. Topography consisted of extensive valleys and flats continuing upward to rolling hills broken by small canyons and mesas; elevation ranged between 750-1,770 m. Annual precipitation was bimodal with peaks in winter and late summer, and averaged 30.6 cm at Wilcox, Arizona (central portion of the study area) between 1898-2003. Seasonal maximum temperatures averaged 34.0 °C in summer and 15.7 °C in winter between 1898-2003 (N.O.A.A. 2003). Most (78%) of our field surveys were on public land managed by the Arizona State Land Department, the remainder falling under the jurisdiction of the U.S. Bureau of Land Management (19%), and the U.S. Forest Service (3%).

Methods

We created maps to predict scaled quail habitat use in southeastern Arizona based on documented habitat preferences, as well as regional habitat selection patterns. Based on habitat selection patterns documented in the scientific literature, we established the range of conditions preferred by scaled quail for the following habitat variables: vegetation type, percent slope, elevation, land-use practices, and average precipitation between April and August. We then produced GIS covers for each variable and used overlay analysis (Arc/Info version 8.0.1) to develop a map of potential scaled quail habitat in Arizona.

To test the accuracy of this first level map, we conducted scaled quail surveys at randomly generated 2.6-km cells (n = 101) both within (n = 53) and outside (≤20 km from mapped potential, n = 48) the periphery of potential scaled quail habitat. To ensure that surveys did not cross between habitat types (within or outside potential habitat), we selected only those cells that were in the center of a 9-cell neighborhood of similar habitat. We conducted pointing dog surveys similar to

Bristow and Ockenfels (2000) and used visual observation, calls, or presence of indirect sign (Stormer 1984) to establish presence of scaled quail in the area. We compared presence of scaled quail from surveys to individual cell classification to establish accuracy of the map, and compared it to previous data (Brown 1970) on scaled quail distribution in Arizona to determine relative efficacy of the technique.

To create a GIS cover of relative quality of scaled quail habitat, we overlaid all scaled quail use sites and random unused sites on the GIS habitat characteristic covers and recorded values for each of the habitat variables. We developed logistic regression models (Hosmer and Lemeshow 1989) to predict habitat use of scaled quail. Our probable models were *a priori*, and we calculated a modified Akaike's Selection Criterion (AIC) to select the most parsimonious model (Burnham and Andreson 1992). We assigned 0.5 as the cutpoint for classification of flush sites and random plots.

Lastly we applied the final landscape scale logistic regression model to the GIS habitat characteristic covers, and used surface analysis to create a map predicting probability of occupation for each 1-km^2 cell within potential scaled quail habitat in Arizona. Each cell received a score of 0.0-1.0 based on the calculated probability of encountering scaled quail there. Based on these scores, each 1-km^2 cell received 1 of 4 habitat quality ratings (Poor = 0.0-0.25, Fair = 0.26-0.50, Good = 0.51-0.75, and Excellent 0.76 -1.0). We used a jackknife resampling procedure (Verbyla and Litvaitis 1989) to evaluate the classification bias of the final model.

Results

We found several authors reporting habitat preferences for scaled quail across their range in the Southwestern United States. To select range of habitat parameters we used references that presented data most appropriate to the available GIS covers. We used information on scaled quail preference for vegetation type, slope, and elevation by Anderson (1974), Medina (1988), and Brown (1989). We used information on land use preference of scaled quail by Saiwana et al. (1998). Brown (1970) provided information on the specific association of precipitation patterns and scaled quail in Arizona (table 1).

The area within potential scaled quail habitat in southeastern Arizona encompassed 13,304 km^2. There was a 67.2% overlap of potential scaled quail habitat with Brown's (1970) estimate of scaled quail distribution (figure 1). We found scaled quail coveys on only 36.5% of surveys conducted inside of potential scaled quail habitat, and failed to find scaled quail on 89.6% of surveys conducted outside of potential scaled quail habitat. Comparatively we found scaled quail coveys on 64.5% of surveys conducted inside Brown's (1970) scaled quail range estimate, and failed to find scaled quail on 91.8% of surveys conducted outside of Brown's (1970) scaled quail range estimate. Of the scaled quail coveys found during random surveys, 80% occurred within the potential scaled quail habitat map, and 84% occurred within Brown's (1970) scaled quail range estimates.

The most parsimonious model (model 1) describing landscape scale habitat selection of scaled quail included all 5 habitat variables, and correctly classified 70.4% of used and unused sites (table 2). When applied to the area within potential scaled quail habitat, this model identified major concentrations of good and excellent quality habitat in the San Simon, San Bernadino, Sulphur Springs, and San Pedro Valleys (figure 2). A jackknifed classification of model 1 correctly classified only 44 of 93 used sites and 66 of 93 unused sites for an overall misclassification rate of 40.9%.

Discussion

We were able to develop a GIS-based map of potential scaled quail habitat in Arizona that correctly classified 80% of scaled quail coveys found during random surveys. Previous range estimates by Brown (1970), based on intensive field surveys and interviews, performed only slightly better. We also developed a habitat selection model that correctly classified 70% of scaled quail use. However, our ability to verify the presence of scaled quail inside potential habitat and the high misclassification rate of the jackknifed habitat selection model would suggest caution in the application of these models.

Numerous factors likely contribute to the apparent inaccuracies of our maps. First, our verification method was less than perfect, simply because we were unable to locate scaled quail during surveys does not mean that the area in question would

Table 1—Variables and Geographic Information Systems coverages used to predict potential scaled quail habitat in southeastern Arizona, 2001.

Variable	GIS coverage source	Range/class included in potential habitat
Slope	U.S.G.S. Digital Elevation Model	Less than 30%
Elevation	U.S.G.S. Digital Elevation Model	Between 1,067 and 1,400 m
Precipitation	N.O.A.A. Arizona climatological data 1987-1997	Average April-August >14.5 cm.
Vegetation type	GAP vegetation type (Graham 1995)	Semidesert grassland, Grassland, Sonoran scrub, Chihuahuan scrub, Mixed oak, Playa, and Agricultural
Land use	Arizona State Lands Department	Shrub and brush rangeland, Herbaceous rangeland, Mixed rangeland, Evergreen forest, and Cropland and pasture

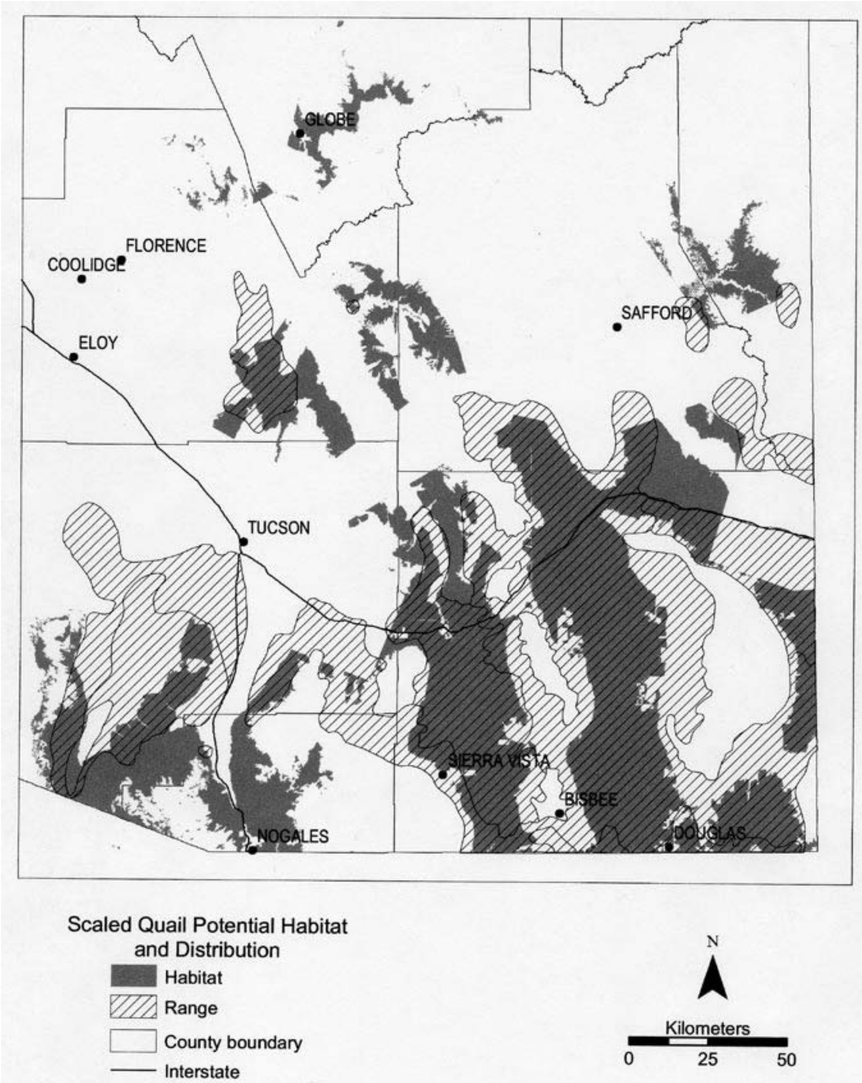

Figure 1—Potential scaled quail habitat and scaled quail range (Brown 1970) in southeastern Arizona.

Table 2—Logistic regression models[a] differentiating scaled quail use sites (n = 93) and random unused sites (n = 93) at a landscape scale, in southeastern Arizona, 2001-2003.

Model	-2 log likelihood	% used sites correctly classified	% unused sites correctly classified	AIC_c	Delta AIC_c
1[b]	198.097	63.4	77.4	226.213	0.000
2	229.347	66.7	69.9	243.816	17.603
3	229.051	65.6	65.6	245.865	19.652
4	233.964	68.8	69.9	246.433	20.220
5	233.940	67.7	69.9	248.569	22.356
6	238.349	59.1	64.5	250.818	24.605

1 Vegetation[c], slope[d], elevation[e], land use[f], and precipitation[g]
2 Vegetation, elevation, and precipitation.
3 Vegetation, slope, elevation, and precipitation.
4 Vegetation, slope, and precipitation.
5 Vegetation, and elevation.

[a] P –values for all models were <0.01 and degrees of freedom were equal to number of variables in the model.
[b] Z = 38.259 –21.968 Sonoran scrub –21.613 semidesert grassland –41.632 mixed oak –20.642 Chihuahuan scrub + 0.0 cropland and pasture –0.016 slope +.002 elevation –21.230 shrub and brush rangeland –19.948 mixed rangeland –42.056 evergreen forest + 0.105 herbaceous rangeland + 0.0 agriculture + 0.218 precipitation.
[c] Vegetation class.
[d] Average percent slope.
[e] Average elevation (m).
[f] Land use class.
[g] Average precipitation (cm) recorded between April and August.

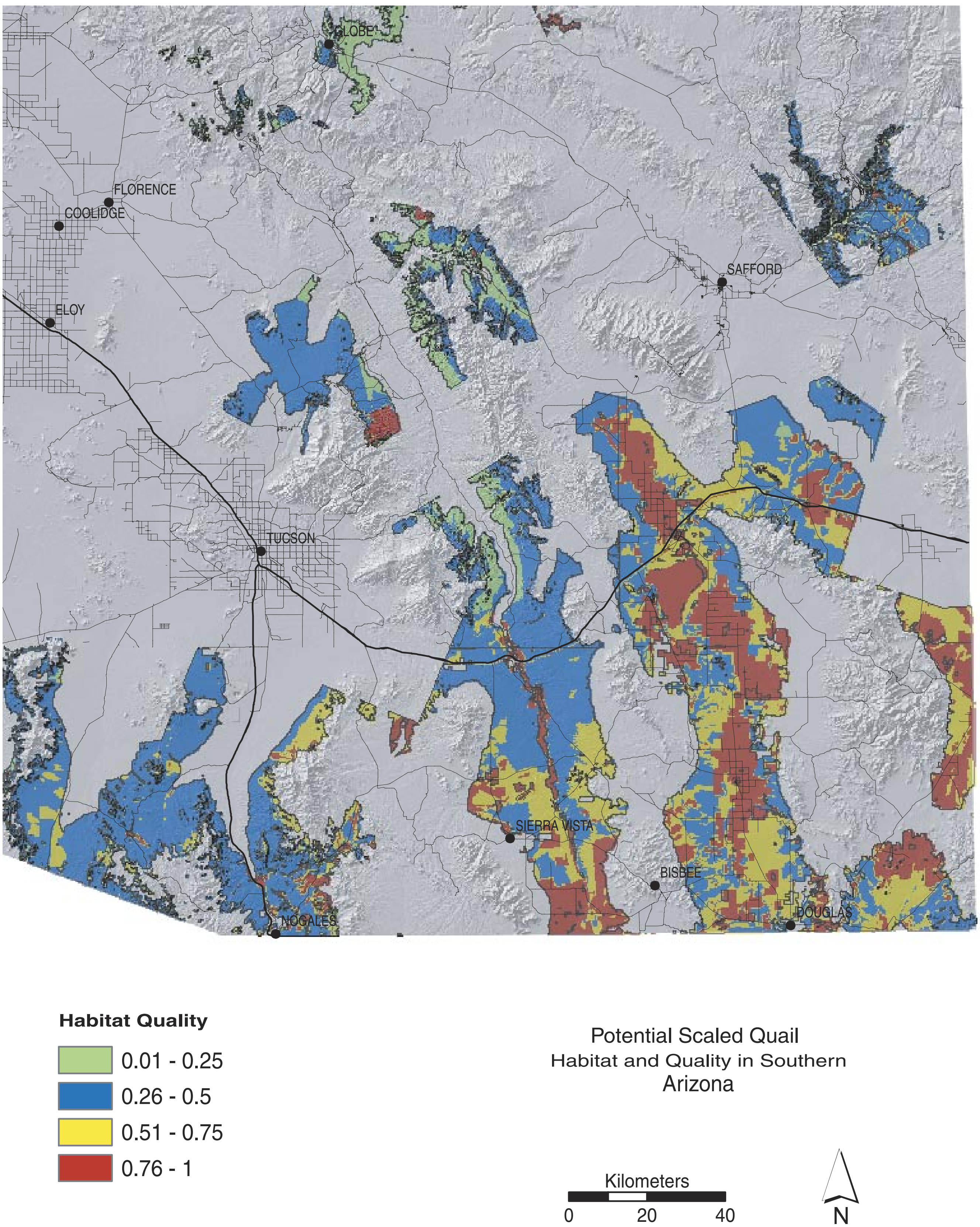

Figure 2—Relative quality of scaled quail habitat within potential scaled quail habitat in southeastern Arizona.

not support scaled quail. Studies using marked quail have found that pointing dog surveys can miss as much as 50% of the coveys in an area (Sisson et al. 2000). Moreover, quail populations in the Southwest are volatile, expanding and contracting in number and distribution each year with changing annual rainfall (Rollins 2000). Our survey efforts were conducted during a drought year when rainfall amounts and presumably scaled quail populations were lower than average.

Another likely explanation for model inaccuracies is that scaled quail are selecting habitat at a finer scale than is available for many of the landscape habitat covers. Habitat factors such as grass and forb coverage and diversity (Anderson 1974; Brown 1978), range condition (Saiwana et al.1998), shrub density (Rollins 2000), and exotic grass invasion (Medina 1988) can affect scaled quail habitat use, yet cannot be differentiated with currently available landscape scale GIS covers.

While many studies of wildlife habitat selection focus on a microhabitat scale, information on landscape scale relationships can provide useful insights into range-wide trends that may relate to population trends. However, to be useful the landscape scale data must be current and specific enough to explain the dynamic nature of wildlife habitat selection. While our models could be useful for identifying areas where habitat improvements may benefit scaled quail, more specific information on scaled quail habitat selection in Arizona is necessary to design effective mitigations and treatments. Without verification, we would advise similar caution in the application and use of other GIS-based landscape scale habitat suitability models.

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The Tectonic Evolution of the Madrean Archipelago and Its Impact on the Geoecology of the Sky Islands

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Abstract—*While the unique geographic location of the Sky Islands is well recognized as a primary factor for the elevated biodiversity of the region, its unique tectonic history is often overlooked. The mixing of tectonic environments is an important supplement to the mixing of flora and faunal regimes in contributing to the biodiversity of the Madrean Archipelago. The Sky Islands region is located near the actively deforming plate margin of the Western United States that has seen active and diverse tectonics spanning more than 300 million years, many aspects of which are preserved in the present-day geology. This tectonic history has played a fundamental role in the development and nature of the topography, bedrock geology, and soil distribution through the region that in turn are important factors for understanding the biodiversity. Consideration of the geologic and tectonic history of the Sky Islands also provides important insights into the "deep time" factors contributing to present-day biodiversity that fall outside the normal realm of human perception.*

Introduction

The "Sky Island" region of the Madrean Archipelago (located between the northern Sierra Madre Occidental in Mexico and the Colorado Plateau/Rocky Mountains in the Southwestern United States) is an area of exceptional biodiversity and has become an important study area for geoecology, biology, and conservation management. No single factor is responsible for the biological richness of the Madrean Archipelago. Rather, numerous biologic, geographic, and geologic factors have fortuitously combined to create the unique setting of the Sky Islands, including: (1) Geographic setting at the convergence of four major ecoregions: two major floristic zones (Neotropic and Holarctic) and two major faunal realms (the Neotropic and Nearctic); (2) location at the convergence of three major climatic zones (tropical, subtropical, and temperate); (3) predominantly NW - SE trending topography, which encourages northward movement of neotropical species (the product of regional tectonic forces); (4) Complex topography combined with large elevation gradients (resulting from the interaction between geology and weathering factors); and (5) A bimodal annual rainfall distribution (due to geographic and climatic factors). Many of these are the result of the continental-scale deformation that has occurred over the past several hundred million years in response to plate tectonic activity. Thus, "deep time" processes that operate over timescales of tens to hundreds of million years need to be appreciated when considering the various sources responsible for the elevated biodiversity of the Sky Islands. The discussion of the relationship between topography and the biodiversity of the Sky Island region is continued in the companion paper (Coblentz and Riitter, this proceedings).

Tectonic Evolution of the Southwest

The Sky Islands form a sub-region of the Southern Basin and Range province which bridge the low elevation saddle in the North American Cordillera between the Sierra Madre Occidental and the Colorado Plateau – Southern Rocky Mountains (figure 1). This part of the Cordillera has been created by the interactions between the Pacific, North American, Farallon (now entirely subducted under North America) and Juan de Fuca plates and is rich in geology features, including major plateaus (The Colorado Plateau), large elevated areas that are actively extending (The Basin and Range), a major continental rift system (The Rio Grande Rift), an active hot spot (Yellowstone), and the remnants of a Paleozoic mountain belt of Himalayan proportions.

The tectonic history of the Sky Island region can be divided into three general stages: (1) Deposition of thick Paleozoic limestone sequences about 300 million years ago during a period when the area was sea floor, (2) A predominately compressional phase associated with Mesozoic to early Cenozoic (200 to 60 million years ago) as the North American Plate converged with and overrode the Farallon Plate and the East Pacific Rise, and (3) A transition from compressional to extensional tectonics in the mid-Cenozoic (about 30 million years ago) in response to the ending of the Farallon Plate subduction and the transition to transcurrent motion between the Pacific and North American plates along the Western North American margin.

During most of the Cretaceous and the early Tertiary, subduction of the Farallon plate beneath North America produced widespread compressional tectonics throughout most of the region. As this subduction evolved, a zone of deformation propagated eastward producing "thin-skinned" deformation (often referred to as the Sevier Orogeny) where the lithosphere was sufficiently weak. The characteristic style of this deformation phase was folding and thrusting of Paleozoic and Mesozoic sedimentary rocks from west to east along steep westward dipping thrust faults. The Sevier thrust faulting formed a large mountain system of north-south trending topography that has subsequently collapsed due to the weakness of the lithosphere in this region. Some Sevier topographic features are preserved in the faulted Basin and Range

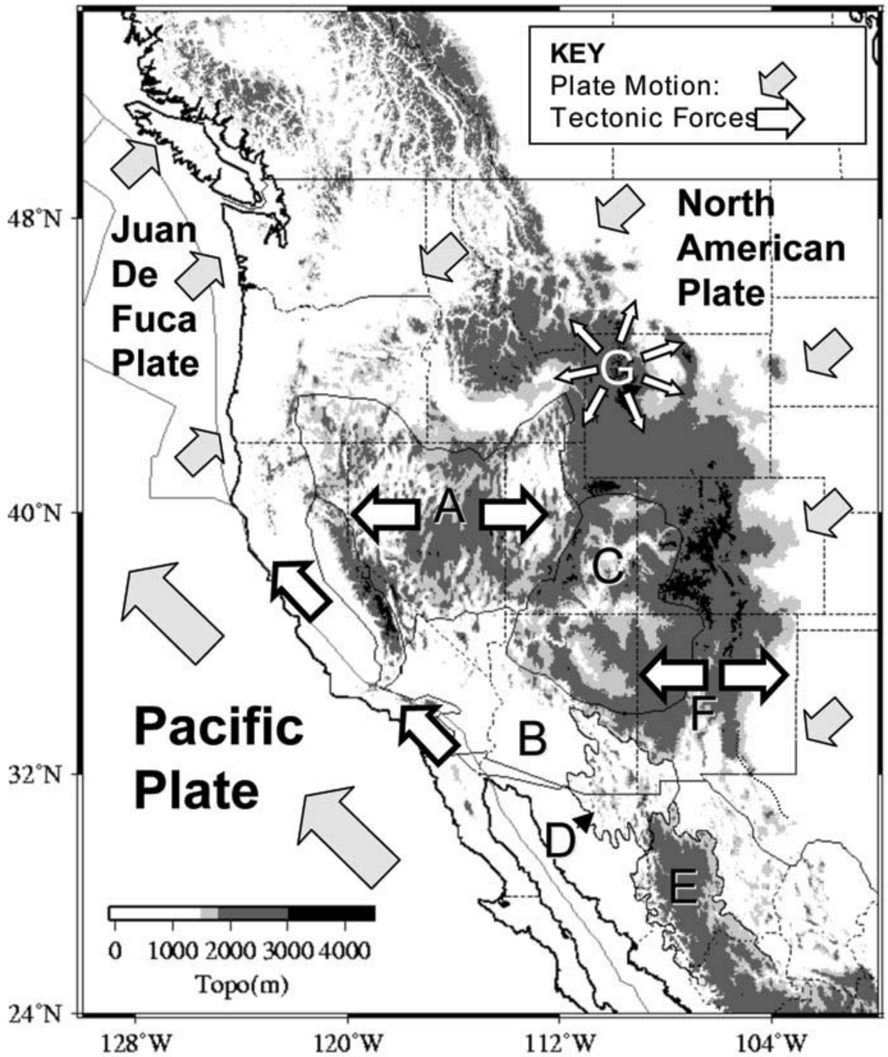

Figure 1—Tectonic setting of the Western United States Cordillera. Gray arrows indicate absolute plate motion of the North American, Pacific, and Juan de Fuca plates; white arrows schematically illustrate approximate present-day tectonic motion. Note that the tectonic setting of the Sky Island regions needs to be viewed in the context of the surrounding four provinces: The Basin and Range (A and B), the Colorado Plateau (C), the Madrean Archipelago (D), the Sierra Madre (E), and the Rio Grande Rift (F), (G) is an active hotspot (Yellowstone).

sequences as well as along the western margin of the Uinta and Wind River Mountains. As the deformation progressed further east during the Late Cretaceous and Early Cenozoic (c. 60 Ma) into stronger parts of the North American plate, deeper parts of the crust become involved (often referred to as the Laramide Orogeny). Mountain ranges formed during this deformational phase include the Rocky Mountains, the San Juans, the Gore Range and the Sawatch Range in Colorado; the Sangre de Cristos and Sandias in New Mexico; the Uintas and Wasatch Range in Utah; the Black Hills in South Dakota; the Bitterroot Range in Montana and Idaho; the Bighorns and Wind River Range in Wyoming; and the Franklin Mountains of West Texas. This topography is characterized by uplifted blocks of crust that include Phanerozoic sedimentary rocks as well as the underlying Precambrian igneous and metamorphic rocks that make up the core or basement of the continental crust. In the Huachucas, Precambrian granite, Paleozoic limestones, and Cretaceous sedimentary and volcanic rocks are together along faults that date back to the Laramide Orogeny. These Laramide structures are presented in dissected and isolated form due to subsequent Basin and Range faulting and are evident in many of the Sky Islands of southeastern Arizona.

Starting about 30 Ma the elevated topography of the cordillera began to collapse in response to a transition from compression-dominated subduction of the Farallon plate off the western coast of North America to transcurrent motion between the Pacific and North American plates. Extensional tectonics produced by this gravitational collapse is responsible for the dominant present-day topographic fabric of *en echelon* north-south oriented mountain ranges separated by valleys filled with erosional detritus. Extensional processes during this period also formed the several large mountain ranges including the Tetons in Wyoming and the Sierra Nevada in California.

Present-day Physiography of the Southwest

The Southwest can be roughly divided into five provinces based on tectonic history and topography (figure 2). A brief description of each of the provinces follows.

The Colorado Plateau is a major tectonic and physiographic province in the Southwestern United States that has behaved as a relatively stable, coherent block during much of Phanerozoic time. The plateau is roughly circular with an area of about 240,000 km^2 centered on the Four Corners region of the Southwest United States. The southern edge of the province roughly correlates with the Mogollon Rim in Arizona. To the east, the bounding edge of the plateau extends into New Mexico, though Tertiary volcanic rocks of the White Mountains and the Gila Highlands obscures its exact location. A site of marine deposition during Cretaceous time, the Colorado Plateau now stands about 2 km above sea level, implying that nearly 2 km of uplift occurred during Cenozoic time. The greatest amount of uplift has apparently been along the southwestern margin of the Plateau, where elevations are often 0.5 km greater than in the center (Lucchitta 1989). Study of vesicular basalts indicates that the southwest Colorado Plateau stood at least 1 km above sea level during Oligocene time (Sahagian and Proussevitch 2000). The Colorado Plateau has apparently remained a relatively rigid block, resistant to faulting, a view reinforced by paleomagnetic studies that show coherent rotation of the plateau (e.g., Bryan and Gordon 1986; Wells and Hillhouse 1989). Given that the Colorado Plateau is in isostatic equilibrium now (the free air gravity anomaly is nearly zero; Thompson and Zoback 1979), and assuming that it was in the past, then some growing mass deficiency at depth must have compensated for its uplift. Several mechanisms have been proposed to account for the most recent phase of uplift, including thermal expansion, crustal thickening, and delamination of the lithosphere (Bird 1979, 1984; McGetchin et al. 1980; Morgan and Swanberg 1985; Spencer 1996; Thompson and Zoback 1979).

The Rio Grande Rift is one of the major continental rifts in the world and a major structural element of the Southern Rocky Mountain region. The rift was recognized as a major continental rift in the 1970's (e.g., Riecker 1979), and since has been extensively studied from both a geologic and geophysical perspective (e.g., see the extensive review in Baldridge et al. 1995). The physiography of the rift is the product of three principal factors: (1) extensional tectonics (that began between 27 and 32 Ma and lasted 10 to 12 Ma) when regional extension reactivated the southern Rocky Mountains, which are a major north-trending zone of weakness that had developed during Sevier and Laramide orogenies; (2) volcanism (that increased slowly after a hiatus in the middle Miocene, 20 to 13 Ma); and(3) regional uplift of the Southern Rocky Mountains and adjacent areas between about 7 and 4 Ma (Chapin and Cather 1994). The current topography along the rift is characterized by broad flat lying topography along the rift axis, bounded by sharp escarpments (e.g., the Sandia, Manzano, and Sacramento Mountain ranges in New Mexico) that expose Paleozoic sedimentary rock and formed major NS alignment of topography.

The Sierra Madre Occidental is a large volcanic plateau in Western Mexico extending parallel to the Pacific coastline for more that 1,200 km from the United States-Mexico border (31°N) to the Trans-Mexican Volcanic Belt (21°N). The total aerial distribution of the volcanic rock is more than 300,000 square kilometers. The volcanics resulted from the eastward subduction of the Farallon Plate along the western Cordillera of North America prior to the mid-Tertiary. By the mid- to late-Tertiary subduction gradually ceased and a broad zone of normal faulting, more than 3,000 km long, was developed in the Western United States and in Northern Mexico. This extension formed the Basin and Range Province in present-day Nevada, Utah, and Arizona. The topography of the Northern Sierra Madre is characterized by high average elevation (~1900 meters) and large topographic range (~2800 meters). In contrast to the other Southwestern tectonic provinces, the topographic relief of the Sierra Madre is not the product of elevated mountain ranges, but rather incised canyons (e.g., the Barranca de Cobre)—reflected in the largest elevation standard deviation of all the Southwestern tectonic provinces (~340 m). The western edge is quite steep while the eastern topographic gradients from the Sierra Madre into the central Mexican Plateau are relatively small. The elevation distribution is fairly flat about the mean value and shows a skewness to lower elevation values, reflecting a sampling of lower elevations along the coastal plain of Sonora. The regional fabric of the Sierra Madre is aligned in a NW-SE orientation (N11°W +/- 9°) and is thought to facilitate dispersal for tropical flora and fauna moving in response to climatic change.

The Madrean Archipelago spans the region formed by the common borders of Arizona, New Mexico, and the Northern Mexican States of Sonora and Chihuahua. The term "archipelago" metaphorically reflects the insular nature of the roughly 40 isolated mountain ranges (Sky Islands) in this region. The topography of the Archipelago is characterized by isolated mountain ranges elongated in a NNW-SSE direction; the average orientation for the entire province is N10°W +/- 11°. There are many area of locally very large vertical relief (more than 2,000 m across the Santa Catalina and Pinaleno Mountains), with a topographic range of about 2,000 meters, a mean elevation of about 1,300 meters with a standard deviations of about 200 meters. The mean elevation of the Sky Islands is significantly lower than the Colorado Plateau (~1900 m) and the Sierra Madre (~1910 m) leading to its identification as a physiographic "pass" that has facilitated the longitudinal mixing of flora and fauna between the Sonoran and Chihuahuan Deserts.

The Basin and Range province, characterized by its disrupted crust, lies to the west and south of the relatively coherent Colorado Plateau and west of the Sky Island region (note that the Sky Islands are a part of the Southern Basin and Range). Topography in this region is characterized by isolated mountain ranges elongated along a northwest-southeast oriented axis (N15°W +/-16°). While elevations in this province approach 3,400 m (e.g., in the Spring Mountains near Las Vegas), the average elevation of the province is relatively low (333 m) with many parts slightly above or below sea level (e.g., in the Salton Trough of Southern California). The area has been stretched and extended as much as 100% since the early Tertiary. The earliest stages of extension began by latest Oligocene time in the southern parts of California and Arizona in the United States, and in Durango, Chihuahua, and Oaxaca, Mexico. By early Miocene time, strong extension had begun on major normal faults across much of Mexico (e.g., Henry and Aranda-Gomez 1992), and metamorphic core complexes were forming along the Colorado River between California and Arizona (Howard and John 1987) and along the southern edge of the Colorado Plateau in southern Arizona (Rehrig and Reynolds 1980). Pliocene and Quaternary eruptions accompany incipient rifting in the Jalisco block that lies at

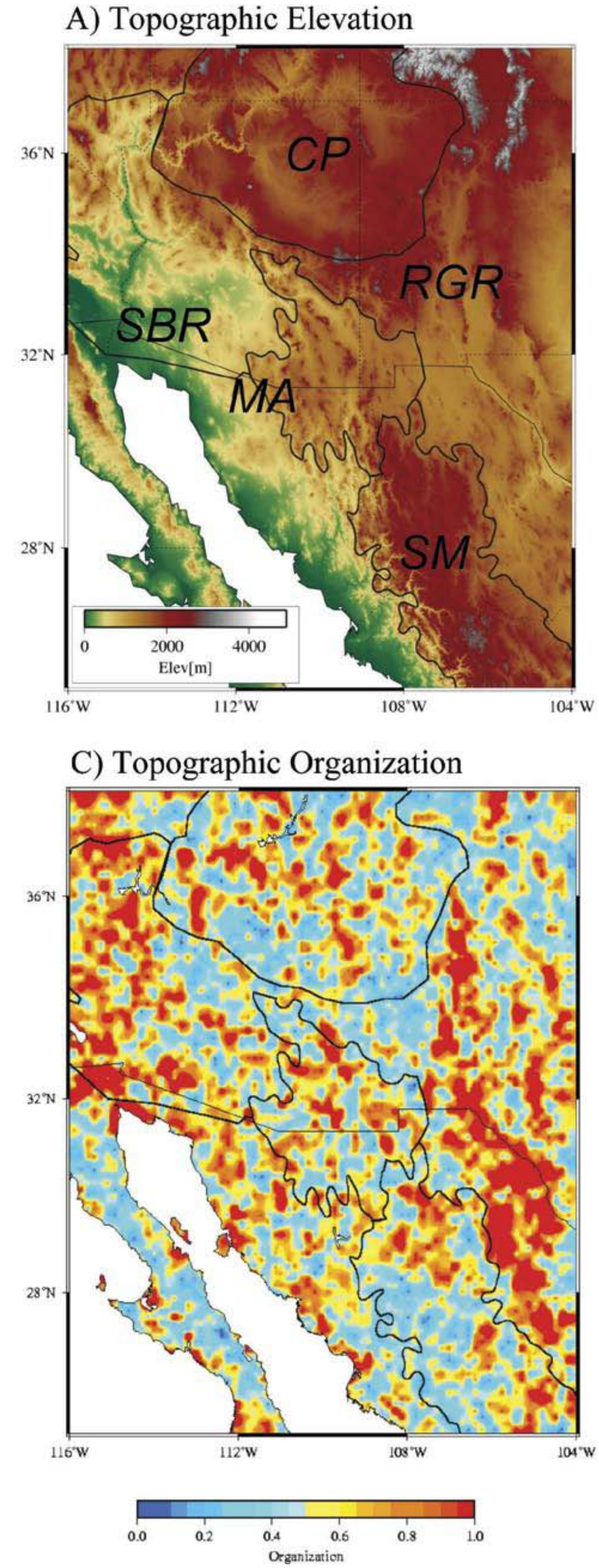

Figure 2—Spatial distribution of various descriptive topographic quantities calculated using the algorithms discussed in the text. (A) Topography of the study. (B) Vectors of the topographic fabric orientation computed for the topography for a 80 km x 80 km analysis window. Vector lengths are scaled by organization with longer vectors indicating greater organization. (C) Topographic organization computed within a 10 km x 10 km window. (D) Topographic roughness computed within a 10 km x 10 km window. Tectonic province abbreviations: CP: Colorado Plateau; RGR: Rio Grande Rift; SM: Sierra Madre Occidental; MA: Madrean Archipelago; and SBR: Southern Basin and Range.

the southern edge of the Sierra Madre Occidental in Mexico (Wallace et al. 1992), possibly indicating that the Basin and Range province is growing to the south.

Topographic Analysis

Topography is a fundamental geophysical parameter that contains valuable information about the geodynamic, tectonic, and climatic history of a region. It is also by far the most readily measurable data and most accurately known information used to describe the Earth. As a consequence, topographic features have historically invited many studies that have sought to extract the information contained in the "character" of the Earth's surface.

The complex tectonic history of the Western United States invites a closer look at the character of the topographic fabric with the aim of evaluating its relative contribution to the remarkable biodiversity of the Sky Island region.

The topography of the Madrean Archipelago (figure 2a) is characterized by insular mountain fabrics that bridge the relatively low elevation gap between the Sierra Madre Occidental and the Colorado Plateau (note the variation in the mean elevation for the elevation distribution shown in figure 3e). Using the topographic analysis method discussed in Coblentz and Riitter (this proceedings), the spatial variation in the topographic orientation, organization, and roughness are shown in figure 2. Histograms for the topographic fabric orientation, organization, roughness, land cover diversity (see discussion) and elevation for the five tectonic provinces are shown in figure 3. The character of the topographic parameters is discussed in the following sections.

The orientation of the topographic fabric (figures 2b, 3a) is primarily controlled by crustal deformation in response to tectonic motion between the North American and Pacific plates, and the resulting tectonic stresses have resulted in boundary-parallel topographic fabric, most evident in the California Coastal Ranges and the Baja California Peninsula. This observation is corroborated by the good correlation of NW-SE regional orientation of the topographic fabric within the five provinces with their proximity to the North American-Pacific plate boundary. In general, the strength of the topographic fabric with the various provinces reflects the degree of active tectonics. In the relatively undeformed Colorado Plateau, the topographic fabric shows considerable scatter about the mean orientation (N1.5^{o}W +/-17^o) and poor topographic organization (0.79 +/- 0.22). In contrast, topography along the Rio Grande Rift is closely distributed about a mean orientation of N3.2^{o}W+/-9^o with a relatively high degree of organization (1.07 +/- 0.35). The orientation of the topographic grain in provinces geographically closer to the plate margin (Sierra Madre, Madrean Archipelago, and Southern Basin and Range) are rotated toward the NW, subparallel to the relative motion between the North American and Pacific plates. There is a high coherence of the topographic grain within the Sierra Madre and Madrean Archipelago provinces that are also characterized by low standard deviations about the mean grain orientation N10^{o}W +/- 11^o and N11^{o}W +/- 9^o, respectively.

Topographic organization (figures 2c, 3b) is a measure of the strength of the fabric, with regions of good orientation coherence having high organization levels. The two tectonic provinces with the strongest tectonic activity (Rio Grande Rift and Southern Basin and Range) have the highest levels of organization (mean values of 1.07 +/- 0.35 and 1.02 +/- 0.32, respectively). The insular nature of the mountain ranges of the Madrean Archipelago province results in an intermediate organization level (0.85 +/- 0.27), while the high level of drainage-related incisement in the Sierra Madre effectively lowers its organization level to that of the Colorado Plateau (0.76 +/- 0.22 and 0.79 +/- 0.22, respectively). The distributions are all skewed toward higher organization, indicating the existence of highly organized topographic regions within each of the provinces. The low level of topographic organization in the Sierra Madre province (0.76 +/- 0.22) is attributable to the high level of drainage-related incisement present in this region; in general, the development of drainage networks has the effect of lowering the organization relative to topography of tectonically active areas. The organization distributions are all skewed toward higher organization, indicating the existence of highly organized topographic regions within each of the provinces.

Topographic roughness (figures 2d, 3c) correlates with relief, standard deviation of elevation, average slope, and standard deviation of slope. A number of tectonic and geomorphic processes can contribute to topographic roughness including high heat flow (tectonically young regions), high erosion, and incision rates. Because no single process is responsible for topographic roughness it is possible to draw only first-order generalizations from figure 2d. The Sierra Madre and the Madrean Archipelago have the highest mean roughness values (0.23 +/- 0.06 and 0.20 +/- 0.04, respectively) reflecting the large amount of topographic relief in these two provinces. In the case of the Sierra Madre province, this is particularly evident in the high roughness region along the southwestern margin of the mountain range. It is interesting to note that the incision-related processes that are responsible for low organization levels in the Sierra Madre province are also responsible for its high level of roughness—in general, canyon cutting by rivers generates rough but poorly organized topography. The Colorado Plateau has a low mean roughness value, which is also evident in figure 2d (with the obvious exception of the very rough Grand Canyon region—which has the largest roughness value in the data set). Similarly, the Rio Grande Rift, dominated by the relatively smooth rift valley, shows a relatively low roughness values (0.16 +/- 0.04), though the negative kurtosis value for the distribution indicates significant spread about the mean value (skewed towards rougher values), reflecting the existence of rough escarpments along the margin of the rift. We note that all the provinces have similar standard deviations, indicating that the spread of the roughness values about the mean roughness values. All distributions are skewed toward higher roughness, suggesting the existence of rough outliers in the distribution (particularly for the CP and SM provinces).

Discussion

This contribution has been an attempt to summarize the geologic and tectonic history and a presentation of how this history has shaped the topographic landscape of the Sky

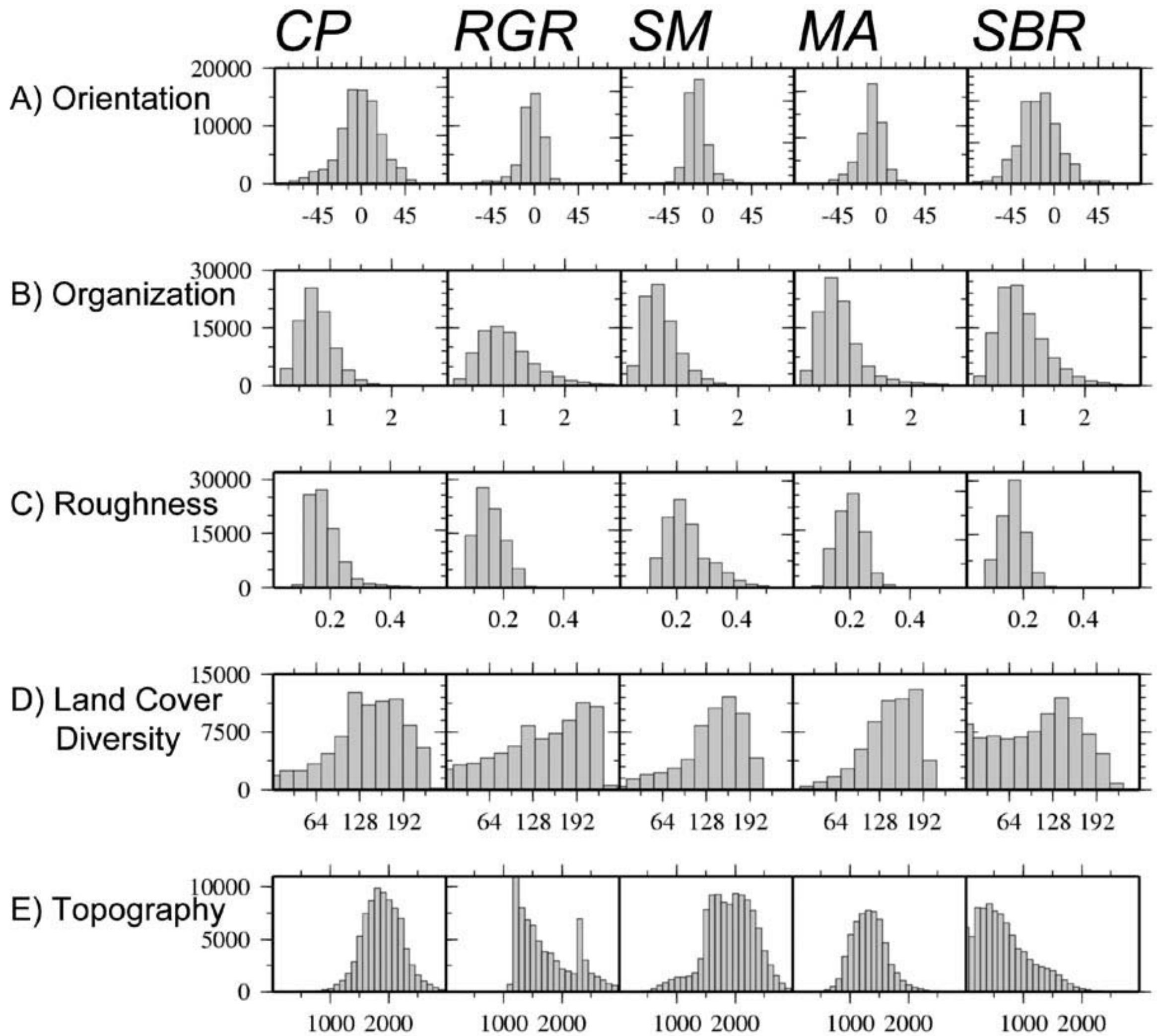

Figure 3—Histograms of the (A) topographic orientation, (B) organization, (C) roughness, (D) land cover diversity (see discussion in Coblentz and Riitter, this proceedings), and (E) elevation for the five tectonic provinces shown in figure 2a. See figure 2 for tectonic province abbreviations.

Islands. In doing so, I have sought to bring into sharper relief the important role played by "deep time" processes in the geoecology of the Sky Islands. The complex tectonic history of the Sky Island region has produced a unique ensemble of topography and geology, which is an important contribution to the biodiversity of the region. The Sky Islands are characterized by a unique mix of bedrock geology spanning several hundred million years of geologic history, and all three principal rock types are present including (1) Igneous rocks in the form of Precambrian and Tertiary granites as well as Mesozoic to Quaternary volcanics; (2) Metamorphic rocks of Precambrian and Mesozoic age including gneisses and schists; and (3) Sedimentary rocks of mostly Paleozoic, Mesozoic and Cenozoic age in the form of limestones, sandstones, quartzites, and shales. The bedrock geology has been mixed by several stages of tectonic deformation, and the diverse soil types resulting from this heterogeneous rock mix invariably has influenced the biodiversity in the Sky Island region.

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A Quantitative Topographic Analysis of the Sky Islands: A Closer Examination of the Topography-Biodiversity Relationship in the Madrean Archipelago

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Abstract—*The relationship between topography and biodiversity is well documented in the Madrean Archipelago. However, despite this recognition, most biogeographical studies concerning the role of topography have relied primarily on a* qualitative *description of the landscape. Using an algorithm that operates on a high-resolution digital elevation model we present a* quantitative *analysis of the topographic fabric in the Madrean Archipelago and explored its utility by evaluating a topography-based predicted biodiversity map. In general, we find excellent agreement between the predicted and observed (based on land cover imagery) biodiversity throughout much of the Sky Island region. While readily acknowledging that many other biological factors influence biodiversity, this study establishes an important first-order estimate of the role topography plays in the regional- to continental-scale biodiversity, particularly in regions characterized by insular mountain fabrics such as the Sky Island region.*

Introduction

It is well known that many landscape characteristics (in particular, relief, slope, aspect, and gradient) play an important role in the distribution of vegetation and biodiversity (e.g., Brown 1978; Merriam 1890; Whittaker 1977; Whittaker and Niering 1965; among many others). For terrestrial habitats, variation in species diversity along gradients of elevation and available soil moisture are almost as striking as latitudinal variations (Cook 1969; Simpson 1964,). Just as the number of species decreases in progressively cooler climates as one moves from the tropics to the polar regions, so it also decreases in the cooler environments as one ascends mountains. This pattern has been well established for trees on mesic mountains of North America (Whittaker 1960, 1977).

The role of topography in the distribution of biodiversity in the arid regions of the Southwestern United States and Northern Mexico is particularly profound. In part, this is a consequence of the extreme aridity at the lower elevations that results in the greatest species diversity of most organisms at intermediate elevations in desert mountains (Whittaker and Niering 1965). In Southern Arizona, the oak woodland biome (at an elevation of about 1,500 m) defines a transition zone between the underlying tropical and overlying temperate life zones, and the ability of flora and fauna to mix across this elevation gradient is considered an important factor in the high level of biodiversity observed in the Sky Island region (Whittaker and Niering 1965; Brown and Lowe 1980; Felger and Wilson 1994; McLaughlin 1994).

Despite the important link between topography and biodiversity, studies of the relationship have been limited to a primarily *qualitative* framework. The current availability of high speed computing platforms, high-resolution digital elevation models, and land cover diversity data sets (e.g., Riitters et al. 2000), invites a *quantitative* analyses and the testing of the relationships discussed in these previous investigations. Here, we undertake such a quantitative analysis by testing the hypothesis that a predictive biodiversity model based on a combination of topographic parameters (organization, roughness, gradient, and mean elevation) can explain the large-scale features of the observed regional biodiversity. We are particularly interested in the applicability of this predictive model in the Sky Island region where the mixing of floristic (Neotropic and Holarctic), faunal (the Neotropic and Nearctic) realms with three major climatic zones (tropical, subtropical, and temperate) is facilitated by high topographic relief and a strong N-S topographic grain orientation.

In the face of continuing global change, an understanding of the many factors affecting biodiversity is becoming increasing relevant. The approach presented here provides new ways of thinking about biodiversity and new assessment techniques to measure and assess it on a regional scale. We note at the onset that we are not proposing that high levels of biodiversity can be explained in terms of topography alone, but rather we seek to evaluate how much of the regional scale diversity is controlled by measurable aspects of the topographic fabric. Of particular interest is the evaluation of regions where large misfit exists between the predicted and observed biodiversity, which provides valuable information about the limitations of this approach.

Land Cover Diversity

Biodiversity is a popular concept that is often ill defined in terms of level of biological organization or spatial scale.

The use of land-cover diversity as a measure of biodiversity is justified by the observation that (at regional scales) community diversity is equivalent to biodiversity (Noss 1990; Stoms and Estes 1993; Wickham et al. 1995). While the existence of suitable land cover may not guarantee the existence of a species (the real object of biodiversity), the absence of suitable land cover usually precludes habitation, and furthermore a variety of land cover types may support a higher variety of species, at least in extra-tropical ecosystems. In this regard, we make the fundamental assumption that land cover diversity can be considered as a measure of potential species diversity.

The land cover diversity data set for the study area was created by using a pixel-based approach that computed a diversity index from the observed proportions of different land-cover types using information from the Global Land Cover Characterization (GLCC) project (Loveland et al. 2000). The maps have a nominal one-kilometer spatial resolution and were derived from satellite (AVHRR) imagery over the time period April 1992 to March 1993. The global thematic resolution is approximately 200 land-cover types, not all of which occur in the study area. We ignored water, urban, and agricultural pixels in order to focus on the diversity of semi-natural vegetation types.

In the present study, a 729 km^2 quadrat (27 x 27 pixels) was centered on each pixel of the original land-cover map, and a land-cover diversity index was calculated within the quadrat and stored in a new biodiversity map at the location of the subject pixel. Each pixel value on the biodiversity map thus represents the land-cover diversity within the surrounding blocks of the original data set. For simplicity, we used Simpson's index (Simpson 1949) that is usually calculated at the species level from the number of individuals of different species observed in a quadrat. In our application, it was calculated at the landscape level from the observed proportions (Pi) of the i different land-cover types in a quadrat as:

$$I = 1 - \Sigma Pi^2 \quad (1)$$

The index I ranges from 0 to 1 with a larger index value indicating greater land-cover diversity.

The observed land cover diversity is shown in 2B. There are broad regions where the diversity reflects the regional topographic fabric (e.g., the Mogollon Rim, northern Rio Grande Rift, central Sierra Madre), and other areas where high diversity appears to be independent of topography (along the coastal plain of Sonora, Mexico, and along the Gila and Colorado Rivers). Histograms of the land cover diversity (LCD) for five subregions in the vicinity of the Sky Islands are shown in 3D of Coblentz (2004, this proceedings). In contrast to spatial distribution of the three principal topographic parameters (roughness, organization and fabric orientation—see figure 2 of Coblentz, this proceedings), the LCD distribution shows significantly less coherence within the individual provinces in the Sky Island region. This large degree of scatter (and associated skewing of all the distributions toward lower diversity) may reflect how the land-cover data were collected (especially the number of different land-cover types that were mapped) or our use of Simpson's index for the construction of the data set. We note that the use of other maps or indices could test these possibilities. Relatively large variances within some provinces (e.g., the Rio Grande Rift and the Southern Basin and Range) could also indicate interactions between tectonic provinces and other drivers of land cover (e.g., water and history) that are not evenly distributed across the study area. We note that the Sierra Madre and Madrean Archipelago provinces have high mean values, relatively low standard deviations, and positive kurtosis (small distribution tails) substantiating the *a priori* observation that these two provinces are centers of high biodiversity.

Topographic Analysis

Landscape topography contains valuable information about the geodynamic, tectonic, and climatic history of a region. Important challenges remain, however, in the development of a quantitative framework for how to "read" this history from the observed topography. Clearly more useful information about topographic fabric is available to supplement basic statistical information. The approach we have taken is to use a 30-arc-second digital elevation model (providing a spatial resolution of about 1 km) to create a terrain classification data set based on information about the mean elevation, gradient, slope aspect, grain orientation, organization, and roughness using the synthetic slope organization method of Chapman (1952), which has been modified to take advantage of fast computing resources afforded by PCs (Guth 1987). Information about the topographic fabric of the Sky Island region using this method is discussed in Coblentz (2004, this proceedings) and Coblentz and Riitter (2004). Here, this information has been used to construct a predicted biodiversity map for the Sky Island region.

Predicted Biodiversity

Construction of a predicted biodiversity map based on the topographic information is based on our hypothesis that in many parts of the Southwest high levels of biodiversity correlate with topography exhibiting the following characteristics: (1) high roughness, (which leads to vertical stacking of biotic communities); (2) highly organized topographic grain oriented in the N-S direction (which encourages the mixture of flora and fauna between the tropic and temperate regions); (3) a median elevation of about 1,500 m (which maximizes mixing between tropical and temperature life zones within the vertically stacked biotic communities); and (4) a northward slope aspect (which effectively lowers the ecotone between the stacked biotic communities due to the cooler, moister environments on northward facing slopes). Following the principle of parsimony we have adopted a first-order approach that uses an unweighted sum of normalized values of these topographic quantities to construct a predicted biodiversity map for the study area.

In contrast to the topographic parameters, the spatial distribution of the land cover diversity shows significantly less coherence within the tectonic provinces. This large degree of scatter (and associated skewing of all the distributions toward lower diversity) may reflect how the land-cover data were collected (especially the number of different land-cover types that were mapped) or our use of Simpson's index for the construction of the data set. We note that the use of other maps or indices could test these possibilities. Relatively large variances within some provinces (e.g., the Rio Grande Rift and the Southern Basin and Range) could also indicate interactions between tectonic provinces and other drivers of land cover (e.g., water and history) that are not evenly distributed across the study area. We note that the Sierra Madre and Madrean Archipelago provinces have high mean values, relatively low standard deviations, and positive kurtosis (small distribution tails) substantiating the *a priori* observation that these two provinces are centers of high biodiversity. If topographic and edaphic drivers are in fact the primary drivers of land cover diversity over the study area, these drivers may simply be less modified by other environmental factors in these provinces compared to other regions.

The resulting database (figure 1A) is renormalized and compared to the normalized observed Land Cover Diversity database (figure 1B). The spatial variations in the misfit between the predicted and observed biodiversity datasets is shown in figure 1C, with regions of positive and negative misfit corresponding to over- and under-predicted biodiversity, respectively. Comparison of the misfit between the calculated and observed biodiversity distributions within the five provinces is facilitated by histograms of the misfit (figure 1D).

High levels of biodiversity are predicted along the western margin of the Sierra Madre (where canyon incisement is greatest), throughout much of the Madrean Archipelago, the Grand Canyon region of the Colorado Plateau, and in the central Rio Grande Rift. In contrast, much of the Southern Basin and Range, Baja California, and coastal Sonora are characterized by low predicted biodiversity values. Examination of the misfit plot (figure 1C) shows good agreement between the predicted and observed biodiversity throughout much of the Sierra Madre and Madrean Archipelago provinces. Our model overestimates the biodiversity throughout much of the central Colorado Plateau, the eastern Sky Island region south in New Mexico, the southern Rio Grande Rift, and the Chihauhuan Desert region east of the Sierra Madre highlands. In contrast, our model underestimates the biodiversity in large regions of the Sonoran coastal plain, along the Gila River in western Arizona, and in the Salton Trough of southern California where other factors contributing to elevated land cover diversity values (namely agricultural development) have not been taken into account.

The misfit distributions for the individual provinces are shown in figure 1D. The misfit in the Sierra Madre is remarkably Gaussian with a mean value very close to zero. The misfit for the other provinces tend to be skewed to positive (overestimation) misfit values. With the exception of the Rio Grande Rift (which samples both large regions of over- and underestimation in the southern and northern sections of the rift, respectively), the individual provinces show very low kurtosis values, indicating a sharp peak in the distribution about the mean (particularly for the Madrean Archipelago and Southern Basin and Range provinces which have kurtosis values less than 0.1). We note, however, that only a weak linear correlation exists between the calculated and observed values for the province-wide distributions (R-squared values less than 0.15 for the Sierra Madre and Southern Basin and Range provinces and near-zero values for the other three provinces). This may be the result of a non-linear relationship between the predicted and observed values (which might be expected given the first-order nature of our predictive algorithm) or may reflect that fact that spatially each of the provinces have larges regions of poor correlation between prediction and observation that prevents the establishment of high R-squared values for province-wide distributions.

Discussion

From biological perspective, topographic variables are indirect factors, which do not necessarily have a physiological influence on species (in contrast to direct factors such as temperature and soil nutrients.) However, while the use of direct factors is preferable for predicting biodiversity, data may not be available, particularly for large regions and inaccessible areas. We are therefore motivated to explore the applicability of predicting biodiversity based on topographic parameters that are readily measured. In the Southwest, the spatial distribution of topography plays an important role in the distribution of biodiversity, particularly in areas characterized by insular mountain ranges. The large elevation gradients in this region have resulted in stacked biotic communities in which species with broadly similar climatic preferences sort themselves along the elevational gradient where the blend of temperature and aridity best supports them. Species of plants and animals originating in north temperate areas are found at the higher elevations, while species from the more tropical south occur nearer the base (Whittaker and Niering 1965, 1968; Brown and Lowe 1980). On a local scale, topography facilitates the compression of biotic communities into relatively constricted vertical spaces and produces rapid species turnover (McLaughlin 1994), and encourages the mingling of species that would normally be widely separated (Felger and Wilson 1994). This is quantifiable in terms of the topographic roughness that we find to be significantly higher in the Madrean Archipelago province relative to the surrounding areas. This aspect of the topography combined with the regional-scale NW-SE orientation of the topographic grain in the Sierra Madre and Madrean Archipelago provinces (that encourages the movement of floral and faunal species up from the neotropical into the temperate biotic zone) are the two most important geographic factors contributing to the high biodiversity in the Madrean Archipelago province.

We readily acknowledge that a predictive biodiversity model based solely on topographic parameters is an over simplification. The principal purpose of the analysis present above is to demonstrate the utility of performing a quantitative topographic analysis and evaluate to what degree topography controls the biodiversity in this region. Other contributing factors that have not been taken into account in our model include information about the bimodal rainfall pattern related to the Mexican Monsoon, the highly diverse bedrock geology of the region, hydrologic distribution, and other topographic parameters such as the slope aspect. Incorporation of these additional factors will need to wait until comprehensive regional-scale

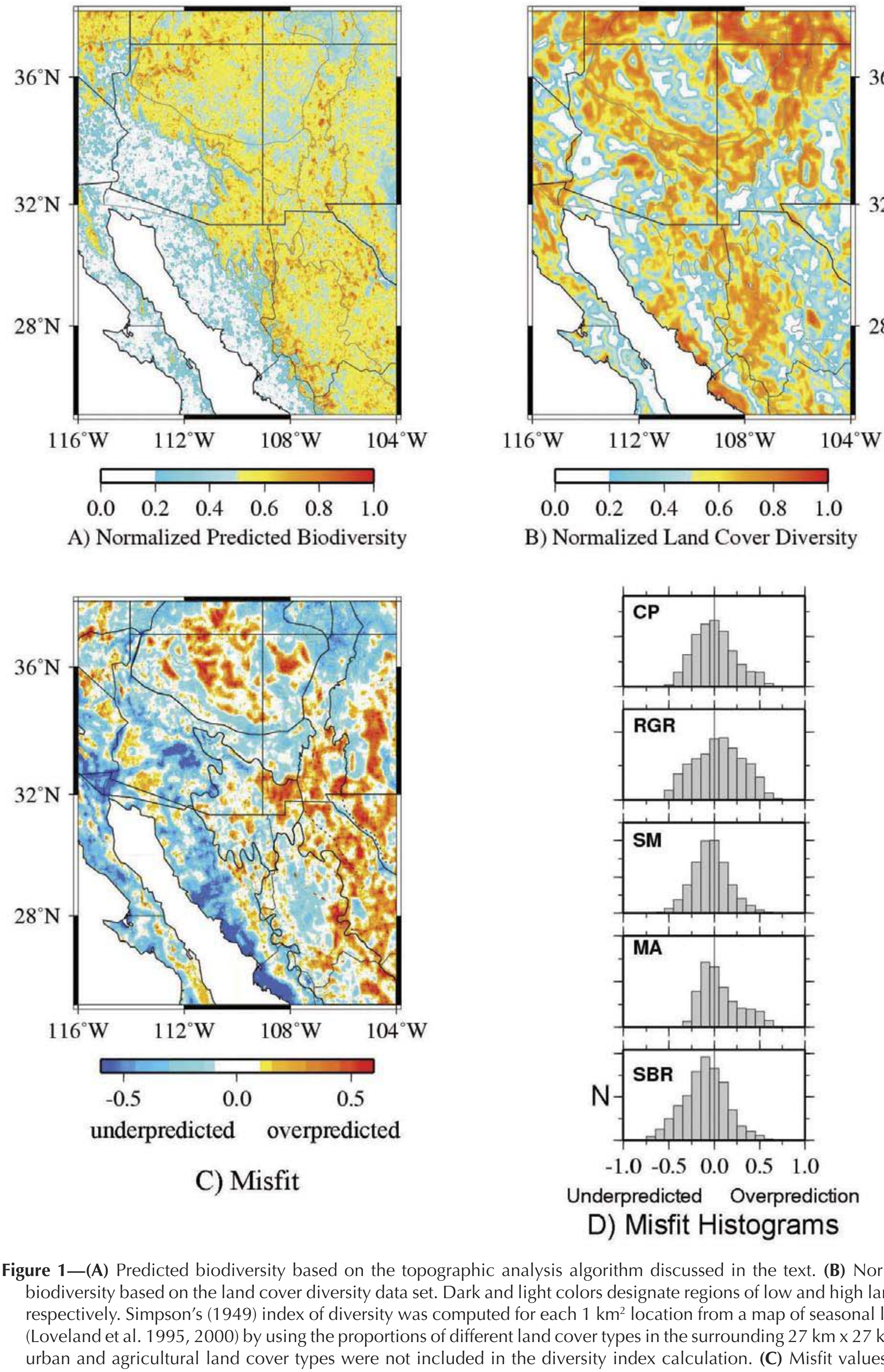

Figure 1—(A) Predicted biodiversity based on the topographic analysis algorithm discussed in the text. **(B)** Normalized observed biodiversity based on the land cover diversity data set. Dark and light colors designate regions of low and high land cover diversity, respectively. Simpson's (1949) index of diversity was computed for each 1 km^2 location from a map of seasonal land cover regions (Loveland et al. 1995, 2000) by using the proportions of different land cover types in the surrounding 27 km x 27 km quadrat. Water, urban and agricultural land cover types were not included in the diversity index calculation. **(C)** Misfit values of the difference between the predicted and observed data sets. Red and blue regions designate regions where the biodiversity has been over- and under-predicted, respectively. **(D)** Histograms of the misfit for the five topographic provinces.

databases are available. We note that in the Southwest the role of soil diversity can be expected to have a profound effect on the biodiversity given the complex geologic history that has resulted in the superimposition of sequences of pre-Cambrian igneous, Paleozoic sedimentary, and Mesozoic volcanic rocks, each of which has a particular soil-vegetation affinity.

While we have only considered the role played by topography in the present-day distribution of biodiversity, we note that its effect becomes even more pronounced over timescales long enough to take climatic change into account. In particular, over the past two million years the location and mix of species along the altitudinal gradients has changed, as cycles of glaciation and warming have triggered species migrations up, down, or off mountain ranges (Van Devender 1990). During cooler times, which have predominated, woodland flora and fauna populated the valleys separating the mountain ranges and formerly isolated species would mix. Northern temperate species immigrated into the region from the north while many desert species would retreat southward. During warmer interglacials, such as the present, subtropical desert vegetation returned. Woodland vegetation would migrate upslope and become stranded on individual ranges, as the valleys between the mountain ranges became barriers they could not penetrate. Thus, quantitative topographic analyses such as those presented in this study can make a significant contribution to studies of the relationship between biodiversity and climatic change (Nobel 1993; Allen and Breshears 1998). Furthermore, the method and results presented above demonstrate that this approach could lead to an adjustment for topography to be used to facilitate a comparison between the biodiversity of two areas by providing a way to remove the potential effects of long-termed constant factors (such as topography) thereby increasing the sensitivity of studies of shorter termed factors such as climate or biotic variables.

From a more speculative perspective, several researchers have recently investigated the implications of characteristic scaling lengths in biology (e.g., Gardener et al. 1987; Wiens and Milne 1989; Milne 1991; Levin, 1992; Allen et al. 1999; Siemann and Brown 1999; Allen and Holling 2002). If they indeed exist, then corresponding characteristic topographic scales must surely play an important role. The approach presented in the present study provides a foundation to test this hypothesis by comparing the characteristic scales of the biodiversity/topography relationship with those being evaluated within a biology/ecology framework. Demonstration of a positive correlation would support arguments that large area patterns in both topography and ecology are the result of long-term tectonic processes; suggesting that continental-scale biodiversity should be studied in the context of large-scale physical processes such as topographic evolution in response to plate tectonic forces as opposed to local-scale phenomena.

Conclusions

In this study we have tested the hypothesis that a combination of three measurable topographic quantities (organization, roughness, and mean elevation) can be used to assemble a reasonable predictive map of spatial biodiversity. Within the underlying assumptions discussed above, we draw the following conclusions: (1) A quantitative topographic analysis is a valuable tool for understanding the distribution of biodiversity, particularly in regions where insular mountain ranges dominate the topographic distribution. Histograms of the misfit between the calculated and predicted biodiversity make a strong case for good general agreement between the datasets. (2) The predicted biodiversity is overestimated in many regions lacking significant vertical relief (e.g., the central Colorado Plateau, Rio Grande Rift, and the low desert areas of the Southern Basin and Range). (3) In regions where topography is expected to play an important role in the high levels of biodiversity (e.g., Madrean Archipelago and Sierra Madre provinces) we find a good correlation between our predicted biodiversity model and observation. (4) The results presented in this study make an important contribution to efforts aimed at establishing predictive geoecological models for describing areal biotic distributions. As such, we feel our results are a significant improvement over efforts seeking correlations in land cover maps. We note that good predictions were only obtained for regions with particular topographic characteristics.

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Occurrence, Structure, and Nitrogen-Fixation of Root Nodules of Actinorhizal Arizona Alder

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Abstract—*Actinorhizal plants are nodulated by the symbiotic, nitrogen-fixing actinomycete* Frankia. *The genus* Alnus *in the family Betulaceae is one of the 24 genera in 8 families of angiospermous plants that are actinorhizal. Arizona alder (*Alnus oblongifolia *Torr.) occurs in isolated populations associated with the watersheds of Madrean Sky Islands in the Southwestern United States between 1,370 and 2,285 m in elevation. We have found root nodules on alder trees from Oak Creek Canyon in central Coconino County, Arizona, and from the Santa Catalina Mountains in southeastern and central Pima County, Arizona. We describe the occurrence of nodules at two locations at or near opposite latitudinal limits of Arizona alder's main range. Capacity of Arizona alder nodules to fix atmospheric nitrogen is confirmed by the acetylene reduction assay and the occurrence of vesicles in infected cortical cells of nodule lobes. Nodule location on roots, nodule morphology, and cellular anatomy confirm symbiotic structure similar to that of other alder species.*

Introduction

Arizona alder (*Alnus oblongifolia* Torr.) is an important riparian tree species that occurs in mountain canyons of the Southwestern United States and Northern Mexico, including many areas within the Madrean Archipelago or "Sky Islands." The genus *Alnus* is actinorhizal and is associated with the symbiotic, nitrogen-fixing actinomycete *Frankia*. Nitrogen is one of the major nutrients that limit productivity of naturally occurring ecosystems throughout the world (Maars and others 1983), and nitrogen fixation by actinorhizal plants is a major source of nitrogen replenishment in many natural terrestrial ecosystems (Dawson 1986). Atmospheric nitrogen also is fixed in the symbiotic microorganism-plant relationship with nodules containing *Rhizobium* bacteria, found in legumes and the elm-family genus *Parasponia*.

A specific relationship between Arizona alder and Frankia, although suspected, has not been previously confirmed. It is not possible to assume that geographically isolated populations of Arizona alder are nodulated by Frankia capable of fixing nitrogen symbiotically because of the complexity of exact dispersal mechanisms, host specificity mechanisms, and isolation factors for Frankia populations. This relative isolation of actinomycete and host populations presents the possibility that the characteristics of its symbiotic biology are unique. Moreover, not even the most rudimentary symbiotic features of this large, riparian tree species have been carefully examined. A symbiotic relationship would be an important source of nitrogen for the ecologically critical riparian communities of the Madrean Archipelago.

Arizona alder is found in riparian habitats along canyons and perennial and intermittent streams within oak woodlands and ponderosa pine (*Pinus ponderosa*) forests generally at 1,370 and 2,285 m in elevation. Arizona alder is a medium to large tree with a straight trunk that can grow to 18 to 24 m in height and to 60 to 80 cm in diameter (Little 1950). The largest Arizona alder tree is found in New Mexico and has a height of 39 m, a circumference of 505 cm, and a spread of 15 m (American Forests 2004). The species grows along many stream channels in southeastern and central Arizona, from Pima County in the south to Oak Creek Canyon in Coconino County in the north. In the Sierra Ancha Mountains of Gila County in central Arizona, alder is associated with big-toothed maple (*Acer grandidentatum*), narrow-leaf cottonwood (*Populus angustifolia*), box elder (*A. negundo*), Arizona walnut (*Juglans major*), several coniferous forest species and Gambel oak (*Quercus gambelii*) (Minkley and Brown 1982; Reynolds and Johnson 1964). Common herbaceous species include fowl mannagrass (*Glyceria striata*), false-Solomonseal (*Smilacina racemosa*), and wondering violet (*Viola nephrophylla*) (Pase and Johnson 1968).

Actinorhizal plants including Arizona alder are nodulated by the symbiotic, nitrogen-fixing actinomycete *Frankia* and include 24 genera in 8 families of angiospermous plants (table 1). Actinorhizal plant families, together with all legumes and the rhizobially nodulated genus Parasponia, have been placed in the rosid clade containing plants with a predisposition to nodular symbiosis with diazotrophs (Soltis and others 1995). The symbiotic organ is a multi-lobed coralloid or compact spherical root nodule formed upon primary roots infected by the actinomycete *Frankia*. Nitrogen fixation by actinorhizal plants is a major source of nitrogen in diverse and widespread terrestrial ecosystems including forests, bogs, swamps, coastal dunes, landslides, glacial deposits, riparian zones, shrub lands, prairies, and deserts (Dawson 1986). Actinorhizal plants play important roles in wildland ecosystem function and have been used in land reclamation, range management, forestry, agroforestry, and horticulture. Dixon and Wheeler (1986) estimated that the contribution of actinorhizal plants to terrestrial global nitrogen fixation could be as great as 25% of the total. Estimated rates of actinorhizal nitrogen fixation are comparable to those of legumes. Nitrogen fixation rates vary widely within and among actinorhizal species and according to assay methodology used as well as ecological and genetic factors. It follows that the ranges of values reported for taxa that have been studied tend to be wide. Estimates of N_2 fixation by *Alnus rubra*, a similarly large tree in the same subgenus as Arizona alder, range from 22 to over 300 kg $ha^{-1}y^{-1}$ (summarized in Hibbs and Cromack 1990). Riparian alders, such as red alder and Arizona alder, may be keystone species in stream corridors, influencing productivity and diversity by increasing nitrogen quantity and availability in soil through primary input via N-enriched litter and root decomposition.

The purpose of the present research was to describe some aspects of the occurrence, morphology, and nitrogen fixation capacity of Arizona alder. Observations of the occurrence and morphology of root nodules on Arizona at distant locales near the northern and southern extremes of its main range that lies within the United States are preliminary to further studies of the genetics and ecology of this prominent tree species. Specific objectives of our study were to determine whether or not Arizona alders were nodulated at our two study sites and to describe in detail for any alder nodules: their location on roots, size and distribution on roots, depth of occurrence in soil, gross morphology, and microscopic features of cells.

Table 1—Currently known actinorhizal plant families and genera (adapted from Bond 1983 and Baker and Schwintzer 1990).

Family	Genus	Number of species
Betulaceae	Alnus	35
Casuarinaceae	Allocasuarina	54
	Casuarina	16
	Ceuthostoma	2
	Gymnostoma	18
Coriariaceae	Coriaria	16
Datiscaceae	Datisca	2
Elaeagnaceae	Elaeagnus	38
	Hippophae	2
	Shepherdia	2
Myricaceae	Comptonia	1
	Myrica	28
Rhamnaceae	Ceanothus	31
	Colletia	4
	Discaria	5
	Kentrothamnus	1
	Retanilla	2
	Talguenea	1
	Trevoa	2
Rosaceae	Cercocarpus	4
	Chamaebatia	1
	Cowania	1
	Dryas	3
	Purshia	2

Study Areas, Materials, and Methods

Nodule samples were collected from three trees along Oak Creek south of the Pine Flat Campground in the Coconino National Forest at approximately 1,705 m in elevation. Ponderosa pine forests occupy the surrounding slopes. Nodule samples were also collected from trees on the headwaters of Sabino Creek in the Santa Catalina Mountains within the Coronado National Forest, south of Summerhaven and north of the Marshall Gulch Campground. Elevations were about 2,315 m. Trees sampled were at least 15 cm in stem diameter at breast height and were located on the stream margins. Samples were collected in July and September of 2003.

Two indicators of nitrogen fixation capacity were examined: acetylene-reduction ability of nodules and the presence of vesicles in infected cortical cells of nodule lobes.

Nodules with attached root pieces were removed and washed in water. The average diameter of each nodule was determined using calipers. The source tree, position with respect to the root collar, color, shape, and the configuration of nodule lobes were observed and recorded for the nodules. Microtome sections from the base of peripheral nodule lobes were examined microscopically for the presence in cortical cells of Frankia hyphae, sporangia, and vesicles. The nitrogenase enzyme responsible for nitrogen fixation resides within the protective layers of vesicles in alder nodule cortical cells, and their presence is diagnostic for the capacity to fix dinitrogen.

A subsample of 6 small (~ 5 mm in diameter) alder nodules with attached root pieces, two from each tree at the Oak Creek site, were placed according to source tree on moist filter paper in loosely sealed plastic bags. Small nodules were chosen because of their relatively high ratio of active, infected cortical cells in relation to functionally inert woody tissue compared to older, larger perennial nodules. Nodule samples were stored in an insulated container cooled by plastic-encased frozen gel refrigerants. The temperature was maintained between 2 and 12 °C as determined by a min-max thermometer for 20 hours prior to gradual warming to 25 °C in a laboratory. Two nodules with attached root pieces from each tree were incubated at 25 °C in a 10% acetylene in air gas mixture in 10 cc glass tubes sealed with a serum stopper. Incubation time was 1 h. Duplicate gas samples were taken from each tube through the serum stopper after incubation using 1-cc gas syringes. Root segments without attached nodules were used to control for low levels of ethylene contaminants in the acetylene source and any plant-derived ethylene hormone in the incubation medium.

In the 10% acetylene in air gas mixture, acetylene is reduced to ethylene by the nitrogenase enzyme while the acetylene blocks dinitrogen fixation, allowing ethylene gas evolution to serve as an indirect assay for nitrogen fixation capacity (for details see Winship and Tjepkema 1990). The acetylene-reduction assay employed in this study was intended only to detect the presence or absence of nitrogenase activity and not to quantitatively represent the actual acetylene reduction rate of the intact system measurable for a brief instant immediately after exposure to acetylene. Rates of acetylene reduction were undoubtedly reduced by excision, chilling, a rapid, acetylene-induced decline in nitrogenase activity, and the time delay between removal from the roots system and the assay. Chilling was intended to slow respirational loss of energy substrates in nodules and nitrogenase turnover during transport.

Ethylene evolution indicated by the amount of ethylene in the gas samples from the nodule incubation vessels was measured by a gas chromatograph fitted with a flame ionization detector.

Results

All trees sampled at both sites were nodulated. The nodules collected were reddish brown, 0.3 to 3 cm in diameter, with compact lobes producing a solid, spherical structure. In some cases nodules were irregular in shape where rocks or other obstructions interfered with growth. The largest nodules were found near the root collar and most nodules at the two Arizona sites were found near the soil surface. None were found at depths exceeding 5 cm. Some were located at the surface of the humic soil under rocks. Soils were moist owing to the proximity to the creeks. Cortical cells of all nodule lobes examined from each site contained *Frankia* hyphae and vesicles. Vesicles in alder nodules contain the nitrogenase enzyme. They only develop in pure culture in nitrogen limited growth media necessary to induce nitrogen fixation. Vesicles are indicative of the capacity of Arizona alder nodules to fix nitrogen.

The cellular anatomy of infected cells from Arizona alder nodules was generally similar to that of other alder species. However, Arizona alder nodules sampled differed in one respect from alder nodules developed on disturbed sites. This difference was the presence in many but not all of the Arizona alder nodule lobes examined of sporogeneous bodies. Such spore nodules produce intracellular sacs containing spores, and are characteristic of alder nodules developed in natural areas long occupied by the actinorhizal host species (Schwintzer 1990).

Nodules from all three trees sampled at Oak Creek Canyon reduced acetylene to ethylene at an average rate of 6 µmole per g dry nodule weight per h (± 3 units standard deviation). This value is clearly indicative of functional nitrogenase activity. The level is equal to low nodule rates that occur early in the spring and late in the fall in field nodules of European black alder (Zitzer and Dawson 1989). Experimental limitations allowed us to determine only that there were biologically significant rates of nitrogenase activity in Arizona alder nodules from two sites, but not to provide rates representative of the actual value or rates that can be compared quantitatively with those of assays performed under conditions of highest stringency (Winship and Tjepkema 1990).

Discussion

Many important ecological interactions, patterns, and functions can be strongly regulated by nitrogen fixation carried out by actinorhizal (*Frankia*-nodulated) plant symbiotic associations. Much information on the patterns and functions of the *Frankia* symbiosis has appeared in the literature (for review see Huss-Danell 1997), and some of this information has important implications concerning its presence and role in riparian ecosystems of the Madrean Archipelago. Of specific concern is the ability of *Frankia* in soils to form nodules on suitable host plants, such as alder, to fix nitrogen symbiotically, to disperse, and to survive.

Actinorhizal Plant Symbiosis and Its Importance

Infectious *Frankia* is known to be widespread throughout the world. This symbiosis occurs in plants on all continents (except Antarctica) and on many islands. However, its occurrence varies widely both spatially (Paschke and others 1994; Simonet and others 1999) and temporally (Wollum and others 1968). Nodulation of an actinorhizal plant may not occur because *Frankia* is absent or, more likely, because specific strains able to nodulate a given host are not present in a soil, or are unable to nodulate a host under existing soil conditions (e.g., soil oxygen limitations). Within their native ranges, most actinorhizal plant species nodulate with *Frankia* strains capable of symbiotic nitrogen fixation, although nodulation with ineffective strains can also occur in nature (Wolters and others 1997). Soil near actinorhizal hosts generally has greater nodulation capacity then surrounding soils (Jeong and Myrold 2001; Smolander 1990; Zimpfer and others 1999).

However, infective *Frankia* can be found in a variety of soils both within and outside the immediate influence of actinorhizal hosts as well as outside the range of actinorhizal plant species (Burleigh and Dawson 1993; Lawrence and others 1967; Maunuksela and others 1999, 2000; Paschke and Dawson 1992a; Zimpfer and others 1997). *Frankia* strains that are able to nodulate *Alnus*, *Myrica*, *Dryas*, and *Elaeagnus* are widespread in occurrence outside the native range of their host plants, suggesting the capacity to persist as a sporophyte (Kohls and others 1994; Maunuksela and others 1999, 2000; Nickel 2000; Nickel and others 1999).

The presence of plant species such as birches that are not actinorhizal, but that are closely related to actinorhizal genera, can increase the overall nodulation capacity of the soil for the actual host species (Gauthier and others 2000; Paschke and Dawson 1992b; Smolander 1990). Increased rhizosphere soil nodulation capacity of actinorhizal hosts and some other closely related plant species suggest the release of compounds that stimulate *Frankia* growth, infectious capacity, or both (Zimpfer and others 2002, 2003). A compound or compounds from the roots of an actinorhizal plant can stimulate *Frankia* spore germination (Krumholz and others 2003). This stimulation could be due to flavonoids, which have been found to stimulate nodulation of actinorhizal plants (Benoit and Berry 1997; Laplaze et al. 1999).

A spatial pattern probably resulting from soil variables was evident on the Oak Creek Canyon site, where nodules were limited to soil depths less than 5 cm. In this location, the soil was saturated near the surface resulting in a high streamside water table, which may have restricted nodule development under hypoxic conditions at deeper soil depths. Low soil oxygen reduces the occurrence of infective *Frankia* in soil and can also inhibit nodule development and function. Thus, the hypoxic conditions in soil could have caused a reduction in respiration and decrease the amount of available energy substrates that would be required in large quantities for nodule development and subsequent nitrogen fixation.

Spore Dispersal Mechanisms

It cannot be assumed that a little-studied species such as Arizona alder is nodulated, or nodulated by *Frankia* populations capable of fixing nitrogen symbiotically because the exact dispersal mechanisms, host specificity mechanisms, and isolating factors for soil *Frankia* populations are not known. However, the dispersal of propagules, such as spores, is an important characteristic that would enable *Frankia* to become widely distributed among host plants of different terrestrial plant communities, including riparian areas. The mechanisms of dispersal of *Frankia* have not been empirically established in nature. However, it is known that infective *Frankia* is present in newly deposited glacial till and on sand dunes prior to colonization by host plants (Kohls and others 2003; Young and others 1992). Common mechanisms for *Frankia* dispersal are wind (anemochoric dispersal), water (hydrochoric dispersal), and biological vectors (zoochoric dispersal). All three of these mechanisms operate, to some extent, in riparian environments of the Madrean Archipelago where the two most important mechanisms are water and biological.

An important mechanism enhancing the dispersal of *Frankia* throughout riparian areas probably involves an earthworm-bird interrelationship. It has been reported that *Casuarina*-infective *Frankia* can pass through the digestive tracts of earthworms, which probably disperse *Frankia* vertically together with large volumes of soil (Reddell and Spain 1991). Birds in turn consume earthworms and other soil invertebrates and also ingest large soil particles that function as grit for grinding food in their gizzards. Some bird species also transport mud containing infective Frankia for nest construction as well as soil invertebrates as a food source for nestlings (Paschke and Dawson 1993). Furthermore, it has been demonstrated that *Frankia* spores can survive and maintain the ability to infect host plants after passage through the digestive tracts of birds (Burleigh and Dawson 1995).

Birds provide a possible aggressive vector for the importation of *Frankia* spores over long distances. For example, it has been reported that soils of tropical lowland forests of Costa Rica contain *Frankia* spores although these extensive lowland forests lack any known actinorhizal hosts (Paschke and Dawson 1992a). This is believed to occur because the migratory routes of many bird species funnel though Costa Rica as they move annually between North and South America along the Central American isthmus. Many of these migrating birds eventually visit and concentrate in the moister environments provided by the riparian corridors found along the streams of the Sky Islands of Northern Mexico and Southwestern United States. Thus it is possible that isolated riparian corridors may not lose soil microbial diversity or develop distinct ecotypes of soil microorganisms owing to frequent genetic mixing of *Frankia* and other soil microorganisms transported long distances by birds.

Summary

Arizona alders from two geographically isolated populations were found to bear actinorhizal nodules typical of species of the genus *Alnus*. Many nodules were spore+, which is a characteristic of alder nodules developed in natural areas long occupied by the actinorhizal host species. The presence of *Frankia* vesicles in infected cells and a positive result from the acetylene-reduction assay for nitrogenase activity indicates that Arizona alder has the capacity to fix atmospheric nitrogen. These findings indicate the possibility that Arizona alder may be a keystone species important for primary nitrogen inputs into biotically diverse and ecologically critical communities of riparian corridors.

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Distribution of Birds and Plants at the Western and Southern Edges of the Madrean Sky Islands in Sonora, Mexico

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Abstract—*The western and southern edges of the Madrean Sky Island region are poorly defined and have received little study. After exploring mountains in these areas, we documented range extensions and additional records for several species of interest. Although many of these disjunct mountains have not been considered Sky Islands, their flora and fauna are similar to other areas within the region. Therefore, we suggest their biota indicate they require inclusion as part of the Madrean Sky Island region. Distribution and abundance of organisms within our study areas should be carefully inventoried while they remain relatively unaltered from human actions.*

Introduction

Located between the highlands of the Mogollon Rim and the Sierra Madre Occidental, the Madrean Archipelago is a region of wooded mountain islands isolated by lowland seas of desertscrub, thornscrub, and grassland. Woodlands of evergreen oaks define these mountain islands and yield to pine-oak, pine, and mixed-conifer forest at higher elevations (McLaughlin 1995). Although the region has yet to be adequately defined it is thought to exist south of the Santa Teresa Mountains, west of the Animas Mountains, east of the Baboquivari Mountains and Sierra Cíbuta, and north or west of the large contiguous forests of the high Sierra Madre Occidental (Marshall 1957; McLaughlin 1995; Warshall 1995).

West of the Sierra Cíbuta and southwest of the Baboquivari Mountains are other wooded ranges that have not been considered part of the Madrean Archipelago (DeBano et al. 1995). Phillips and Amadon (1952), however, noted oaks in the Sierra San Juan (el Carrizal), Russell and Monson (1998) noted oaks in the Sierra el Humo, and Brown and Lowe (1980) mapped the westernmost Madrean evergreen woodland in these ranges (figure 1). Although known, ornithologists have spent only two hours among oaks of Sierra San Juan (Phillips and Amadon 1952) and three days in the Sierra el Humo (S. Russell, personal communication), and botanists have yet to visit these and many of the surrounding mountains (R. Felger, personal communication). Data on the distribution and abundance of plants and birds is therefore limited (Van Rossem 1945; Turner et al. 1995; Russell and Monson 1998).

West of the Sierra Madre Occidental in central Sonora are other mountains with Madrean evergreen woodland isolated by lowland thornscrub (Brown and Lowe 1980). Although the Sierra Aconchi and las Guijas have been considered part of the Sky Island region, others ranges with oak woodland to the south, such as the Sierra de Mazatán, have not (DeBano et al. 1995). Presence of oak woodland in this and other nearby ranges indicates they may provide habitat for species found in the Madrean Archipelago.

We describe the distribution of birds, plants, and plant communities in selected mountains at the western and southern edges of the Madrean Archipelago. Based on these observations and past work, we attempt to define the western and southern limits of the region.

Study Area

We focused on four mountains west of the Sierra el Cíbuta and east of the Gran Desierto known or thought to have potential to support flora and fauna found in the Madrean Archipelago. From east to west these mountains and their elevation range are the Sierra San Juan (800-1,630 m), Sierra el Humo (720-1,650 m), Sierra el Cobre (860-1,350 m), and Sierra el Durazno (800-1,210) (figure 1). In central Sonora we selected the Sierra Mazatán (550-1,540 m), an isolated mountain approximately 70 km east of Hermosillo and south of the Sierra Aconchi (figure 1).

Methods

We visited each range for one to six days between 2000 and 2004 and attempted to reach the summits and all major vegetation communities. We described vegetation communi ties in upper elevation areas of each range and estimated area of oak woodland to the nearest km^2 by outlining its approximate extent on 1:50,000 m topographic maps.

We recorded all bird species detected and estimated maximum number of individuals observed per day during each visit. We noted the vegetation communities and elevation where

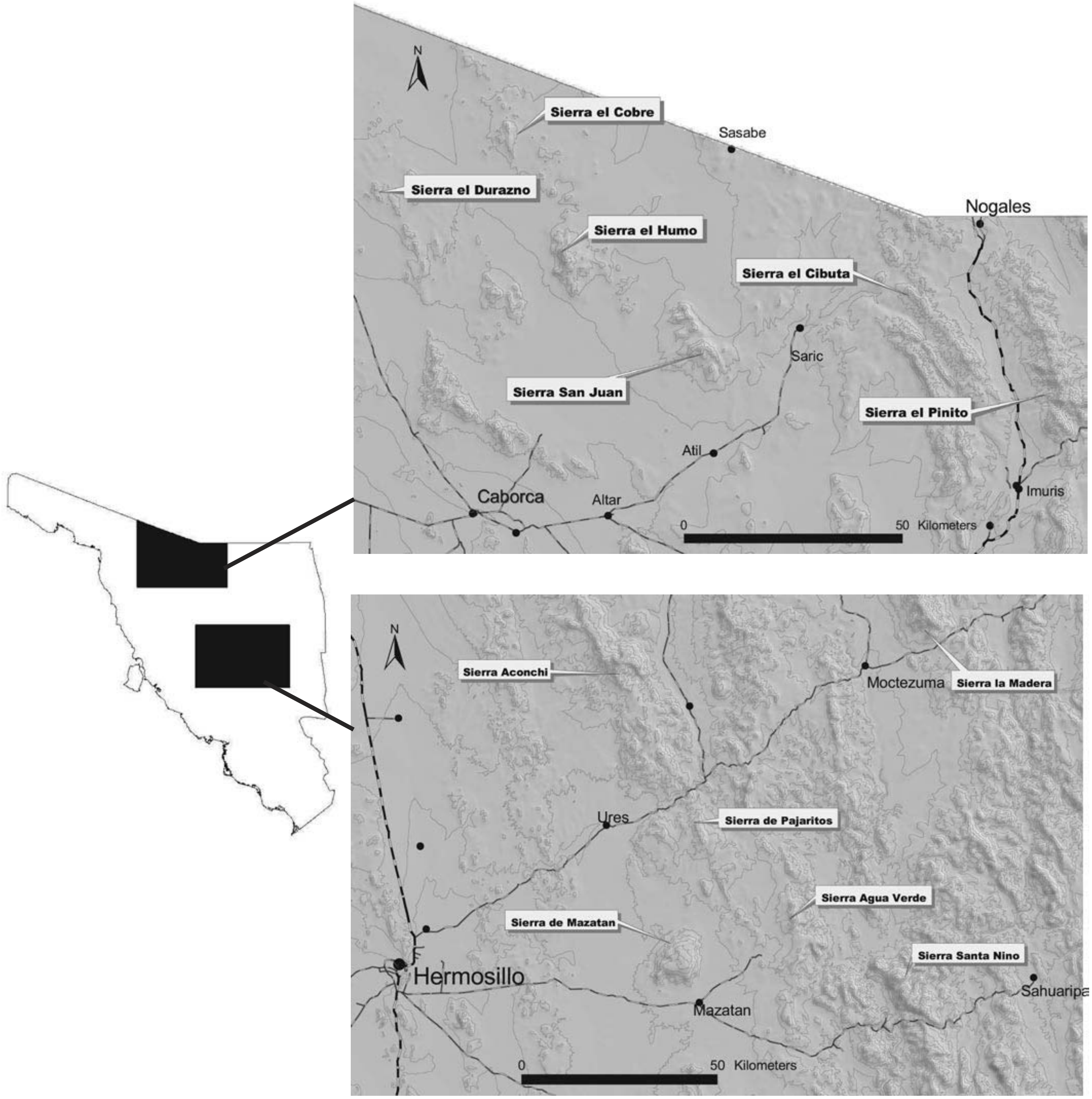

Figure 1—Maps of the western and southern edges of the Madrean Sky Island region in Sonora, Mexico, depicting selected mountain ranges, cities, roads, and topography within the study area.

each species occurred and described evidence of breeding. Because visits were not always made during the breeding season, we lack complete information on residency and breeding status. To determine the distributional significance and likely residency status of birds, we used published information (e.g., Marshall 1957; Phillips et al. 1964; Russell and Monson 1998). To determine similarity between bird communities with that in oak woodlands in the Madrean Archipelago, we compared bird species listed by Marshall (1957: 54-57) that prefer oak woodland with species we observed.

We collected voucher specimens of selected species of interest and deposited them in the University of Arizona Herbarium. We noted whether species were common, uncommon, or rare and whether they were distributed in the upper or lower half of each range. To determine the distributional significance of species, we used published information (e.g., Bowers 1980; Turner et al. 1995; Felger et al. 2001), herbarium collections, and information from local experts. To determine floristic affinities, we compared a list of dominant or conspicuous species from the upper elevation half of each range with 195 floras from the United States and Mexico using methods outlined by McLaughlin (1992). To determine each range's similarity with the Madrean Archipelago, we compared the percentage of species in each range that occurred in all 10 floras in the Apachian District of the Madrean Floristic Province because they are roughly coincident (McLaughlin 1995). We focused on western ranges as floristic information for the Sierra de Mazatán is provided elsewhere (Sánchez-Escalante et al., this proceedings).

Results

We observed approximately 13 km^2 of oak woodland in the Sierra San Juan on slopes, ridges, and bottoms above 1,200 m. In the Sierra el Humo we observed approximately 10 km^2 of oak woodland in similar areas but often restricted to north- and east-facing slopes. In the San Juan, oak woodland occurred in a relatively contiguous block in the center of the range whereas in the Humo, higher topographic complexity produced patches separated by desert grassland or hopbush (*Dodonaea viscosa*), gumhead (*Gymnosperma glutinosum*), or *Mimosa* scrub. In both ranges closed-canopied encinal was restricted mainly to steeper north- or east-facing slopes and canyon bottoms. Mexican blue (*Quercus oblongifolia*) and Emory (*Q. emoryi*) oaks were dominant at lower elevations and often replaced by Arizona oak (*Q. arizonica*) >1,500 m. Common understory species included beargrass (*Nolina microcarpa*), silktassel (*Garrya wrightii*), and bunchgrasses. We observed few signs of domestic livestock grazing and numerous signs of wildfire >1,300 m in the Sierra el Humo and limited grazing in the San Juan. Oak woodland in the San Juan is approximately 30 km from similar vegetation in the Humo and 40 km from oak woodland in the Sierra Cíbuta.

In the Sierra el Cobre, oak woodland was limited to a small (~100 m^2) patch of Mexican blue oak along a northeast-facing drainage centered at 1,280 m. We observed extensive grasslands >1,200 m dominated by sotol (*Dasylirion wheeleri*) and bunchgrass that included shrub live oak (*Q. turbinella*) on one north-facing hillside. Elsewhere, a jojoba (*Simmondsia chinensis*)-mixed scrub association dominated much of the range. In the Sierra el Durazno >1,000 m, we observed woodland and scrub dominated by shrub live oak on north- and east-facing slopes that reached heights of approximately five m. We did not observe juniper (*Juniperus* sp.) or pinyon (*Pinus* sp.) in the study area.

In the Sierra de Mazatán we estimated approximately 35 km^2 of oak woodland on flats and hills on the mesa and adjacent upper slopes. Woodland of Chihuahua oak (*Q. chihuahuensis*) dominated much of the range and was often replaced by closed-canopied encinal of Mexican blue and willow oak (*Q. viminea*) >1,350 m. On the upper slopes of a large west-facing canyon we observed a mosaic of roble (*Q. turberculata*) and foothill thornscrub dominated by *Bursera*, *Lysiloma*, and *Ceiba acuminata* that included palms (*Brahea brandegeei*) along the drainage. We did not observe pines (*Pinus* sp.).

Birds

West

Of the 15 diurnal species listed by Marshall (1957) that prefer oak woodland in the Madrean Archipelago, we detected 12 (80%) in the San Juan, 11 (73%) in the Humo, three (20%) in the Cobre, and one (7%) in the Durazno (table 1). Some species such as hepatic tanager (*Piranga flava*) may occur but had not arrived at the time of our surveys. Acorn woodpeckers (*Melanerpes formicivorus*) were vocal and conspicuous in the San Juan in February 2004 but were not detected in November 2003.

We detected all eight oak woodland species listed by Marshall (1957) that are typically permanent residents in the San Juan and seven (88%) in the Humo. In the Humo, four Arizona woodpeckers (*Picoides arizonae*) drummed and called nearly simultaneously from neighboring ridges or slopes on the morning of March 2, 2004.

We observed other species often found among oaks in the Madrean Archipelago including a male and female elegant trogon (*Trogon elegans*) in the San Juan on November 17, 2003, but not during our subsequent visit in February 2004. Trogons were in a large north-facing canyon dominated by oaks. We observed spotted towhees (*Pipilo maculatus*) in the San Juan and Humo in mountain shrubland of oak, silktassel, beargrass, and bunchgrass. Spotted towhees were paired and singing in the Humo on March 2, 2004. We observed a single band-tailed pigeon (*Columba fasciata*) at 1,300 m in the San Juan on February 9, 2004.

Winter residents included one to three Townsend's warblers (*Dendroica townsendi*) per day in the San Juan, Humo, and Cobre. They were observed in oaks on both visits to the San Juan and in the only stand of Mexican blue oak in the Cobre. Other wintering species included two Lewis woodpeckers (*Melanerpes lewis*) and a Steller's jay (*Cyanocitta stelleri*) on February 8, 2004, in the San Juan and a Townsend's solitaire (*Myadestes townsendi*) on March 2, 2004, in the Humo, all in oaks.

Eight species we observed were at the westernmost limits of their range in Sonora and seven (88%) were associated with oak woodland (table 1). Arizona woodpeckers and buff-collared nightjars (*Caprimulgus ridgwayi*) in the Humo are the westernmost populations for these species.

South

In the Sierra de Mazatán we detected 11 of 15 (73%) diurnal oak woodland species listed by Marshall (1957) and seven of eight (88%) that are typically permanent residents (table 1). We detected only one pair of Arizona woodpeckers and one singing Hutton's vireo (*Vireo huttoni*). Mexican jays (*Aphelocoma ultramarina*) were conspicuously absent. We detected a whiskered screech-owl (*Otus trichopsis*) and two calling elegant trogons in tall Mexican blue oak woodland above 1,400 m and three northern pygmy-owls (*Glaucidium gnoma*) between 1,340 and 1,500 m. We detected pairs of ladder-backed (*Picoides scalaris*) and Gila (*Melanerpes uropygialis*) woodpeckers in oaks as high as 1,520 m and a singing brown-crested flycatcher (*Myiarchus tyrannulus*) and greater pewee (*Contopus pertinax*) in tall Mexican blue oak woodland at 1,500 m. A calling male black-vented oriole (*Icterus wagleri*) and two singing Sinaloa wrens (*Thryothorus sinaloa*) were present at the edge of a roble, thornscrub, palm association at 1,200 m. We also detected one pair and another singing white-striped woodcreeper (*Lepidocolaptes leucogaster*) in Mexican blue and willow oak woodland along a shallow north-facing canyon at 1,460 m.

We detected 11 of the 14 (79%) oak woodland species observed by Marshall (1957) that occur in the neighboring Sierra Aconchi. Other similarities with the Aconchi included absence of blue-gray gnatcatchers (*Polioptila caerulea*) and spotted towhees and presence of brown-crested flycatchers in encinal.

We observed 13 species at the western limits of their potential breeding range south of the latitude of Hermosillo, and 10 (77%) were listed by Marshall (1957) as oak woodland species. Closest known potential breeding localities for these 10 species to the east were 30-60 km away above La Estrella for six species and >130 km away near Sahuaripa for four species (Russell and Monson 1998). White-striped woodcreepers were at the westernmost known locality for the species.

Plants

West

We collected 43 voucher specimens of 22 species in and around the four mountain ranges. Ten species we observed were at the western or northernmost limits of their global distribution and 16 were at their westernmost limits in Sonora (table 2). Species at their westernmost limits in Sonora included southwestern chokecherry (*Prunus serotina* subsp. *virens*), Arizona spikenard (*Aralia humilis*), and white, Mexican blue, and Emory oak (table 2). Shrub live oak in the Humo, Cobre, and Durazno are the only known populations in mainland Mexico. Feather tree (*Lysiloma watsonii*) in the Humo is at its northwestern limits, California buckthorn (*Rhamnus californica*) in the San Juan appears to be the only known locality in Sonora, and Gentry indigo bush (*Dalea tentaculoides*) in the Humo is only the second known population in Sonora.

We identified 41 to 54 dominant or conspicuous species in the upper elevation half of each mountain range. On average, 25.5, 21.6, 17.7, and 11.6% of species found in the Sierra el Humo, San Juan, Cobre, and Durazno, respectively, occurred in all 10 Apachian floras used in the analysis. Similarity with Apachian floras was greater than for any other floristic area in all ranges except the Durazno where 18.0 and 13.9% of species were associated with the Central Gulf Coast and Sonoran Districts, respectively.

Discussion and Conclusions

Our work represents the first attempt to describe vegetation and avifauna in many of the mountains we visited. Many of the range extensions we observed are probably the result of little past field work rather than recent colonization events.

Although our timing was not sufficient to determine breeding status for most species, observations combined with published information enabled us to determine likely status for some species. Drumming and calling behavior by Arizona woodpeckers in spring is consistent with self-advertisement and pair formation that begins in March (Johnson et al. 1999). These behaviors, and the size and location of cavities we observed imply breeding. Acorn woodpeckers often move seasonally and although we observed no granaries, some breeding populations in encinal use natural holes for storage (Stacey and Bock 1978). Acorn woodpeckers in the San Juan may breed in years of high acorn production, but the birds we observed had probably moved from higher elevations to the east sometime in mid winter in search of insects. The male and female trogon we observed in the San Juan may have bred, as the canyon appeared suitable for nesting or have been migrants from further north (Kunzmann et al. 1998). Hutton's vireos in the San Juan and spotted towhees in the Humo were singing in areas similar to those where they breed in the Baboquivari Mountains. Additional work will further elucidate breeding status of birds in these areas.

The small size and isolation of oak woodlands we visited offer insights into the area necessary to support populations for some species. Arizona woodpeckers are elevational migrates and rarely occur in lowland vegetation adjacent to their breeding grounds, and Mexican jays are virtually unknown in the lowlands (Phillips et al. 1964; Johnson et al. 1999). These species have likely persisted in the San Juan and Humo for many years. In comparison, all resident oak woodland species were absent in the small patch of Mexican blue oaks in the Cobre.

Although the Sierra San Juan and Humo have not been considered part of the Madrean Archipelago, bird communities in oak woodlands were similar to those found in Sky Islands to the east and dominant plants had greater affinity to Apachian floras than any other. Therefore, we suggest their biota indicates they require inclusion as part of the Madrean Archipelago. In contrast to Sky Islands to the east, these ranges are smaller, lower elevation, and almost completely surrounded by the Sonoran Desert. Although the Sierra el Cobre supported some oak woodland, it was too small or isolated to support birds typically found in the Sky Islands.

We suggest that mountains that support oak woodland surrounded by lowland vegetation be considered part of the Madrean Archipelago if they have conditions and resources to promote occupancy, survival, and reproduction of plants and animals found in the Sky Islands. Presence of resident birds with specialized habitat requirements and distributions associated with the Sierra Madre Occidental such as Arizona woodpecker are good indicators of the region's extent.

The Sierra de Mazatán also supported a bird community similar to that found in the Madrean Archipelago, yet the flora seems to have greater affinity to the Sierra Madre Occidental than to Apachian floras. The Mazatán are Sky Islands in a physiographic sense, yet it is not clear where we should draw the line between Apachian and Sierra Madrean biogeographic areas. Whether the Mazatán and other nearby ranges close to the Sierra Madre Occidental are part of the Madrean Sky Island region requires further study.

Despite limited information on the status of organisms along the United States-Mexico border, the region is of profound bi-national interest. The fate of some species may depend on actions occurring in neighboring countries, and Sonora populations may provide an important source of individuals for species that have declined in the United States. Anticipated development or climate change may alter these communities before they can be adequately described or protected. Therefore, organisms in this region should be carefully inventoried while it remains relatively unaltered.

Table 1—Distribution, maximum number detected per day, and notes for selected bird species found in five mountain ranges at the of days in each range. Visit dates are as follows: Sierra San Juan - 4/29/00, 1/12/02, 11/17/03, and 2/7 - 2/9/04. Sierra el Humo -

	Location and effort				
	West				South
Species	**San Juan (6)**	**Humo (5)**	**Cobre (3)**	**Durazno (1)**	**Mazatan (2)**
Zone-tailed Hawk (*Buteo albonotatus*)	2	2	1		1
Red-tailed Hawk (*Buteo jamaicensis*)	3	1	2	1	2
Peregrine Falcon (*Falco peregrinus*)		1			
Montezuma Quail[a] (*Cyrtonyx montezumae*)	4				1
Band-tailed Pigeon (*Columba fasciata*)	1				
Western Screech-Owl (*Otus kennicottii*)	2		1		1
Whiskered Screech-Owl[b] (*Otus trichopsis*)					1
Northern Pygmy-Owl (*Glaucidium gnoma*)					2
Common Poorwill (*Phalaenoptilus nuttallii*)	1	5			1
Buff-collared Nightjar (*Caprimulgus ridgwayi*)		1			
Costa's Hummingbird (*Calypte costae*)	5			2	
Anna's Hummingbird (*Calypte anna*)	3				
Rufous Hummingbird (*Selasphorus rufus*)			2		
Elegant Trogon (*Trogon elegans*)	2				2
Acorn Woodpecker[b] (*Melanerpes formicivorus*)	8				15
Lewis's Woodpecker (*Melanerpes lewis*)	2				1
Arizona Woodpecker[a] (*Picoides arizonae*)	3	5			2
Northern Flicker (*Colaptes auratus*)	6	7			1
White-striped Woodcreeper (*Lepidocolaptes leucogaster*)					3
Greater Pewee (*Contopus pertinax*)					2
Nutting's Flycatcher (*Myiarchus nuttingi*)					8
Ash-throated Flycatcher[b] (*Myiarchus cinerascens*)	2	3	2	2	
Hutton's Vireo[a] (*Vireo huttoni*)	10	1			1
Steller's Jay (*Cyanocitta stelleri*)	1				
Western Scrub-Jay (*Aphelocoma californica*)	1				
Mexican Jay[a] (*Aphelocoma ultramarina*)	10	8			
Bridled Titmouse[a] (*Baeolophus wollweberi*)	20	12			40
Bushtit[a] (*Psaltriparus minimus*)	10	5			10
White-breasted Nuthatch (*Sitta carolinensis*)					8
Sinaloa Wren (*Thryothorus sinaloa*)					3
Bewick's Wren[a] (*Thryomanes bewickii*)	12	20	1		10
Blue-gray Gnatcatcher[b] (*Polioptila caerulea*)		1			
Western Bluebird[b] (*Sialia mexicana*)	10				
Townsend's Solitaire (*Myadestes townsendi*)		1			
Black-throated Gray Warbler[b] (*Dendroica nigrescens*)	4	1			4
Townsend's Warbler (*Dendroica townsendi*)	4	1	1		
Hepatic Tanager[b] (*Piranga flava*)					4
Spotted Towhee (*Pipilo maculatus*)	5	12	6	3	
Canyon Towhee (*Pipilo fuscus*)	10	2	3		10
Rufous-crowned Sparrow[a] (*Aimophila ruficeps*)	15	3			6
Black-vented Oriole (*Icterus wagleri*)					1
Scott's Oriole[b] (*Icterus parisorum*)		2	1		1

[a] Indicates species listed by Marshall (1957) that prefer oak woodland that are likely permanent residents in the study area.
[b] Indicates species listed by Marshall (1957) that prefer oak woodland that are likely migratory in the study area.

Acknowledgments

We are indebted to Steve McLaughlin for floristic analyses. We thank Steve Russell for information on birds in Sonora and Richard Felger, Ed Gilbert, Phil Jenkins, Ana L. Reina, Richard Spellenberg, and Tom Van Devender for help with plants. Walt Anderson and Sky Jacobs contributed to our observations on ≥1 field trip. We also thank local landowners for access and Steve Russell, Tom Van Devender, and Eric Wallace for reviews of the manuscript.

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western or southern edges of the Madrean Sky Islands in Sonora, Mexico 2000-2004. Effort, noted in parentheses, equals the number
6/23/02 and 2/29 - 3/2/04. Sierra el Cobre - 5/3/00, 2/8/03, and 3/16/04. Sierra el Duranzo - 2/16/04. Sierra Mazatan - 4/8 - 4/10/04.

Comments	Significance
Nests along lowland drainages at Western sites	Few nests known in NW Son.
Soaring near large cliffs on west side	
Reported by local residents in Humo and Cobre	At or near the westernmost limits of range
Soaring above oak woodland	Westernmost locality in Son.
In small patch of oaks in Cobre	
Calling from blue oak woodland near summit at 1,500 m	At or near the westernmost limits of range
Calling at dawn at both camps	
Calling in S. Juan on evening of 11/16/03	
Occurs on E, N, & NW sides of Humo	Westernmost localities in Son.
Present in S. Juan on 1/12/02	
All females	
Migrating through highlands on 3/16/04	
Found 11/03 in S. Juan, males calling in encinal >1,400 m in Mazatan	Westernmost locality in Son. in S. Juan
Present 2/04 but not 11/03 in S. Juan	Westernmost locality in Son. in S. Juan
In oak savannah	Not seen in San Juan since 1948
4 drumming simultaneously in Humo on 3/2/04,	Northwesternmost locality for sp. in Humo
In oak savannah and woodland	
In large blue/willow oak encinal, 1 pair and another singing	Northwesternmost locality for sp.
Singing in blue oak woodland near summit at 1,500 m	Rarely in pure encinal
All paired, near oak woodland - thornscrub ecotone to 1,260 m	
Detected in lowlands	
Several singing on 2/04 in S. Juan, only 1 singing in Mazatan	
On ridge at 1,500 m	Few records for W. Son.
In scrub at 1,100 m	
Noted between 1,600 and 1,100 m	Westernmost localities in Son.
Common throughout oak woodland and scrub	Westernmost localities in Son.
Common throughout oak woodland and scrub	Westernmost localities in Son.
2 singing in thornscrub at 1,240 m, fresh nest in *Q. turberculata*	At or near the westernmost limits of range
Singing in woodlands	
In lowland riparian vegetation	
Flock in oak woodland	
In oak savannah	Few winter records in N. Son.
Wintering in oaks, no singing noted	Few winter records in N. Son.
Wintering in oaks	Only known winter localities in W. Son.
1 pair and 2 singing males in blue/ willow oak encinal >1,400 m	
Paired and singing in Humo on 3/2/04	
Paired and courting in Mazatan on 4/9/04	
Singing in oak savannah and grasslands	
Male in *Brahea brandegeei, Q. turberculata*, thornscrub association	At or near the westernmost limits of range
All singing males	earliest Spring arrival (3/1/04)

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Table 2—Distribution, abundance and significance of selected plant species observed in the Sierras at the western edge of the Madrean Arizona Herbarium.

		Distribution and	
Family	**Species**	**San Juan**	**Humo**
Anacardiaceae	*Rhus trilobata* Nutt. (skunkbush sumac)	U-H	U-H
Araliaceae	*Aralia humilis* Cav. (Arizona spikenard)	R-H	R-H
Asclepidaceae	*Asclepias linaria* Cav. (pineleaf milkweed)	U-H	
Asteraceae	*Carphochaete bigelovii* Gray (bristlehead)	C-H	U-H
	Ambrosia carduacea (E. Greeen) Payne (Baja California ragweed)		U-L
Burseraceae	*Bursera fagaroides* var *elongata* McVaugh & Rzed. (fragrant elephant tree)	U-L	U-L
Cactaceae	*Echinocereus rigidissimus* (Engelm.) Haage f. (rainbow cactus)	C-H	C-H
Fabaceae	*Acacia angustissima* (Mill.) Kuntze (white ball acacia)	U-H	U-H
	Dalea tentaculoides H.C. Gentry (Gentry indigo bush)		R-H
	Indigofera sphaerocarpa Gray (Sonoran indigo bush)	R-H	R-H
	Lysiloma watsonii Rose (feather tree)	U-L	U-L
	Zapoteca formosa ssp schottii (Torr. ex S. Wats.) H. Hern.		
Fagaceae	*Quercus arizonica* Sarg. (Arizona oak)	C-H	C-H
	Quercus emoryi Torr. (Emory oak)	C-H	C-H
	Quercus oblongifolia Torr. (Mexican blue oak)	C-H	C-H
	Quercus turbinella Greene (shrub live oak)		U-H
Garryaceae	*Garryi wrightii* Torr. (silktassel)	C-H	C-H
Hydrangeaceae	*Fendlera rupicola* Gray (clif fendlerbush)		U-H
	Philidelphus microphyllous Gray (mockorange)	U-H	U-H
Liliaceae	*Dasylirion wheeleri* S. Wats. (sotol)	C-H	C-H
	Nolina microcarpa S. Wats. (beargrass)	C-H	C-H
Poaceae	*Elyonurus barbiculmis* Hack. (wooly bunchgrass)	C-H	C-H
	Muhlenbergia emersleyi Vasey (bullgrass)	C-H	C-H
	Trachypogon secundus (J. Presl) Scribn. (crinkleawn)	C-H	C-H
	Schizachyrium cirratum (Hack.) Woot. & Standl. (Texas bluestem)	C-H	C-H
Rhamnaceae	*Rhamnus californica* Eschsch. (California buckthorn)	R-H	
	Rhamnus crocea Nutt. (hollyleaf buckthorn)		
	Sageretia wrightii S. Wats. (mock buckthorn)		
Rosaceae	*Prunus serotina* subsp *virens* (Woot. & Standl.) McVaugh (southwestern chokecherry)	R-H	R-H
	Vauquelinia californica ssp *sonorensis* Hess & Hendr. (Sonora rosewood)		U-H
Rutaceae	*Ptelea trifoliata* subsp *angustifolia* (Benth.) V. Bailey (hoptree)		R-H

[a] **C**ommon, **U**ncommon, **R**are at **H**igh, **L**ow, or **A**ll elevations

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Sky Island region in northern Sonora, Mexico 2003-2004. Voucher specimens for most records are deposited in the University of

Abundance[a]			
Cobre	Durazno	Comments	Significance
		Near summits and along drainages	Few Sonora localities
		Restricted to north facing drainages or rock piles	Westernmost localities in Sonora
	U-H	Among rocks or along drainages	Westernmost localities in Sonora
		Among bunchgrass and *Nolina* in oak savannah	Westernmost locality for sp.
		Common along washes on west side, rare east	Only known localities in northern Sonora
		Only on west sides	Northwesternmost extant locality for sp.
U-H		On rock outcrops in oak savannah or grassland	Westernmost localities for sp.
U-H	C-H	Often along drainages	Westernmost locality in Sonora
		Along 1 drainage on west side at 1,260 m	Second known and westernmost locality in Sonora
		Along north facing drainages	Westernmost locality in Sonora
		On lower slopes and occasionally at base of Mts	Northwesternmost locality for sp.
U-H	C-H	Along drainages	Northwesternmost localities in Sonora
		Dominant woodland tree >1500 m	Westernmost locality in Sonora
		Forms closed-canopy woodlands with next sp.	Westernmost locality in Sonora
R-H		Limited to ~30 plants in Cobres	Westernmost locality in Sonora
R-H	C-H	On steep slopes just below summits	Only known localities in mainland Mexico
		Along drainages and on slopes	Westernmost locality in Sonora
		Near summitt >1550 m	Westernmost locality in Sonora
		In north facing drainges and slopes	Westernmost locality in Sonora
C-H		In oak savannah or grasslands	Northwesternmost localities in Sonora
C-H		In oak savannah or grasslands >1200 m	Westernmost localities in Sonora
		In oak savannah >1400 m	Westernmost localities for sp.
C-H		In oak savannah and grassland	Westernmost localities in Sonora
		In oak savannah >1400 m	Westernmost localites in Sonora
		In oak savannah and grassland	Westernmost localities for Sonora
		Along north-facing drainages	Only known locality in Sonora?
	U-H	Dense stands along northeast facing shoot	Only known locality in W. Sonora
R-H		Resticted to 1 north facing drainage at 1200 m	Northwesternmost locality for sp.
		Short trees along north facing drainages	Westernmost locality in Sonora
		On or near rocky outcrops	Second known locality in Sonora
		Near summits and along north-facing drainages	Westernmost locality in Sonora

Chiricahua Leopard Frog Status in the Galiuro Mountains, Arizona, With a Monitoring Framework for the Species' Entire Range

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Abstract—*The Chiricahua leopard frog (*Rana chiricahuensis*) was historically widespread in suitable habitat throughout its range. Reports of recent population declines led to inventories of Chiricahua leopard frog localities. Surveys reported here establish a new baseline of occurrence in the Galiuros: only two of 21 historical localities were found to be occupied in 2003. One of these sites may represent the only source population for the species in that mountain range. The species' reduced occurrence in the Galiuros may reflect its situation elsewhere. To aid in tracking recovery action efficacy, we offer a framework for future monitoring of this threatened species.*

Introduction

The Chiricahua leopard frog (*Rana chiricahuensis*) is found in Arizona, New Mexico, Sonora, and Chihuahua (Platz and Mecham 1979). Its range is divided into at least two portions. One consists of northern montane populations along the southern edge of the Colorado Plateau in central and eastern Arizona and west-central New Mexico (=Mogollon Rim population). Another includes southern populations located in the mountains and valleys south of the Gila River in southeastern Arizona and southwestern New Mexico and extends into Mexico along the eastern slopes of the Sierra Madre Occidental (=Madrean populations).

Populations of all of Arizona's native ranid frogs (leopard frogs, *Rana pipiens* complex, and the Tarahumara frog, *R. tarahumarae*) have declined in recent years (Clarkson and Rorabaugh 1989, Sredl et al. 1997). The Chiricahua leopard frog (*Rana chiricahuensis*) is one of these species, and it has undergone large-scale population declines throughout much of its range (Jennings 1995, Painter 2000, Sredl et al. 1997). In 2002, it was listed as threatened by the U.S. Fish and Wildlife Service (USFWS 2002).

In order for the Coronado National Forest (Coronado) to assess the status of the Chiricahua leopard frog across some of its administered lands, it contracted surveys in 2002 (reported on by Hays [2002]). This included some of the historical (substantiated with reliable locality records) and potential (previously undocumented) sites in the Galiuro Mountains and five other Madrean Sky Islands. As a follow-up, in 2003, one of us (LLCJ) conducted surveys of all historical sites in the Galiuros. In this paper we report on the 2003 surveys, with an update on the current knowledge of the status of the species in the Galiuros. We also introduce a framework for intensive future monitoring strategies to assess the efficacy of recovery actions across the species' range.

Survey History Before 2003

Surveys of ranid frogs in Arizona were sporadic and poorly documented before the 1990s, about the time when the World Congress of Herpetology noted a global decline in certain amphibian taxa. Surveys of the Chiricahua leopard frog and other native ranids were conducted throughout the 1990s, primarily by Arizona Game and Fish Department (AGFD). Personnel searched for animals visually and by sweeping pools and the vegetation with a dip net to cause movement and detection (Sredl et al. 1997). During each visit, field personnel collected data on amphibian species present, habitat characteristics, and other variables, such as weather and time of day. They also assessed the suitability of the site for leopard frogs. These surveys detected frogs at 20 sites (figure 1). Populations occurred along the lower eastern flank of the Galiuro Mountains from at least the Ash Creek/High Creek drainages on the south to at least Deer Creek on the north. In 1995 and 1996, the first years with relatively intensive surveys, frogs were found to be present in about 80% of the sites surveyed (figure 1). In subsequent years, occupancy rates were lower: 47% in 1997, 20% in 1998, and 35% in 1999. Although visits were irregular and data were collected under various conditions, results still indicated a pattern of decline.

No data were collected in 2000 or 2001, but the Coronado's 2002 surveys (Hays 2002) shed additional light on recent site occupancy. The surveys covered all five of the Forest's Districts. Sites for surveys for ranid frogs (not just *R. chiricahuensis*) were selected by District Biologists, and pre- and post-monsoon surveys were conducted. Ranid frogs were found in 3/50 (6%) historical and potential sites. Hays (2002) surveyed 16 sites in the Galiuros (6 historical and 10 potential). Ranids were found in one new locality (site #21, figure 1). These were reported to be Plains leopard frogs (*R. blairi*) based on a single larval individual held through metamorphosis, but no vouchers were retained. A "plop" (from an unidentified anuran suspected to be a leopard frog) was recorded at another site.

In addition to the surveys reported by Hays (2002), one of us (LLCJ) surveyed 5 additional sites in the Galiuros (4 historical, 1 potential). One historical site (#9) had Chiricahua leopard frogs, and one potential site had a possible but unconfirmed observation. Of the sites surveyed, 50% were dry during the pre-monsoon surveys. Pre-monsoon water level minima were recorded consistently for the first time in 2002. The District also surveyed in the Pinaleños at 34 sites, but none were seen although leopard frogs (probably *R. yavapaiensis*, the Lowland leopard frog) were once common in the range (Nickerson and Mays 1969).

2003 Surveys

All known historical sites of Chiricahua leopard frogs in the Galiuros were surveyed in 2003. Sites to be surveyed were based on records gleaned from AGFD's Heritage Data Management System and Riparian Herpetofauna Database, Hays (2002), unpublished data (LLCJ 2002), and other sources. The primary intent was to establish a new baseline of occurrence in the Galiuros. Twenty-one sites had credible observations and were considered historical sites (figure 1), while four sites had questionable data and were not included. Three potential sites were additionally surveyed. Surveyors used the standardized sampling protocol (USFWS 2003) and visited sites during the pre-monsoon season. If water was present when they arrived during daylight, the site was also visited at night. In addition to USFWS (2003), a supplemental data form was used to summarize the changes in water level and other site parameters. Digital images of all sites were recorded in the four cardinal directions.

Two of the 21 sites were found to be occupied (#9 and #21), which were also the only sites found to be occupied in 2002. Site 9 is a stock tank and Site 21 a natural lotic system; these may be close enough together to be part of a single population, but they are in separate tributaries of a larger drainage.

Sites 9-12 (refer to figure 1) are a series of tanks representing a metapopulation, but only the largest tank (Site 9), which never dried up, was found with frogs in 2002 and 2003. The site was visited twice in 2003, with up to 4 frogs recorded, although there had apparently been some recruitment, as a metamorphic individual was seen on one occasion. The tank at Site 9 is

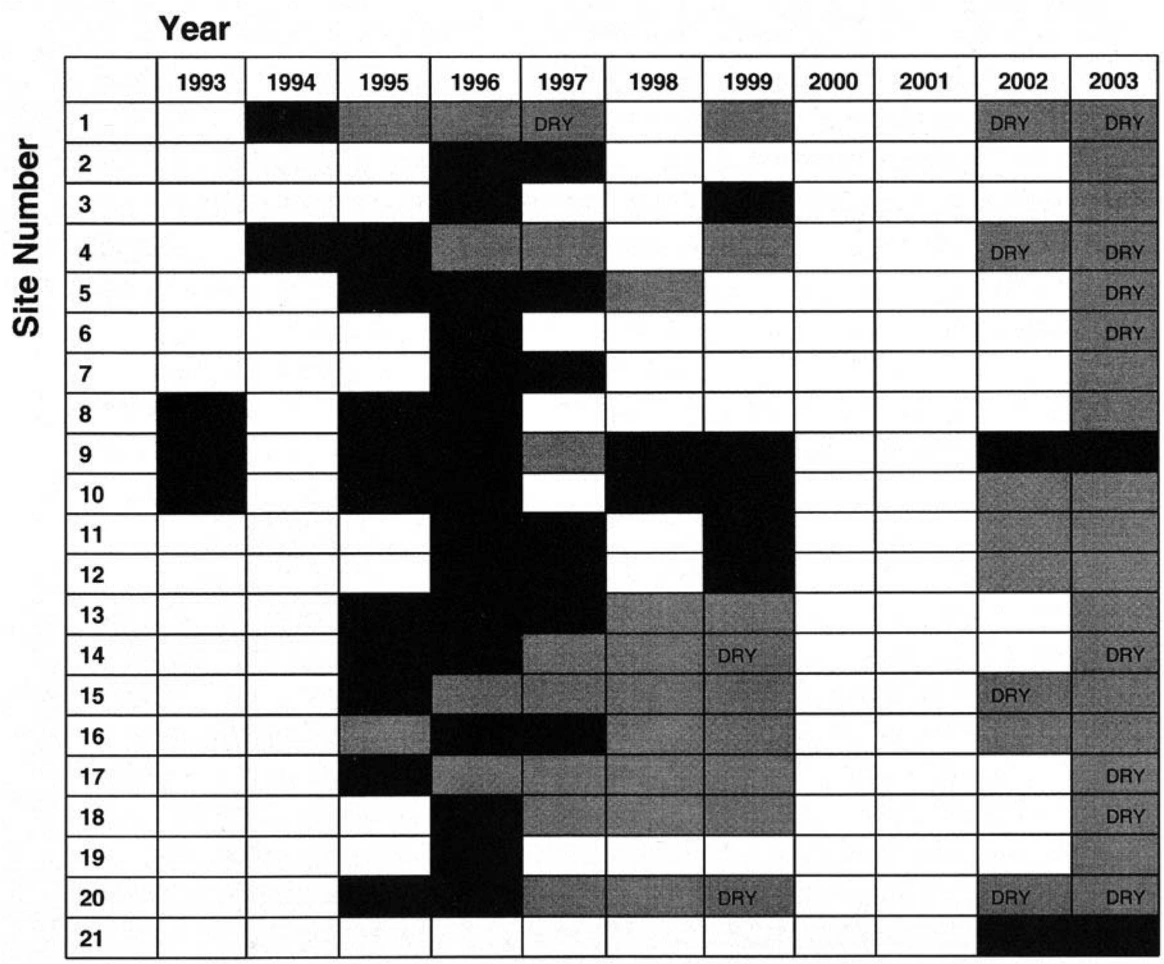

Figure 1—Occurrences of Chiricahua leopard frogs in the Galiuro Mountains from 1993 to 2003. Black = detection, gray = no detections, and white = no data or no surveys. Low-flow/pre-monsoon surveys were only consistently done in 2002 and 2003, so designating sites as dry (or not) were only valid for those years during the pre-monsoon period.

contained by an earthen dam in a tributary of a lotic system near site 21. The lotic system below Site 9 had little water during the dry season in 2002 and 2003, and was represented by a few small isolated pools during the dry season. Because so few frogs were detected at Site 9, we were concerned that this population was on the verge of extirpation.

Site 21 was visited on 7 occasions from June 10 to November 11. The identification of the resident ranids needed to be confirmed, because we questioned the likelihood of *R. blairi*, given its distribution. On a night visit (June 30), photographic vouchers were taken of various aspects of three captured frogs. We identified them as *R. chiricahuensis*, although the rear thigh pattern was not unlike *R. blairi*.

Because this Site 21 could possibly be the only viable population for the species in the Galiuros, subsequent visits were conducted to: determine the extent of the population along the lotic system; characterize and map the pools during low and high water; determine if native and non-native predators were present; look for evidence of a die-off by the recently identified chytrid fungus (Berger 1998); and identify other potential threats. On each visit, as many as 25 frogs were counted, with all age classes except eggs (i.e., adults, juveniles, metamorphs, and larvae) present. Frogs occupied several of the approximately 25 large pools (during low water), but one pool in particular seemed to be the epicenter of the population.

Potential Threats to the Galiuros Populations

At Sites 9 and 21, no exotic predators were seen. However, during low water at Site 21, belostomatids and Black-necked Gartersnakes (*Thamnophis cyrtopsis*) were evident native predators. In the low-water situation, belostomatids, in particular, seemed likely to be a serious threat, because their numbers far outweighed frog numbers. There was no evidence of chytrid fungus disease at either site, but frogs from the Galiuros have never been tested. Cattle were absent from most of Site 21 because it is a steep, bedrock-dominated system. Cattle were present at the occupied stock tank. One obvious threat across the Galiuros was the lack of water, as evidenced by the apparent local extirpation that occurred concomitantly with the drought beginning in 1996/1997, and the large number of previously occupied sites that were dry during 2002-3 surveys. Because these frogs require essentially perennial waters to live and reproduce, there is an obvious direct effect. The drought exacerbates other negative effects by reducing the number of aquatic sites in a metapopulation. This increases vulnerability of predators, increases cattle use, and reduces emergent and bank vegetation. On the other hand, periodic drying of tanks and pools can rid a system of unwanted predators (including noxious non-native species) and may block the spread of disease.

Beyond these two extant populations, the prognosis is dismal. The few splashes heard in 2002 suggest there may be a few *R. chiricahuensis* in the southern part of the Galiuros, but it is not known if populations would be viable if conditions improve. Also, non-native predators have been documented in some of the southern populations. Clearly, this species urgently needs conservation measures in this and other mountain ranges.

Measures of Species Status and a Framework for Monitoring Ranid Frog Conservation

The pattern of decline seen in the Galiuros is typical of the Madrean populations in the United States. Based on intensive surveys in recent years, most of the Sky Islands managed by the Coronado have Chiricahua leopard frog populations at only one or two distinct sites. The difficulty in describing increasing or decreasing trends in populations is exacerbated when trying to describe these trends from a baseline of only one or two subpopulations. In this section, we propose survey and monitoring programs to include in the recovery plan to describe species status and detect threats (Brigham et al. 2002, Campbell et al. 2002). Our suggestions take into consideration the difficulties inherent in describing status changes in small populations, the need to identify threats early, the necessity to document progress in reintroduction programs (which also involve small number of reintroduced animals), and the importance of providing objective, measurable delisting criteria.

Focal Area Surveys

One of the criteria to delist the Chiricahua leopard frog will likely be the maintenance of some minimum number of metapopulations within each recovery unit. Each metapopulation will include occupied and unoccupied sites and will be part of an area where considerable conservation effort will be focused. One measure of metapopulation health is the ability to disperse into available habitat patches and to maintain subpopulations in a high proportion of these sites. Recently, proportion area occupied (PAO) has been proposed as a measure of this ability (MacKenzie et al. 2002). PAO uses comparable survey data within and between years at a set of identified sites to describe the probability of encountering or detecting the species if it is present, and then estimate the probable proportion of sites that are occupied. Even if a given site is occupied, if detection probabilities are low, consideration of simple observations only might lead to scoring that site unoccupied. Two great benefits have been identified for this type of population status descriptor. First, it allows the estimation of the proportion of occupied sites that may have been scored as unoccupied due to low detection probabilities, which apply to southwestern ranids (Blomquist 2003). Also, this technique can be implemented more easily and less expensively than the methods used for abundance estimation, such as traditional mark-recapture. For these reasons, this method should be attractive to a large-scale monitoring program, as will be needed for the recovery plan of the Chiricahua leopard frog. PAO estimation performs best when detection probabilities are greater than 0.3 (MacKenzie et al. 2002), so opportunistic sampling may have to be replaced with seasonal sampling designed to target each site when detection is most likely.

Applied Conservation Surveys

The objective of applied conservation surveys will be to assess the potential of a particular unoccupied site or area in conservation of native ranid frogs or to detect threats to extant populations. Data sheets for these surveys will reflect this goal by including detailed information on: 1) abundance and habitat use of resident frogs, 2) availability of potential habitat for all life stages, 3) habitat characteristics such as water permanence and quality, dispersal corridors, foraging areas, and quality of aquatic and terrestrial vegetation, 4) possible impacts such as land use, presence and abundance of introduced species or diseases, 5) needed habitat renovations, 6) land ownership, and 7) site accessibility.

Translocation Monitoring

Because translocation has already been used and will probably continue to be used for conservation of this species (Sredl and Healy 1999), it will be important to institute monitoring to describe the success or failure of each translocation effort. Sredl and Healy (1999) presented an approach to evaluate stages of success of translocations, including the timeline and frequency of data collection, to efficiently and effectively track the course of success or the point at which failure occurs. They defined stages of success as: 1) initial survival of released animals, 2) over-winter survival of released animals, 3) long-term survival of released animals, 4) reproduction of released animals at the site of release, and 5) recruitment in a population of released animals. To measure dispersal, nearby non-release sites also need to be monitored. When suitable habitat exists in the vicinity (1.5-4 km), surveys should be conducted sporadically to determine whether colonization occurs. Surveys during stage 1 can use daytime visual survey assuming all tadpoles or juveniles encountered are from a recent release. Surveys addressing the remaining stages of success, except stage 4, would use intensive nighttime searches, involving capture and identification of cohort.

We view this monitoring framework as a starting point; the Chiricahua Leopard Frog Recovery Team (Technical and Stakeholder subgroups) will develop the final monitoring scheme as part of the recovery plan. Whatever the final categories of field monitoring are called, we feel it is important for each category to have explicit objectives that facilitate recovery and measure progress toward delisting in a cost-efficient and defensible manner.

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Flora of the San Pedro Riparian National Conservation Area, Cochise County, Arizona

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Abstract—*The flora of the San Pedro Riparian National Conservation Area (SPRNCA) consists of 618 taxa from 92 families, including a new species of* Eriogonum *and four new State records. The vegetation communities include Chihuahuan Desertscrub, cottonwood-willow riparian corridors, mesquite terraces, sacaton grasslands, rocky outcrops, and cienegas. Species richness is enhanced by factors such as perennial surface water, unregulated flood regimes, influences from surrounding floristic provinces, and variety in habitat types. The SPRNCA represents a fragile and rare ecosystem that is threatened by increasing demands on the regional aquifer. Addressing the driving forces causing groundwater loss in the region presents significant challenges for land managers.*

Introduction

Understanding biodiversity has the potential to serve a unifying role by (1) linking ecology, evolution, genetics and biogeography, (2) elucidating the role of disturbance regimes and habitat heterogeneity, and (3) providing a basis for effective management and restoration initiatives (Ward and Tockner 2001). Clearly, we must understand the variety and interaction of the living and non-living components of ecosystems in order to deal with them effectively. Biological inventories are one of the first steps in advancing understanding of our natural resources and providing a foundation of information for a variety of fields.

A flora is defined as an inventory of plants growing within a specific geographic boundary (Palmer et al. 1995). Floras represent one the most comprehensive sources of data to assess biodiversity (Withers et. al. 1998). They can range from simple checklists of small areas to multivolume, descriptive and analytical floras of continental regions. Floristic data have been used in a variety of ways in academia: to study plant distribution and diversity, test premises of island biogeography, assess biological species concepts, and determine the prevalence of exotic species (Barkley 2000; Palmer et. al. 1995). Local floras are valuable for historical information, documenting range extensions, providing baseline information on immigrant or extinct species, and providing data for regional floristic comparisons (Bowers 1981). Local floras in Arizona have been used to fill in gaps in species distribution, study geographic patterns of endemism, and identify floristic elements on a regional scale (McLaughlin 1986, 1995). Agency scientists use floras to document endangered or vulnerable species, plan and conduct restoration projects, and monitor commercial and recreational activities (Charlet 2000). Floristic information is relevant to applied fields such as horticulture, crop development, resource management, ecological consulting, mining, and environmental law (Wilken et al. 1988). Additionally, the potential value of a species-level botanical inventory may not be realized until well into the future.

Study Site

San Pedro Riparian National Conservation Area

In 1988 Congress designated the San Pedro Riparian National Conservation Area (SPRNCA) as a protected repository of the disappearing riparian habitat of the arid Southwest. The SPRNCA was the Nation's first riparian NCA and extends from the United States/Mexican border to the town of St. David, Arizona (figure 1). The SPRNCA is a narrow strip approximately 69 kilometers (43 miles) long and 4 kilometers (2.5 miles) wide encompassing 19,291 hectares (47,668 acres, 74 m^2), at an average elevation of 1,200 meters (~4,000 feet). Significant concerns over water quality and quantity, protection of cultural and paleontological resources, as well as conservation of natural resources are among the challenges for current and future land managers. Currently, there is a moratorium on historical land use activities such as livestock grazing, sand and gravel mining, and off-road vehicular traffic.

The SPRNCA is positioned in a crossroads of biological regions and is one of the most diverse areas in the United States. It is also one of the most important migratory corridors in the Western Hemisphere (The Nature Conservancy 2003). Millions of birds take advantage of the north-south orientation, surface water, and resource abundance. The southwestern willow flycatcher (*Empidonax trailli extimus*) and the Huachuca water umbel (*Lilaeopsis schaffneriana* var. *recurva*) are two endangered species found within the SPRNCA (United States Fish and Wildlife Service 2003).

The San Pedro is a low-gradient, alluvial desert river originating from the Sierra La Mariquita, Sierra San Jose, and

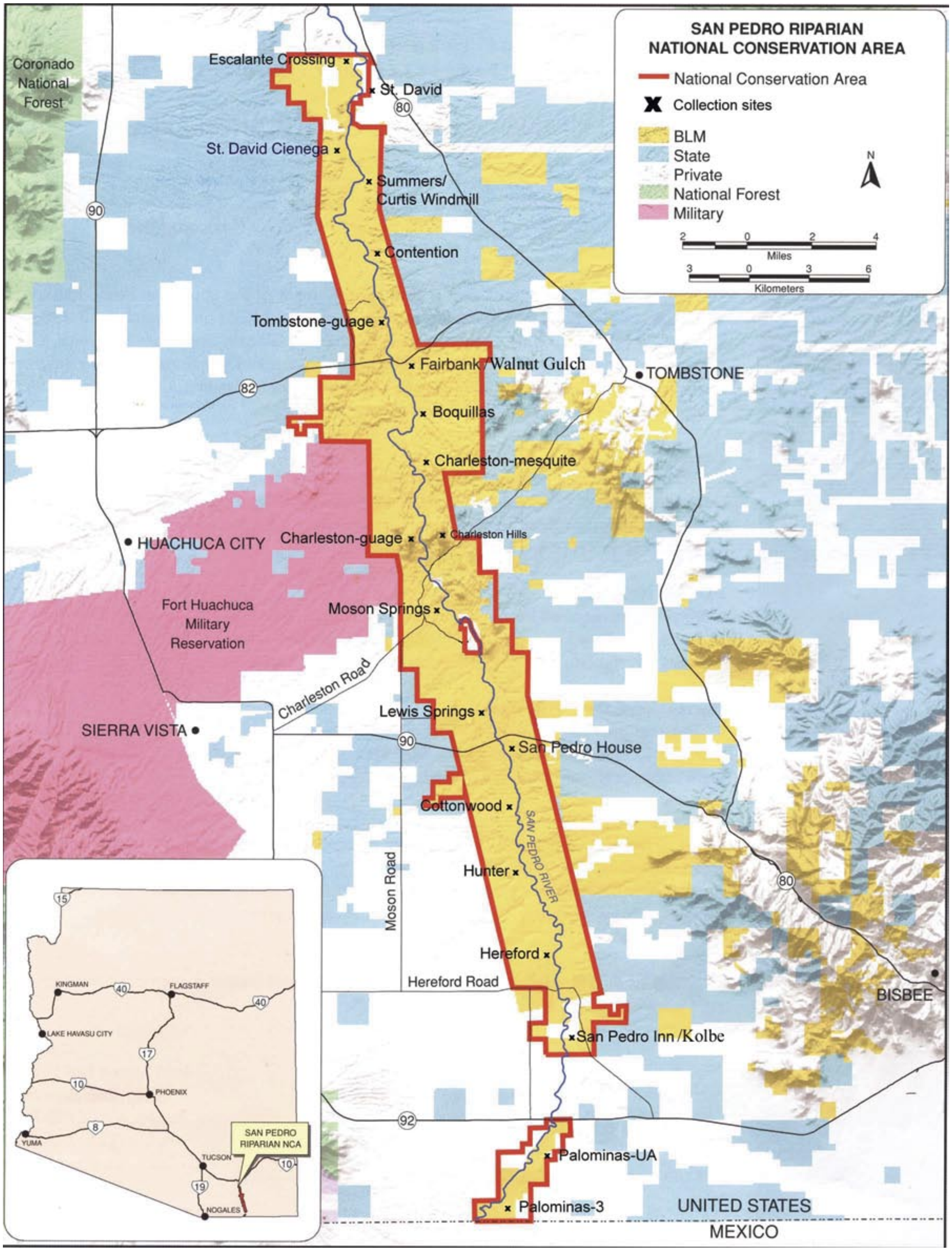

Figure 1—San Pedro Riparian National Conservation Area boundary, showing surrounding land ownership and commonly accessed collection sites. Map provided by Bureau of Land Management, used with permission (U.S. Government Printing Office: 2001-673-079/43005 Region No. 8).

Sierra Los Ajos in north-central Sonora, Mexico. It flows north approximately 240 kilometers (145 miles) to its confluence with the Gila River near the town of Winkelman, Arizona. The free-flowing hydrology of the San Pedro River is notable. Uncontrolled rivers are relatively rare in the region, making the San Pedro River an important reference for degraded riparian ecosystems throughout the Southwest.

A complex sub-surface geology creates a surface hydrology of perennial and intermittent reaches along the upper San Pedro River. Shallow bedrock helps to maintain perennial flows, i.e., reaches that have surface flow throughout the year. Intermittent reaches typically lack surface flow during periods of drought and the summer dry months. The upper San Pedro River also has a number of spring sources with localized perennial surface water.

An episode of arroyo cutting and channel trenching in the region probably began between 1890 and 1908 due to a combination of factors (Bryan 1925; Hastings 1959). Severe drought followed by a series of large floods, beaver extirpation, woodcutting for mining operations, overgrazing, and a sizeable earthquake transformed the San Pedro River from an almost imperceptible bed lined with bottomland marshes and grasses, to the current two-tiered floodplain where banks are often separated from the stream bed by several meters.

The St. David Cienega is an area of rare hydrology along the upper San Pedro River valley. Cienegas, the regional name for marshes, are wetlands where water permanently intersects the surface of the ground. Broadly speaking, the marshy character of the St. David Cienega is probably a function of the low relief and topographic gradient, specific geology, deep soils, and presence of springs.

The climate of the upper San Pedro valley is typical of the Chihuahuan Desertscrub region characterized by hot summer temperatures, moderately cold winter temperatures, and low levels of annual precipitation (Brown 1994). Average annual precipitation is 335 mm (13.2 inches). June and July are the hottest months with maximum average temperatures of 36 C (97 F). December lows average –2.3 C (18 °F). Intense, localized convective thunderstorms in late summer provide nearly two-thirds of the annual rainfall.

The upper San Pedro valley separates the Dragoon and Mule Mountains in the east from the Whetstone and Huachuca Mountains in the west. Elevation range along the River is a moderate 291 m (955 ft). The highest point in the SPRNCA is 1,411 m (4,628 ft) in the Charleston Hills (a subset of the Tombstone Hills), a localized set of rocky outcrops near the center of the study site.

Methods

The SPRNCA was explored on foot, and collections were made over the course of 3 years mainly during the spring, summer, and fall growing seasons of 2001, 2002, and 2003. Voucher specimens are deposited at the Arizona State University Herbarium (ASU). Herbarium searches at regional herbaria added six taxa that were not collected during the study: *Eragrostis barrelieri* (Mediterranean lovegrass), *Eragrostis intermedia* (plains lovegrass), *Euphorbia spathulata* (warty spurge), *Flaveria trinerva* (clustered yellowtops), *Phyla nodiflora* (common frogfruit), and *Samolus velarandi* ssp. *parviflorus* (water pimpernell). An additional ten collections from other researchers working within the SPRNCA are also vouchered and included in the flora: *Boerhavia spicata* (creeping spiderling), *Cynanchum ligulatum* (milkweed vine), *Cuscuta tuberculata* (tubercle dodder), *Echeandia flavescens* (Torrey's craglily), *Erigeron concinnus* (fleabane), *Fraxinus gooddingii* (Goodding's ash), *Melampodium leucanthum* (plains blackfoot), *Milla biflora* (Mexican star), *Pectis linifolia* (romero macho), and *Penstemon stenophyllus* (beardtongue).

A digital database was compiled with information on each plant's form, phenology, lifespan, wetland indicator score (USFWS 1996), native/exotic status (based on USDA PLANTS database), and habitat. Collection data such as latitude/longitude coordinates, plant description, associated species, and habitat were entered in the ASU collections database and made available on the World Wide Web at seinet.asu.edu collections/selection.jsp. Many photographs have been digitized and entered into the ASU images database and are displayed online with the checklist of the upper San Pedro River. The complete list of the flora can be viewed at http://lifesciences.asu.edu/herbarium/uppersanpedro/index.html, or click the link to "flora projects" from the ASU Vascular Plant Herbarium Web page.

Vegetation Types

In general, plant distributions can be explained in terms of variations in available moisture, as well as topographical gradient, geological substrate, disturbance, and elevation. The major vegetation types within the SPRNCA are Chihuahuan Desertscrub, mesquite terraces, cottonwood-willow riparian corridors, sacaton grasslands, rocky outcrops, and cienegas.

Chihuahuan Desertscrub

Chihuahuan Desertscrub vegetation covers the largest area within the SPRNCA, characterized by an abundance of long-lived, microphyllous shrubs such as *Larrea tridentata* (creosote), *Acacia constricta* (whitethorn acacia), *A. neovernicosa* (viscid acacia), and *Flourensia cernua* (tarbush). *Prosopis velutina* (mesquite), in its low, shrubby xerophytic form is also common in the desert uplands.

Mesquite Terraces

The distinct terrace vegetation on pre-entrenchment alluvium above the River channel is dominated by *Prosopis velutina* of various age classes. Mature mesquite forests with dense canopies are known as "bosques," the Spanish word for "forests." Examples of remnant mesquite bosques remain on river terraces throughout the SPRNCA.

Cottonwood-Willow Riparian Corridors

The riparian plant community is characterized by species and life forms strikingly different from that of the immediate non-riparian surroundings. The broadleaf deciduous trees of the riparian corridor represent the "signature" vegetation of the SPRNCA, maintained by relatively permanent water sources. *Populus fremontii* (Fremont cottonwood) are the giants of this gallery forest, creating a ribbon of green that stands out against the desert background in summer months.

Sacaton Grasslands

Sporobolus wrightii (sacaton) is the dominant herbaceous species within the SPRNCA. Sacaton grasslands cover large areas of lower alluvial terrace not previously cleared for agriculture. In summer months the flowering panicle can reach heights of greater than 2 m, creating sacaton "seas."

Rocky Outcrops

The San Pedro valley is abruptly broken by an isolated set of rocky outcrops known as the Charleston Hills. Roughly 10% of the SPRNCA species were restricted to the unique edaphics, geology, and topography of this area. In general, the shrubs *Aloysia wrightii* (oreganilla), *Acacia greggii*, *Mimosa aculeaticarpa* var. *biuncifera* (cat's claw mimosa), *Prosopis velutina*, *Acacia constricta*, and *A. neovernicosa* represent the dominant species. *Janusia gracilis* (slender Janusia), *Fouquieria splendens* (ocotillo), *Agave palmeri* (Palmer's agave), and *Ferocactus wislizeni* (barrel cactus) occur with greater frequency as one moves higher up the slopes.

Cienegas

The plant community of the St. David Cienega, located in the northern end of the SPRNCA, is primarily composed of aquatic and semi-aquatic graminoids and forbs such as *Schoenoplectus americanus* (chairmaker's bulrush), *Lythrum californicum* (California loosestrife), *Berula erecta* (cutleaf water parsnip), *Carex praegracilis* (clustered field sedge), *Eleocharis rostellata* (beaked spike rush), and *Juncus arcticus* var. *balticus*. Along the immediate perimeter, soils become less saturated and increasingly saline, and species such as *Anemopsis californica* (yerba mansa), *Muhlenbergia asperifolia* (alkali muhly), *Distichlis spicata* (salt grass), *Sporobolus airoides* (alkali sacaton), and *Almutaster pauciflorus* (alkali marsh aster) thrive.

Flora Composition

The flora of the San Pedro Riparian National Conservation Area includes 618 documented taxa from 608 species, 9 additional infraspecific taxa, and 1 interspecific hybrid. Ninety-two families are represented. Asteraceae (composites), Poaceae (grasses), and Fabaceae (legumes), are the largest, which combined, account for 42% of the flora. The best represented families and genera are shown in figure 2 and table 1, respectively. Figure 3 is a summary of lifespan and growth forms of the SPRNCA flora. Percentage of the total flora is noted in parentheses after growth form category. Annuals account for 38% of the flora (figure 4), and wetland plants comprise 15% of the flora (table 2).

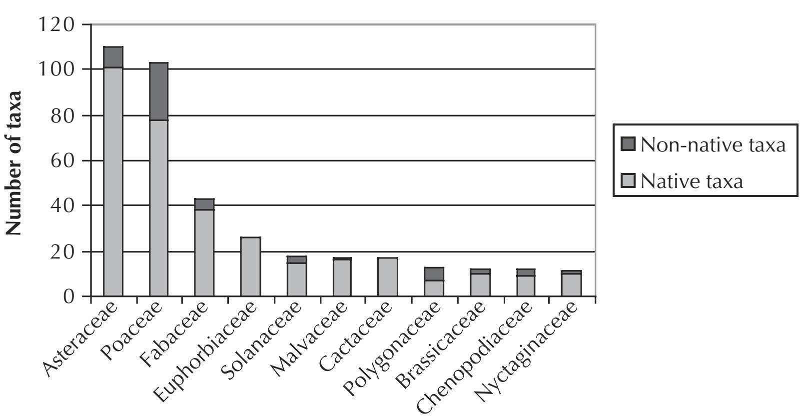

Figure 2—Best represented families in the San Pedro Riparian National Conservation Area.

Taxa of Interest

The SPRNCA flora is by nature capricious and unpredictable, since it represents influences from entire watersheds and beyond. The vagaries of this riparian ecosystem are exemplified by the occurrence of several novel taxa.

Range Extensions

The upper San Pedro River has been at best moderately collected, especially in the last 50 years, so it is not surprising to find plants new to the State flora. Three of the four State flora additions, *Carlowrightia texana* (Texas wrightwort), *Mancoa pubens* (Transpecos cress), and *Psilactis brevilingulata* (Transpecos tansyaster), represent moderate range extensions from their previously known distributions. *Carlowrightia texana* and *P. brevilingulata* are previously known from New Mexico, Texas, and the Mexican States of Chihuahua and Sonora. *Mancoa pubens* is previously known from three counties in southwest Texas and northwestern Chihuahua, Mexico, and the Arizona plants represent a disjunct of some 500 kilometers (Makings 2002). *Psilactis brevilingulata* was fairly common in the SPRNCA, collected in mesquite terrace, marsh, and cottonwood-riparian habitats, suggesting an established presence. *Mancoa pubens* and *Carlowrightia texana* are probably more recent arrivals, restricted to single locales and few individuals.

Tagetes minuta (wild marigold) is the fourth new State record, and was collected in the SPRNCA near the international border. Its annual habit, proximity to the San Pedro River, and "invasive" label suggest a likely recent introduction, probably within the last few years. Originally from Argentina, this plant is listed as a "noxious weed" on the USDA's Plants Database. Previous collections are from north-central California and several southeastern Atlantic states, making the San Pedro population highly disjunct.

New Species

A new shrubby species of *Eriogonum* (*Eriogonum terrenatum* Reveal sp. *nov., ined.*) was discovered within the boundaries of the SPRNCA, the type locality near the ruins of the old Spanish Presidio of Terrenate. The species is apparently restricted to late Tertiary lacustrine deposits, isolated in patches of limey tuffs in noticeably contrast with surrounding soil conditions. The occurrence of "*E. terrenatum"* and possibly other rare taxa can be explained in the context of the regional geology. The mid-Miocene Basin and Range Disturbance created a series of fault block mountains in central and southeastern Arizona (Damon et al. 1984; Smiley 1984). The resulting closed basins accumulated lacustrine (lake bed) deposits that were partially eroded during later Pleistocene glacial periods. These exposed limey tuffs and relatively

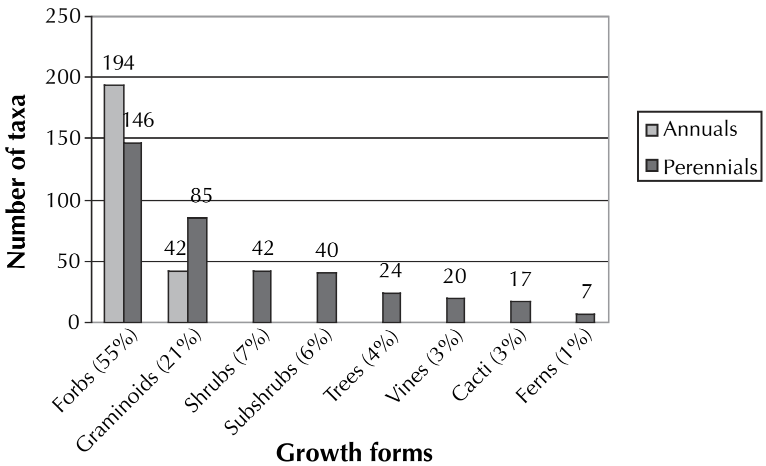

Figure 3—Lifespan and growth forms of San Pedro Riparian National Conservation Area flora.

Table 1—Best represented genera in the San Pedro Riparian National Conservation Area.

Genus	Number of taxa
Chamaesyce	13
Bouteloua	9
Eragrostis	9
Baccharis	7
Dalea	7
Panicum	7
Boerhavia	6
Cryptantha	6
Eriogonum	6
Ipomoea	6
Mentzelia	6
Muhlenbergia	6

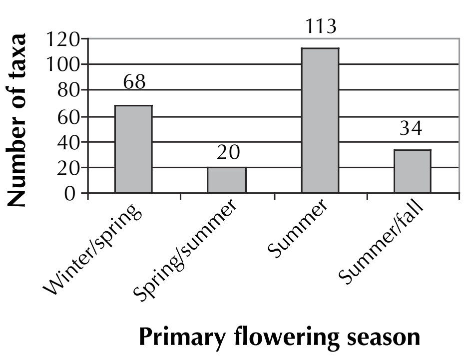

Figure 4—Number of taxa during different flowering seasons in the San Pedro Riparian National Conservation Area.

infertile azonal soils have been shown to host endemic and disjunct species (Anderson 1996). Coincidentally, another taxon of interest, *Hymenopappus filifolius* var. *pauciflorus* (yellow cutleaf), was found among "*E. terrenatum*," and fairly disjunct from known floristic areas, reinforcing the concept of the role of late Tertiary deposits as edaphic refugia. It is possible that further exploration of these deposits may reveal other interesting floristic patterns. Table 3 is a list of other rare and/or under-collected taxa within the SPRNCA.

Discussion

Diversity Influences

Aspects of spatio-temporal diversity at multiple scales interact in complex ways in the San Pedro Riparian National Conservation Area, resulting in a botanically rich ecosystem. Broadly speaking, the species richness of the study site is enhanced by a combination of the following factors, (1) influences from surrounding geographical provinces, (2) influences from regional watersheds, (3) spatial heterogeneity within the SPRNCA, and (4) hydrological processes.

At the broad regional scale, diversity is related to influences from surrounding geographic regions and floristic provinces (McLaughlin 1986, 1995). The San Pedro River is a part of the Colorado River basin, where many geographic elements converge, including clockwise from southeast, (1) Chihuahuan Desert, (2) Sonoran Desert, (3) Mohave Desert, (4) Great Basin Desert, (5) Rocky Mountains, and (6) Southern Great Plains.

The species richness of the SPRNCA can also be explained in the context of adjacent watersheds. The sky islands of southeastern Arizona are rich reservoirs of biological diversity (McAuliffe and Burgess 1995). The diversity of plant life is reflected in the ecological variability created by a complex regional geology, abrupt topography, and climatic gradients. Riparian valley floors such as the San Pedro, situated between such areas, echo the diversity of their surroundings, and may play a role in maintaining regional biodiversity (Naimen et al. 1993). Further, they may harbor displaced taxa not only from surrounding uplands, but remote environs as well. Additionally, the SPRNCA flora has a number of sky island endemics listed by McLaughlin (1995), including *Agave palmeri* (Palmer's century plant), *Brickellia floribunda* (Chihuahuan brickellbush), *Phacelia arizonica* (Arizona phacelia), and *Bouteloua eludens* (Santa Rita grama).

Within the SPRNCA, species diversity is also high due to habitat heterogeneity and hydrological processes. Patterns in species assemblages exist in the SPRNCA from a fine patch scale, to a larger landscape one, and environmental gradients influence vegetation associations (sacaton grasslands, cienegas, rocky outcrops, etc.) at the intermediate scale. Within the SPRNCA, longitudinal environmental gradients are minimal due to the lack of significant elevation range, but lateral environmental gradients are abundant and produce a diversity of vegetation associations. Spatial complexity is positively correlated with species diversity in the SPRNCA, as multiple habitat types offer niche opportunities for variety in vegetation associations, and therefore, increased numbers of species (Ward and Tockner 2001).

Table 2—Best represented wetland plant families of the San Pedro Riparian National Conservation Area[a].

Family	Genera	Native taxa	Non-native taxa	Total taxa
Poaceae	12	11	5	16
Asteraceae	12	14	1	15
Cyperaceae	4	10	0	10
Polygonaceae	2	1	5	6
Salicaceae	2	5	0	5
Scrophulariaceae	3	4	0	4
Apiaceae	3	3	0	3
Onagraceae	2	3	0	3
Juncaceae	1	2	0	2
Lemnaceae	1	2	0	2
Lythraceae	2	2	0	2
Ranunculaceae	2	2	0	2
Typhaceae	1	2	0	2

[a] Defined as having ≥ 66% chance of being found in wetlands.

Table 3—Rare and/or under-collected species in the San Pedro Riparian National Conservation Area*.

Species	Localities of Arizona collections held at ASU
Achnatherum eminens	Southern Huachuca Mts., Cochise Co., Parfitt and Christy 5088 in 1991.
Astragalus vaccarum	None.
Ammannia coccinea	Lake Pleasant, Maricopa Co., Lehto 4300 in 1964. Hooker Cienega, Cochise Co., Thornber s.n. in 1905.
Bouchea prismatica	Sycamore Canyon, Santa Cruz Co., Fishbein 2,879 in 1996. Keil, Pinkava, Lehto 9911 in 1967.
Carlowrightia linearifolia	Near Portal, Cochise Co., Cazier 236 in 1966.
Carlowrightia texana	None. New State record.
Cissus trifoliata	Santa Teresa Mts., Graham Co.: Beugge 1129, 1133 in 1999.
Cryptantha pusilla	Southern Huachuca Mts., Cochise Co., Parfitt 4903 in 1991. Pinal Mts., Gila Co., Keil 4672 in 1969.
Cynanchum ligulatum	None
Cyperus spectabilis	Southern Huachuca Mts., Cochise Co., Parfitt 4435 in 1990.
Digitaria insularis	Sierrita Mts., Pima Co., John and Charlotte Reeder 7975 in 1986.
"Eriogonum terrenatum"	SE of Vail, AZ, Pima Co., Anderson 84-71 in 1984. New species of *Eriogonum*.
Eryngium sparganophyllum	Near Tanque Verde Wash, Pima Co., Titus s.n. in 2001. Agua Caliente, Pima Co., Thornber 2812 in 1908.
Gleditsia triacanthos	Yavapai Co: Pase 2146 in 1976; Baker 10856, in 1993; Forister s.n., in 1969.
Halimolobos diffusa	Lean Peak, Mohave County, Butterwick/Parfitt 5448 in 1979; Santa Catalina Mts., Pima Co., Bertelsen s.n. in 1988.
Hermannia pauciflora	Santa Catalina Mts., Pima Co., Keil 4303 (no date).
Lilaeopsis schaffneriana ssp. *recurva*	Federally listed endangered plant (several ASU collections).
Mancoa pubens	None. New State record.
Psilactis brevilingulata	None. New State record.
Mirabilis jalapa	No wild or non-cultivated collections.
Pyrrhopappus pauciflorus	O'Donnel Cienega, Santa Cruz, Co., Lehto 24526 in 1980.
*Salvia tiliifolia**	None.
Sphinctospermum constrictum	None.
*Tagetes minuta**	None. New state record.
Tridens albescens	Near Santa Cruz River at Casa Grande, Pinal Co., J.R. & C.G. Reeder 4598 in 1997. College Farm, Mesa, Maricopa Co., Judd s.n. in1939. Recently recorded in Arizona.

* Indicates non-native

Finally, measures of species diversity in the SPRNCA are explained in the context of the fluvial processes of the San Pedro River. The two most important factors as they relate to the San Pedro hydrology are perennial surface water and flood dynamics (Decocq 2002; Hupp and Osterkamp 1996). Within the riparian zone, water is not a limiting resource along major portions of the upper San Pedro River. Perennial surface water and low depth-to-groundwater conditions amid a desert environment have resulted in an ecosystem with rare aquatic and wetland habitat types. With more than 15% of the flora as wetland species, the presence of perennial water is likely one of the most important factors influencing species diversity.

The presence of relatively natural fluvial dynamics on the San Pedro River results in an active floodplain with high structural diversity. While upper topographic levels offer a relatively steady habitat, flooding in the riparian zone results in a dynamic environment characterized by instability. Flood patterns of variable magnitude, frequency, and duration drive active successional processes. Disturbance from flooding results in high seral diversity due to shifting microtopography and patchy resources (Lyon and Sagers 1998). Because different successional stages contain distinct species associations, species richness also increases with successional diversity (Ward and Tockner 2001; Pollock et al. 1998).

Considerations for the future

The discovery of outliers, disjuncts, and rare taxa along the San Pedro River underscores the importance of floristic studies in the region. Botanically rich areas such as the San Pedro River deserve conservation status, not only for protection of endangered species like the diminutive Huachuca water umbel, but for their botanical potential. This inherently dynamic ecosystem will continue to harbor novel taxa, and welcome immigrant species as long as steps are taken to maintain its functional integrity. Given the enormous complexity of ecosystem processes at multiple scales within the SPRNCA, clear advice about priorities for conservation is difficult. One effective strategy is to identify the dominant ecological processes that structure the ecosystem and focus efforts there (Folke et al. 1996). On the San Pedro River, perennial surface water is the key component sustaining biodiversity. A simplified strategy regulating the demands on the regional aquifer must be implemented if this fragile and rare ecosystem is to survive. Addressing the social, cultural, and economic driving forces causing groundwater loss in the region presents significant challenges for land managers. Ultimately, the preservation of the San Pedro River ecosystem will only be accomplished through an interplay of stakeholder planning and regulation, public participation, and input from the scientific community.

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Variation in Populations of Yarrow's Spiny Lizard, *Sceloporus jarrovii*, in the Northern Madrean Archipelago Region

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Abstract*—Population genetic analysis of Yarrow's spiny lizard,* Sceloporus jarrovii, *suggests a metapopulational distribution pattern with potential divergence of genetically based traits. Comparing male pushup displays revealed populations east and west of the San Pedro River valley to be more similar among themselves than to those on the other side. Intensive studies of a single population revealed high site fidelity and movement constrained by the availability of crevices suitable for over-wintering and habitat with suitable thermal and humidity ranges. Observations suggest a species that does not disperse over large distances, and that current distribution patterns arose during extended Pleistocene pluvial periods.*

Introduction

Because understanding population structure is a major concern for ecologists, the use of electrophoretic and molecular techniques to traditional approaches has been of great benefit. However, they have been viewed skeptically rather than as supportive (Avise 1994). Patterns of dispersal, mating systems, migrations and genetic drift due to isolation influence population gene flow and genetic integrity. If barriers reduce dispersal and isolate populations, divergence among populations may occur. Suites of characteristics can be compared to identify selection pressures (whether environmental change or due to drift and stochastic forces) and the strength of genetic change. Fragmented populations can provide natural experiments of evolution in parallel, and comparison among isolated populations can provide important information concerning historical dispersal events (Foster and Endler 1999). In a series of studies over the past 30 years, we collected data on population structure and dispersal in a geographically fragmented montane lizard. Together, these data provide a more complete understanding of factors influencing current populations and historical movement patterns.

Whether some classes of traits evolve faster than other categories has been controversial in evolutionary studies, but the issue has intensified with new molecular techniques (Flores-Villela et al. 2000). Behavioral traits might be considered more conservative, that is, more resistant to change in gene frequency, than either molecular or morphological traits because behaviors, particularly reproductive behaviors, should be subject to strong stabilizing selection where species identification, fitness cues, and mate choice are important. If unusual or novel displays are selected against, stabilizing selection may constrain variation. Conversely, sexual selection may force rapid change if specific display patterns are favored (Masta and Maddison 2002). Thus, among-population variation in reproductive display patterns is biologically interesting (Foster and Cameron 1996).

Because lizards use pushup displays in territorial displays and courtship (Carpenter and Ferguson 1977), they play an important communication role and should be subject to strong selection pressures. Whether the selection is stabilizing or directional has not been well investigated. Carpenter (1978) analyzed displays in many iguanid lizards for a phylogenetic analysis and treated each species as independent units, ignoring population and individual level variation. His analysis revealed enormous variation, even among related species, and phylogenetic relationships were not clearly delineated. More recently, Martins' (1993) reanalysis of these data revealed low predictability of display pattern to either body size or habitat. Although geographic variation in pushup displays in *Uta* and *Sceloporus* was examined by Ferguson (1971, 1973), such an approach has been poorly appreciated as an evolutionary tool for understanding population structure. Comparisons of electrophoretic and behavioral variation would be useful in testing hypotheses about congruent changes in characters.

The montane lizard *Sceloporus jarrovii* occurs in a disjunct geographic distribution in the island mountains of southern Arizona and New Mexico (Chrapliwy 1964). Most of its biology is known from work in the Chiricahuas (Ballinger 1973; 1979 Duncan et al. 2003; Middendorf 1984; Middendorf and Simon 1988; Simon 1975; Simon and Middendorf 1976, 1980), the Pinaleños (Ruby 1977, 1978, 1981, 1986; Ruby and Baird 1993, 1994), and the Quinlan Mountains (Goldberg 1971). However, genetic, morphological, and behavioral variation, which might result from the current fragmented geographic distribution, has not been fully examined.

The goal of this study is to discuss electrophoretic variation among populations, to characterize behavioral displays in ten mountain ranges within Arizona and New Mexico, with emphasis on five major mountains, and to document patterns of dispersal of individual lizards. Together, the results may infer constraints on history of these populations, suggest selective factors affecting displays, and allow testing of hypotheses about display evolution by treating each population as a phylogenetic unit (Foster and Cameron 1996).

Methods

Genetics

The genetic differences within and among populations of *S. jarrovii* in the southeastern Arizona region were investigated by examining the electrophoretic profiles of soluble esterase isozymes. Tissue samples were obtained from the tail muscle of 313 individuals sampled from 37 locations in southeastern Arizona. Lizards were collected at study sites in the Chiricahua, Huachuca, Pinaleño, and Santa Rita Mountains. In the Chiricahua Mountains, lizards were obtained from at total of 17 collection sites; four locations in Pinery Canyon (30 females, 24 males), five in Turkey Creek (33 females, 29 males), three in Cave Creek Canyon (20 females, 34 males), one in Tex Canyon (7 females, 0 males), and four in Rucker Canyon (25 females, 30 males). In the Huachuca Mountains, lizards were sampled from multiple locations in Ramsey Canyon (15 females, 6 males) and from a single study site in Carr Canyon (3 females, 0 males). In the Pinaleño Mountains, lizards were sampled from four locations on Mount Graham (30 females, 8 males). In the Santa Rita Mountains, lizards were obtained from study sites in Madera Canyon (12 females, 7 males). Protein samples were obtained from each tail by removing the skin and vertebrae, and homogenizing the muscle with a glass tissue grinder in an equal volume of 2% 2-phenoxyethanol (Spohn and Guttman 1976). Homogenates were centrifuged at 4 ^{o}C, and 40 µl aliquots of supernatant were subjected to electrophoretic analysis.

Electrophoresis was conducted using an acrylamide vertical slab system, maintained at 4 ^{o}C. Samples were run on 6% gels containing a 0.375 M Tris-HCl buffer at pH 8.9 at 300 V for 3 hr. The electrode buffer was 0.3 M sodium borate at pH 8.0. The gels were incubated in solutions containing alpha-naphthyl acetate, beta-naphthyl acetate, or alpha-naphthyl propionate.

Esterases were classified by their relative susceptibility to various sulfhydryl and organphosphorus inhibitors (Tashian 1965; Holmes and Whitt 1970; Frankel 1982). These included eserine sulfate (ES), diisopropylfluorophosphate (DFP), parahydroxymercuribenzoate (PHMB), and parachloromercuribenzoate (PCBM). Esterases inhibited by ES and DFP are classified as cholinesterase, those by DFP alone as carboxylesterase, and those by PHMB and/or PCBM as arylesterase. Isozymes resistant to all inhibitors are designated as esterase resistant (ER), and those resistant to inhibition but preferentially hydrolyzing acetate substrate as acetylesterase.

Display Analyses

Animals were extensively filmed at sites in five mountain ranges in southeastern Arizona: the Chiricahuas (Cave Creek Canyon), Pinaleños (Wet Canyon), Dragoons, Huachucas (Miller Canyon), and Santa Ritas (Madera Canyon). In each range, displays of eight to ten resident males were filmed by staging aggressive encounters with a tethered intruder male of similar size. Fewer displays were filmed in five other ranges: the Dos Cabezas, Galiuro, Animas, Peloncillo, and Mule Mountains. Filming was done during summers of 1973-1974 and 1995-1997. Movies were taken with a Bolex H16 movie camera with 80 mm zoom lens or a Sony videocam with zoom lens. Films were analyzed frame by frame on a Vanguard motion analyzer (24 f/s) or measured on a video monitor screen (30 f/s).

For the five major ranges, the timing of specific units of the display and the relative height of display units (H1, H2, etc., depending on their position in the display sequence) were measured, ratios were calculated, and average values were computed for each mountain range. Relative heights of displays were used because of variation in the field condition, such as the size of lizards, the distance between animal and camera, and the amount of zoom. The unit 1 in each display set served as an arbitrary standard of relative height. Differences between mountain ranges were examined through a comparison of typical patterns. Because homologies among display elements remain presumptive at this time, statistical analyses were not conducted. Variation between individuals within a population may occur but is not reported here.

Dispersal

Patterns of movement by individual lizards were examined through mark-recapture studies of *Sceloporus jarrovii* in Crystal Creek Canyon in the Chiricahua Mountains. During six study periods from March 2001 through July 2003, 460 lizards were noosed along a 0.5 km transect. Animals were captured during a 1-2 week period in March when in their winter hibernacula locations and during a 3-4 week period in July on their summer territories. For each capture, we recorded location in the canyon, size (snout-vent and tail length), weight, and sex. All animals were individually identified by toe-clipping and paint-marked. Data were analyzed to determine distances moved by individuals on seasonal (between hibernacular and territorial sites) and annual (between hibernacular sites and between territorial sites) bases.

Results

Genetics

Electrophoretic differences exist both within and between populations of *S. jarrovii*. A total of three soluble esterase phenotypes were exhibited by *S. jarrovii* from the 37 collection sites. Electropherograms of all lizards expressed a highly anodal zone of esterolytic activity (isozyme a), probably

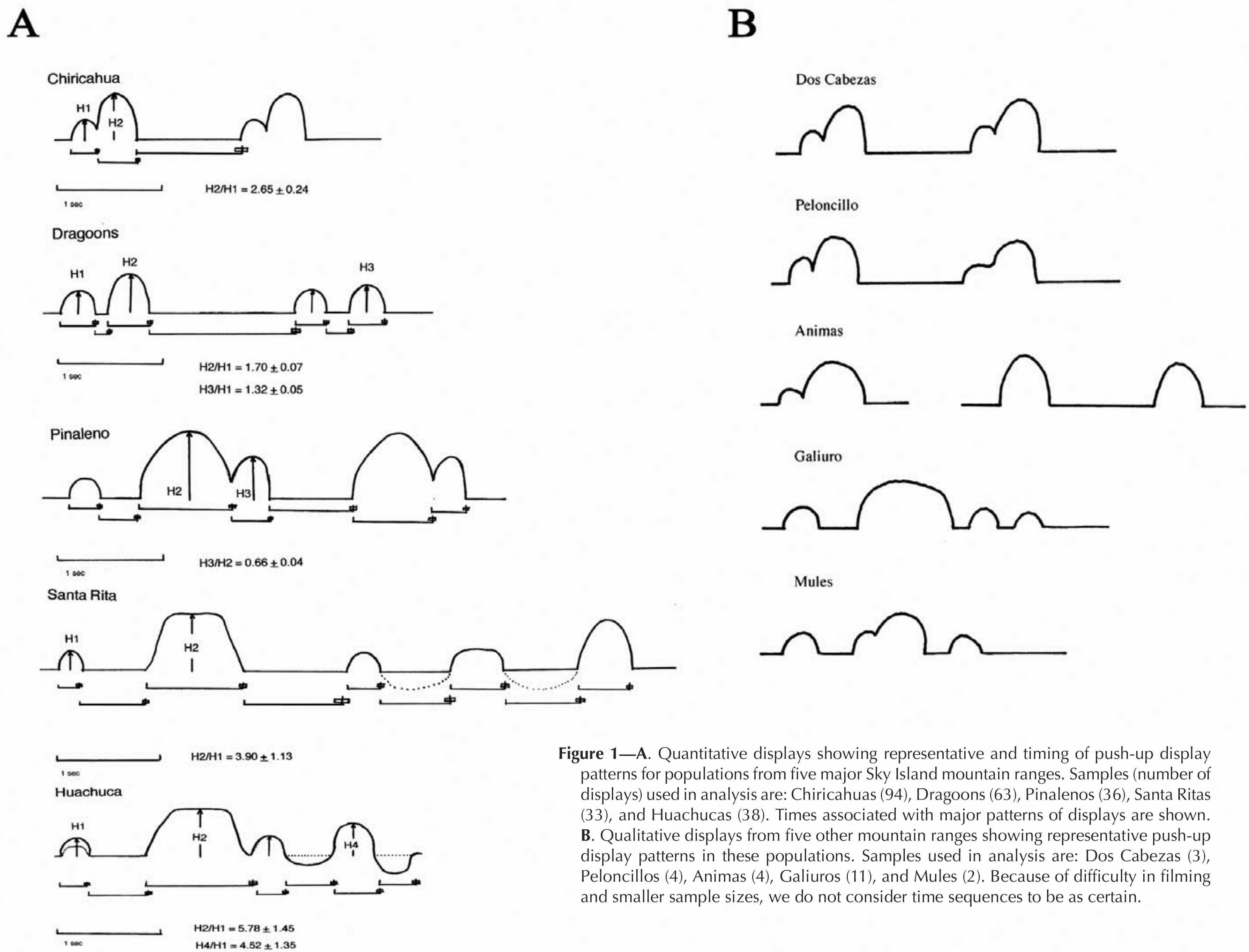

Figure 1—A. Quantitative displays showing representative and timing of push-up display patterns for populations from five major Sky Island mountain ranges. Samples (number of displays) used in analysis are: Chiricahuas (94), Dragoons (63), Pinalenos (36), Santa Ritas (33), and Huachucas (38). Times associated with major patterns of displays are shown. **B**. Qualitative displays from five other mountain ranges showing representative push-up display patterns in these populations. Samples used in analysis are: Dos Cabezas (3), Peloncillos (4), Animas (4), Galiuros (11), and Mules (2). Because of difficulty in filming and smaller sample sizes, we do not consider time sequences to be as certain.

resulting from the expression of a monomorphic locus designated as *Est-1*. A second zone of activity (isozymes b, c, and d) for each phenotype probably results from the expression of a polymorphic locus (*Est-2*). Lizards sampled from each of the Chiricahua and Huachuca locations exhibited one of two phenotypes, each showing the single zone of EST-1 activity and two zones of EST-2 activity, i.e., isozymes abc or abd, although the genetic basis for these phenotypes is unclear. Further, lizards sampled from sites in the Pinaleños and Santa Ritas exhibited only a single zone of EST-2 activity, along with the monomorphic expression of the *Est-1* locus (i.e., isozymes ab).

Each of the four esterase isozymes was capable of esterolytic activity with all substrates. The EST-1 isozyme (a), by virtue of its sensitivity to PHMB and PCBM, was classified as an arylesterase. Isozymes b, c, and d were found to be sensitive to inhibition by DFP and were classified as carboxylesterases. Since no breeding data are available, the genetic basis for the esterase phenotypes is inferred from their electrophoretic and inhibitor profiles. Indeed, our studies support the presence and expression of two esterase loci: *Est-1* encoding an arylesterase (isozyme a) and *Est-2* carboxylesterases b, c, and d.

Display Analyses

Each of five major populations studied (and most others) has distinct pushup patterns noticeable even to human observers and presumably also to lizards (figure 1). Moreover, we recognize a division into eastern and western patterns, where populations are separated by the San Pedro River drainage, which runs north/south through this part of Arizona and joins the Gila River north of Phoenix. The three major populations in the east (Chiricahuas, Pinaleños, and Dragoons) had relatively simple displays of repetitions of two peak units that differ between populations in both comparative height and timing (table 1; figure 1). Three other populations in the east (Dos Cabezas, Peloncillo, and Animas Mountains) have similar displays to the Chiricahuas, probably resulting from their proximity to one another. The Dos Cabezas connects to the Chiricahuas via a series of low hills, while the Animas and Peloncillos are geographically close to the Chiricahuas. Further analysis of these mountains may reveal more subtle population level differences. The western populations (Huachucas and Santa Ritas) displayed longer and more varied sequences, including a dip downward below the starting height. Eastern populations were more similar among themselves than any were to the western populations and vice versa.

Table 1—Ratios of display elements in five major populations of *Sceloporus jarrovii* in Arizona.

Mountain range	No. animals	Display elements	Ratio (X ± SD)
Chiricahuas	11	H2/H1	2.65 ± 0.24
Pinaleno	13	H3/H2	0.66 ± 0.04
Dragoons	8	H2/H1	1.70 ± 0.07
Dragoons	8	H3/H1	1.32 ± 0.05
Santa Ritas	9	H2/H1	3.90 ± 1.13
Huachucas	10	H2/H1	5.78 ± 1.45
Huachucas	10	H4/H1	4.52 ± 1.35

Dispersal

Total distance moved by individual lizards ranged from 0 to 138 m (x = 13.7 ± 22.7 m; n = 98) between first and last capture (range = 107 to 851 days). When adjusted for time, daily movement ranged between 0 and 0.4 m/day (x = 0.05 ± 0.09 m/day; n = 98). Daily movement by males (range = 0-0.43; x = 0.06 ± 0.09 m/day; n = 44) did not differ greatly from females (range = 0-0.38; x = 0.05 ± 0.08 m/day; n = 54). Most lizards did not move all that far between first and last capture sites; 72 of 98 (73%) moved <10 m. However, while a few of these were recaptured close to their original point of capture, they moved considerable distances either seasonally or annually. For instance, one male moved 167 m up canyon between March 2002 and 2003, and by July 2003, 177 m down canyon—returning to within 10 m of the point of original capture.

Seasonal movement (March-July or July-March) ranged from 0 to 177 m (x = 17.0 ± 32.8 m; n = 43). Seasonal movement by males (range = 0-177; x = 24.0 ± 38.6 m; n = 19) exceeded that of females (range = 0-128; x = 11.5 ± 27.0 m; n = 24). Annual movement between hibernacula (March-March) differed from that between territories (July-July). Average hibernacula movement ranged from 0 to 167 m (x = 20.6 ± 38.9 m; n = 28), while average territorial movement ranged between 0 and 150 m (x = 12.4 ± 21.8 m; n = 55). Note that the vast majority of individuals moved quite limited distances (table 2), and that the dispersal between hibernacula or from one territory to another are not significantly different (p > 0.05).

Discussion

We found geographic variation in molecular and behavioral traits among montane populations of *S. jarrovii* that can be related to isolation of populations since the Pleistocene and to the annual movement pattern of this territorial species. Animals sampled from the Pinaleños and Santa Ritas exhibited no variation at either the *Est-1* or *Est-2* loci; these individuals are monomorphic at these loci and exhibit the ab phenotype exclusively. Their esterase profile is clearly distinguishable from

Table 2—Numbers of individuals shown by category range for annual movement between winter hibernacula (n = 28) and between summer territories (n = 55).

Range category (m)	Hibernacula	Territory
0-25	20	47
26-50	5	7
51-75	1	0
76-100	0	0
101-125	0	0
126-150	1	0
151-175	1	1
176-200	0	0

those animals sampled from collecting sites in the Chiricahua and Huachuca Mountains (see also Frankel and Middendorf 1991), and is suggestive of a major barrier to gene flow between populations inhabiting these distinct locales, perhaps in conjunction with historical dispersal events, but this isozyme pattern does not follow the expected split between east and west of the San Pedro River drainage.

Display patterns for different populations follow two general forms. Patterns in the eastern populations show a higher, tighter combination of two initial units (H1 and H2), while the western populations exhibit longer, slower displays, along with dips in the latter portions of the display that heighten following peak(s). Display differences among individual ranges in both the eastern and western groups are distinguishable. While determination of homologies between displays as varied as the ten populations under study is complicated by the east-west differences, the results support the electrophoretic conclusions presented above and elsewhere (Middendorf and Frankel 1992), as well as suggesting that populations have been isolated for a significant evolutionary time (between 8,000-10,000 years) with significant divergence (Van Devender 1995). The similarity in pushup patterns within eastern and within western populations suggests clustering as a result of a major separation event with subsequent fragmentation into individual mountain populations as seen today (figure 1).

The regional differences between populations may represent founder effects or genetic drift after the complete fragmentation occurred. Habitats where *S. jarrovii* is found are similar for all sites. Both thermal and humidity requirements for habitat are indicated because the species is typically associated with rocky outcrops in the oak-juniper community or higher elevations. Because it is restricted to elevations above 1,400 m, acceptable dispersal corridors across the desert seas between mountain islands probably require much more mesic conditions. Currently these Sky Island mountains are separated by inhospitable terrain (Gehlbach 1981). The east-west divide in *S. jarrovii* populations is marked by the San Pedros River drainage, a particularly low elevation zone that may have barred east-west dispersal in the past, even while more localized dispersal occurred between ranges. Regional topography suggests suitable connecting habitat between eastern and western populations would be much further south in Mexico. Our data suggest a pattern comparable to that of jumping spiders in the Arizona Sky Islands, which includes an inverse relationship between display similarity and geographic distance (Maddison and McMahon 2000; Masta and Maddison 2002). Conceptually similar barriers to dispersal have been proposed for tropical species (Janzen 1967) and for *Cnemidophorus tigris* hybridization in lowland, desert habitat (Dessauer et al. 2000).

Movement between hibernacula and territories, site fidelity to both, and over-wintering aggregations occur in *S. jarrovii* (Burns 1970; Ruby 1977) and are known for other reptiles, e.g., lizards (Boykin and Zucker 1993; Weintraub 1968) and snakes (Aleksuik 1976; Parker and Brown 1980). Distribution and dispersal of *S. jarrovii* appears constrained as individuals did not generally move long distances and observed movements were often back and forth, rather than to more distant locations. Given that reproduction takes place in September and October (Ruby 1981), effective gene flow is likely to be restricted by the distance an individual moves from hibernacula to territory and the spatial distribution of each. When spacing exceeds territorial dispersal distance, gene flow between these isolated populations is reduced to only those few, over-dispersing individuals.

Further research into geographic variation of behavior, morphology, and molecular characters is currently underway. Comparison of the behavioral divergences with molecular (mitochondrial or nuclear DNA) and morphological traits will provide insight into gene flow and population structure within a population as well as, we believe, demonstrate the "phylogeography" (*sensu* Foster and Cameron 1996) of this now disjunctly distributed species.

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Lowland Riparian Herpetofaunas: The San Pedro River in Southeastern Arizona

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***Abstract**—Previous work has shown that southeastern Arizona has a characteristic, high diversity lowland riparian herpetofauna with 62-68 or more species along major stream corridors, and 46-54 species in shorter reaches within single biomes, based on intensive fieldwork and museum record surveys. The San Pedro River supports this characteristic herpetofauna, at least some of which still occurs in the lower basin within the Sonoran Desert. It has about 64 species (55 vouchered to date), with 48-53 species within each of three somewhat ecologically homogeneous portions of the basin. This assemblage is more similar to other lowland herpetofaunas than to an example of a canyon riparian herpetofauna. Most of the characteristic riparian species are not known to be abundant along the San Pedro, and some expected species are apparently absent, suggesting that the herpetofauna may have not yet recovered from the history of grassland, cienega, and bottomland degradation.*

Introduction

Remarkably, the riparian herpetofauna of southeastern Arizona has not been accurately described between Ruthven's (1907) and Van Denburgh and Slevin's (1913) annotations and records for the Santa Cruz River riparian at Tucson and the present. Two reports with limited circulation provided data on riparian herpetofaunal assemblages in southeastern Arizona (Johnson and Lowe 1978, in the northern Santa Rita Mountains; and Corman 1988, for the upper San Pedro River). Jakle and Gatz (1985), Jones (1981, 1988a,b, and others), Szaro and Belfit (1986), Vitt and Ohmart (1978), and Warren and Schwalbe (1985) provided data on riparian herpetofaunal assemblages in western and central Arizona and the Colorado River, yet Szaro and Belfit (op. cit.) noted the absence of a clear description of this distinctive assemblage. Lowe (1989) initiated a synthetic analysis of the riparian herpetofauna of the warm deserts of North America, and Rosen et al. (this proceedings) summarized the herpetofaunas of 4 sites in southeastern Arizona. The San Pedro River is the largest, reasonably intact example of the original riparian richness of southern Arizona. Here I present an account of its herpetofauna and compare it to that of other riparian sites in Arizona.

Methods

I constructed a checklist and a preliminary estimate of species' relative abundances based on a survey of museum specimen records and Troy Corman's (1988) outstanding unpublished study of the upper basin. I included museum records for the river environs, including up to two miles from the riparian bottomlands, since it is impossible to be certain whether such records are or are not definitely from the bottomland, and since species occurring that close would likely be found in the bottomlands at least occasionally. Collecting effort has been most focused in the upper basin, and it is difficult to entirely separate riparian and non-riparian records, so I have summarized the latter for the upper basin; in the lower reaches, so little collecting has been done away from the river that this was not possible. Museum records were excluded if localities could not be located to an adequate precision, but I did not examine most of the specimens to verify identifications; questionable records are discussed below. To compare the San Pedro to other riparian systems in southeastern Arizona, I computed its coefficient of similarity (according to the formula $\% \ Similarity = 100 \ X \ 2C/(N_1 + N_2)$, where C is the number of species in common between the sites, and N_i is the number of species at each site) for comparison to results presented by Rosen et al. (this proceedings).

Description of the River System

For this report, I treat the river in three sections: (1) the upper basin, from the international border (4,269 ft elevation) to the origin of the St. David Ditch south of Curtiss Flats (3,704 ft); (2) the Benson region, from Curtiss Flats to Pomerine and down to The Narrows (3,305 ft); and (3) the lower basin, from the Narrows to the Gila River confluence at Winkelman (1,907 ft). I treated the broad flats around Benson separately because they include the broadest floodplain, most intensive human utilization, and a limited history of herpetofaunal survey, and did not include the uppermost basin, in Mexico, because I lacked data for it.

The upper basin includes the Bureau of Land Management's San Pedro River National Conservation Area, with perennial flow in much of its length, large pools, and a mature cottonwood-dominated gallery forest fringed with mesquite bosque and sacaton. The surrounding uplands grade from semi-desert grassland down to Chihuahuan desertscrub dominated by creosotebush. Pump irrigation occurred in the upper reach of the upper basin, near Hereford and Palominas, although some of this activity is being retired to conserve water for the river. Rocky hills are close to the river near Charleston and Fairbank.

The Benson region has floodplain widths of up to two miles or more, in contrast to 3/4 mile or less for most of the upper and lower basins. Flow is diverted and pumping is extensive as the river enters the Benson region at Curtiss Flats, and water moves through an often densely populated pastoral landscape where it supplies numerous fields and ponds. There are substantial groves of cottonwood and mesquite in this area, as well as well-watered pastures, and at least one relict cienega. The river, however, is not perennial in this reach, and the riparian environment is dominated in places by non-native saltcedar (*Tamarix ramosissima*). Chihuahuan desertscrub growing on highly eroded benches surrounds this reach.

The lower basin begins in The Narrows, where the steep bajadas of the Rincon and Galiuro Mountains encroach with rocky habitat near the river. Downstream of this non-perennial reach, the river alternates between several short perennial reaches with a small stream in a relatively large sandy bed. The stream is often surrounded by mixes of cottonwood, willow, saltcedar, and mesquite, whereas in the dry reaches the broad strand is margined by a more arid riparian vegetation with much mesquite and saltcedar. Where the floodplain allowed it, farms and irrigated pastures were established using pump irrigation, but these are being purchased and retired by The Nature Conservancy, which now has extensive holdings along in the lower basin.

The lower basin is fringed by steep bajadas that increasingly support Sonoran desertscrub with declining elevations, and these bajadas are dissected by major canyons that support important perennial streams, some of which approach or reach the river bottom. In contrast, in the upper basin and Benson region, the bottomlands are distant from the few surrounding, small perennial waters, which are almost completely confined to mountain canyons.

There are one or two cienegas on the bottomlands in the lower basin, which are thought to be relicts of a more mesic habitat type (cienega and sacaton grasslands interspersed with stands of bosque and gallery forest) that occupied much of the riparian lowlands of southeastern Arizona prior to their degradation about a century ago (see McLaughlin 2004; Hendrickson and Minckley 1985, and references therein). Prior to this, significant portions of the river were marshy and grassy, and the San Pedro Valley supported much more grassland and less desertscrub than it does today (Turner et al. 2003).

Results

Species Richness

The occurrence of 55 species of amphibians and reptiles is verified by vouchers along the 126-mile reach of San Pedro River in the United States, including 4 non-natives. The expected total list is about 64 species, including 5 non-natives (table 1). Expected totals for other lowland riparian systems in southeastern Arizona are 62 for Cienega Creek, and over 68 for the Santa Cruz River (unpublished data). By way of contrast, Organ Pipe Cactus National Monument supports about 48 species (Rosen and Lowe 1996), the Whetstone Mountains support about 40 (Turner et al. 1999), the Colorado River below Lake Mead supported about 46 (Vitt and Ohmart 1978; Stebbins 2003), and the lower Gila River below Phoenix supported about 45 (Rosen, in press). Riparian areas in southeastern Arizona support relatively high species richness reflecting the proximity of woodlands and grasslands (see Jones et al. 1985), as well as the apparently optimal conditions for many species that occur at elevations between 2,400 and around 4,500 feet.

Three relatively homogenous segments of the San Pedro River yielded 34-44 vouchered species, with expected totals of 48-53 species (table 1), compared to 37-42 vouchered species and expected totals of 46-54 species at comparable areas in southeastern Arizona (Rosen et al., this proceedings). Thus, there is remarkably consistent, relatively high species richness in these environments, with the San Pedro River approaching the regional maximum for a riverine system, which probably occurs along the Santa Cruz River.

Species Composition

The San Pedro species list was less similar to that of Leslie Canyon (63.8% similarity) than to those of San Bernardino NWR, Las Cienegas NCA, and Tucson-San Xavier (78.7%, 75.3%, and 78.8%, respectively), confirming the marked similarity among lowland riparian sites in southeastern Arizona (Rosen et al., this proceedings).

The San Pedro supported all the characteristic lowland riparian species identified in four other herpetofaunas in southeastern Arizona (Rosen et al., this proceedings), except that the Great Plains narrow-mouthed toad was present only on the Santa Cruz River. Species diversity is elevated by the appearance and increasing dominance of characteristic Sonoran Desert species in the lowermost basin, including the side-blotched lizard, zebra-tailed lizard, tiger whiptail, banded sand snake, saddled leaf-nosed snake, and many others. Elevational range of the system thus likely plays an important role in its species diversity (table 2).

It is remarkable, however, that despite relatively limited collecting effort in the lower basin, there is already a vouchered set of core riparian-obligate species, including the desert grassland box turtle, Clark's spiny lizard, eastern fence lizard, and southwestern black-headed snake along the riparian corridor deep in Sonoran Desert of the lower basin, with at least some reaching the area of the Gila River confluence.

Species richness is also elevated to some extent by the presence of rocky habitat near the river at Charleston, Fairbank, and The Narrows. These areas are sources of records for the eastern collared lizard, and Sonoran whipsnake, and are sites where the red-spotted toad, canyon treefrog, black-necked gartersnake, and other rock-dwelling species could be found along the river.

Discussion

While some of the characteristic riparian species, such as the desert grassland (western) box turtle, were apparently fairly abundant in recent decades (Corman 1988), many of

Table 1—Herpetofauna of the San Pedro River and its riparian environs in the United States. Numbers in the table are museum voucher specimens found in a nationwide search. Records interpreted as within ≤2 miles of the riparian bottomland are included. The Benson reach is defined as from Curtiss Flats to Pomerine, while the upper reach is from the international border to there and the lower reach from there to the Gila River confluence. TEC and PCR refer to additional records by Troy Corman (1988 and personal communication) and P. C. Rosen (unpublished notes); E indicates a species that is expected to occur, with (r) indicating rock-dwelling species that have been or are likely to be found very locally along the river where appropriate habitat abuts the riparian zone. Species less likely, but possible, are indicated with a question mark (?). Non-native species are denoted by (NN), and dangerously venomous ones by (*). The specimen of *Gyalopion canum* from the lower basin was lost (Mayne 1985 and personal communication). The table also provides a listing for the upper San Pedro Valley outside the river environs, as explained in text.

		River Reach				
English name	**Scientific name**	**Lower**	**Benson**	**Upper**	**Entire U.S. reach**	**Upper valley**
Amphibians (12 species)						
Tiger Salamander - NN	*Ambystoma tigrinum*		E		**E**	E
Sonoran Desert Toad	*Bufo alvarius*	4	1	TEC	**5**	3
Great Plains Toad	*Bufo cognatus*	E	1	1	**2**	2
Green Toad	*Bufo debilis*		14	?	**14**	1
Red-spotted Toad	*Bufo punctatus*	TEC	?	C?	**TEC**	3
Woodhouse's Toad	*Bufo woodhousii*	1	2	67	**70**	7
Canyon Treefrog	*Hyla arenicolor*	2(r)	?(r)	?(r)	**2(r)**	
American Bullfrog - NN	*Rana catesbeiana*	6	PCR	1	**7**	E
Chiricahua Leopard Frog [1]	*Rana chiricahuensis*			1(ex)	**1(ex)**	E
Lowland Leopard Frog	*Rana yavapaiensis*	7	1	13	**21**	E
Couch's Spadefoot	*Scaphiopus couchii*	TEC	E	10	**10**	8
Mexican Spadefoot	*Spea multiplicata*	?	E	PCR	**PCR**	32
Turtles (5 species)						
Spiny Softshell - NN	*Apalone spinifera*	1	?	TEC	**1**	
Desert Tortoise	*Gopherus agassizii*	?(r)			**?(r)**	
Sonoran Mud Turtle	*Kinosternon sonoriense*	1	2	14	**17**	
Western Box Turtle	*Terrapene ornata*	1	PCR	15	**16**	PCR
Slider - NN	*Trachemys scripta*	1	E	TEC	**1**	
Lizards (21 species)						
Giant Spotted Whiptail	*Aspidoscelis burti stictogramma*	?	?	TEC	**TEC**	
Little Striped Whiptail [2]	*Aspidoscelis inornata*			1(?)		
Sonoran Spotted Whiptail	*Aspidoscelis sonorae*	4	E	TEC	**4**	E
Tiger Whiptail	*Aspidoscelis tigris*	8	3	6	**17**	2
Desert Grassland Whiptail	*Aspidoscelis uniparens*	PCR	2	32	**34**	17
Zebra-tailed Lizard	*Callisaurus draconoides*	3	4	2	**9**	1
Western Banded Gecko	*Coleonyx variegatus*	1	E	1	**2**	E
Greater Earless Lizard	*Cophosaurus texanus*	7	E	2	**9**	E
Eastern Collared Lizard	*Crotaphytus collaris*	1(r)	?(r)	1(r)	**2(r)**	E
Madrean Alligator Lizard	*Elgaria kingii*	1	E	2	**3**	1
Long-nosed Leopard Lizard	*Gambelia wislizenii*	1	E	1	**2**	E
Mediterranean Gecko - NN	*Hemidactylus turcicus*	E	E		**E**	E
Lesser Earless Lizard	*Holbrookia maculata*	1	E	5	**6**	49
Texas Horned Lizard	*Phrynosoma cornutum*		2	4	**6**	9
Short-horned Lizard	*Phrynosoma hernandesi*			1	**1**	1
Regal Horned Lizard	*Phrynosoma solare*	PCR	4	3	**7**	PCR
Clark's Spiny Lizard	*Sceloporus clarkii*	5	4	10	**19**	4
Desert Spiny Lizard	*Sceloporus magister*	8	1	3	**12**	2
Eastern Fence Lizard	*Sceloporus undulatus*	21	2	8	**31**	4
Tree Lizard	*Urosaurus ornatus*	29	1	21	**51**	12
Side-blotched Lizard [2]	*Uta stansburiana*	12	?	1(?)	**12**	
Gila Monster *	*Heloderma suspectum*	1	1	1	**3**	5
Snakes (25 species)						
Glossy Snake	*Arizona elegans*	3	1	1	**5**	E
Banded Sand Snake	*Chilomeniscus cinctus*	2			**2**	
Ring-necked Snake	*Diadophis punctatus*	E	1	1	**2**	E
Chihuahuan Hook-nosed Snake	*Gyalopion canum*	(1)	1	2	**3**	E

Table 1—*Continued.*

English name	Scientific name	River Reach: Lower	Benson	Upper	Entire U.S. reach	Upper valley
Snakes—*continued*						
Western Hog-nosed Snake	*Heterodon nasicus*		?	1	**1**	4
Night Snake	*Hypsiglena torquata*	1	2	1	**4**	3
Common Kingsnake	*Lampropeltis getula*	1	2	3	**6**	8
Plains Blindsnake	*Leptotyphlops dulcis*		2	TEC	**2**	1
Western Blindsnake	*Leptotyphlops humilis*	E	1		**1**	?
Sonoran Whipsnake	*Masticophis bilineatus*	?	?	1	**1**	2
Coachwhip	*Masticophis flagellum*	5	4	1	**10**	10
Saddled Leaf-nosed Snake	*Phyllorhynchus browni*	3			**3**	
Gopher Snake	*Pituophis catenifer*	3	2	4	**9**	11
Long-nosevd Snake	*Rhinocheilus lecontei*	3	7	2	**12**	13
Mountain Patch-nosed Snake [3]	*Salvadora grahamiae*			?	**?**	E
Western Patch-nosed Snake	*Salvadora hexalepis*	2	3	4	**9**	5
Ground Snake [3]	*Sonora semiannulata*			?	**?**	2
Southwestern Black-headed Snake	*Tantilla hobartsmithi*	8	4	1	**13**	E
Plains Black-headed Snake	*Tantilla nigriceps*	?	2	1	**3**	E
Yaqui Black-headed Snake [3]	*Tantilla yaquia*			?	**?**	?
Black-necked Gartersnake	*Thamnophis cyrtopsis*	?(r)	?(r)	?(r)	**E(r)**	1
Mexican Gartersnake	*Thamnophis eques*	?	(ex?)	6	**6**	E
Checkered Gartersnake	*Thamnophis marcianus*	6	5	22	**33**	5
Lyre Snake	*Trimorphodon biscutatus*	1	1	2	**4**	E
Sonoran Coralsnake *	*Micruroides euryxanthus*	5	2	2	**9**	2
Massasauga * [1]	*Sistrurus catenatus*			(ex)	**(ex)**	1
Western Diamondback *	*Crotalus atrox*	2	1	9	**12**	6
Mohave Rattlesnake *	*Crotalus scutulatus*	2	3	1	**6**	14
Tiger Rattlesnake *	*Crotalus tigris*	TEC			**TEC**	
Total Museum Records Found		174	89	292	**555**	251
Vouchered Total		40	34	44	**55**	35
Expected Species Total		50	48	53	**64**	57
Non-native species		4	4	3	**5**	3

[1] Apparently extirpated in the U.S. reach, but might still occur upstream in Mexico.
[2] The following species are excluded from the known and expected herpetofauna based on probable locality errors (Sidewinder [*Crotalus cerastes*]; Side-blotched Lizard from the upper basin; taxonomic confusion (Chihuahuan Spotted Whiptail [*Aspidoscelis exsanguis*]; and use of base camp or transshipment point as the given locality (Rock Rattlesnake [*Crotalus lepidus*], Twin-spotted Rattlesnake [*Crotalus pricei*], Mountain Skink [*Eumeces callicephalus*], Sonoran Mountain Kingsnake [*Lampropeltis pyromelana*], and Mountain Spiny Lizard [*Sceloporus jarrovi*]; similarly, the Little Striped Whiptail is provisionally excluded, as specified in the Discussion and in Rosen et al. 1998).
[3] Not confirmed in the river herpetofauna, but may occur in upper basin in Mexico, which has not been extensively surveyed.

Table 2—Elevational ranges, reach lengths, and maximum expected herpetofaunal diversity (species richness) for a series of major lowland corridors in southern Arizona. Similar accounting methods were used to include or exclude species for each case, as described in the text and in Rosen et al. (this proceedings).

	Elevation (ft)			Reach length	Number
	Min	Max	Range	(mi)	of species
San Pedro River (U.S. only)	1907	4269	2362	126	64
Santa Cruz River (Bog Hole to Tucson Mountains)	2060	5040	2980	132	68
Cienega Creek (Santa Cruz Co. line to Vail Diversion)	3192	4554	1362	32	62
Gila River (Salt R. to Colorado confluence)	115	931	816	300	45
Colorado River (Hoover Dam to Int'l border)	91	665	574	183	46

them were uncommon or rare; this may reflect the historic degradation of mesic riparian communities such as cienegas and grassy meadows. The cessation of grazing during the 1980s is having profound effects on vegetation and avifaunal recovery (Krueper et al. 2003), but this has not been investigated for the herpetofauna. To the extent that mesic grassland and cienega re-develop, marked changes in the herpetofauna may be expected, and these could be documented by comparison with Corman's (1988) solid baseline data.

Corman (1988, and personal communication, 2004) made the only recorded observations to date of the giant spotted whiptail on the San Pedro, and its presence, if verified, suggests it should be more widespread elsewhere than it is currently known to be (Rosen et al. 2002). The San Pedro River in the region where Corman found this lizard (on stony slopes adjoining the river near Charleston and the Babocomari at its confluence with the river [T. Corman, personal communication]) was originally dominated by grass rather than thornscrub and woodland (Turner et al. 2003), and therefore the species' absence from much of the Santa Cruz River is more likely due to its disappearance following habitat degradation rather than natural absence associated with grassland environments.

Grassland species of long tenure may have disappeared from the San Pedro in the immediate aftermath of the grazing-induced catastrophe of the late 1800's. Wright and Lowe (1965) suggested this for the little striped whiptail. Although I have argued that the original locality label may have been in error (Rosen et al. 1998), this species may still be declining in parts of New Mexico that suffered similar grazing impacts (C. W. Painter, personal communication, 2002), and the issue remains unresolved.

The mapped occurrence of the Massasauga on the upper San Pedro (Lowe et al. 1986), though based on un-vouchered observations, suggests that this grassland species also was present, but has dwindled and probably been extirpated from the valley. This rattlesnake has certainly become progressively less widespread in southeastern Arizona based on its recorded occurrences on the orders of 100, 50, and 10 years ago (A. T. Holycross, unpublished). Suitable habitat probably existed near the river in the upper basin, and may have continued to exist into the mid-late 20th century near Palominas and Hereford, where the species could conceivably be relocated.

Other species may have disappeared without a trace when the grassland was razed. A likely example is the bunchgrass lizard (*Sceloporus slevini*). Smith et al. (1998) demonstrated that this often-montane species is sensitive to drought and grazing at low elevations. Its occurrence in the Sonoita Grasslands suggests it should also be at the San Pedro River. At Empire Cienega, lowland populations have continued to thrive in sacaton, which is only lightly impacted by grazing, but the population is centered on an intact cienega and cienega stream where sacaton and mesquite contact it closely. This habitat situation may have been too rare to sustain this lizard in the larger, more heavily scoured San Pedro River through the period of maximal grassland destruction and bottomland erosion, although it seems likely that suitable habitat is currently present.

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Herpetofauna of Lowland Bottomlands of Southeastern Arizona: A Comparison of Sites

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Abstract—*We intensively sampled the riparian herpetofauna at three sites in southeastern Arizona, a canyon site, Leslie Canyon, and two lowland sites, San Bernardino NWR and Empire-Ciénega Creek at Las Ciénegas National Conservation Area. We also compiled a list of herpetofaunal records for the original lowland riparian area at Tucson using museum records. The herpetofaunas of the three lowland sites are more similar to one another than they were to the Leslie Canyon assemblage, and, collectively, the lowland riparian system may support the richest herpetofauna in the Southwest, at least when* α*-diversity is considered. A number of species not generally considered to be riparian species are well represented and in some cases locally restricted to the riparian environment. Although this environment supports (or supported) a high proportion of the most threatened vertebrate taxa in the region, conservation plans have not correspondingly focused on it, and its degradation continues in many areas.*

Introduction

Although riparian areas in the Southwest are widely recognized to be much diminished, it is less widely appreciated that lowland riparian areas, on the floors of major valleys, are the primary sites of impact. For example, of 32 Priority Vulnerable Species of vertebrates identified to guide conservation reserve design in Pima County's Sonoran Desert Conservation Plan (http://www.co.pima.az.us/cmo/sdcp/reports.html), 22 tend to be associated with riparian areas in eastern Pima County, Arizona, 20 of the 22 occur (or occurred) in lowland riparian systems, and about a dozen of these are or were almost exclusively in lowland systems. The lowland riparian zones were probably the richest ecosystems in the Southwest, as attested to by reports of early ornithologists (Swarth 1905; Willard 1912; Brandt 1951), who arrived at San Xavier del Bac, south of Tucson, before the lowlands had reached their present stage of degradation.

Early ichthyologists (see Minckley 1999) and herpetologists (Ruthven 1907; Van Denburgh and Slevin 1913) also visited the Santa Cruz riparian bottom near present downtown Tucson and reported a lowland herpetofauna that would be unfamiliar to many present-day observers. Lowe (1986, 1989) commented on the dire threats to the riparian herpetofauna of the Southwest, but provided few details about its status or original composition. The purpose of this paper is to revive the now antique knowledge of this lowland herpetofauna, provide examples where it is extant today, and contrast it with a representative mountain canyon herpetofauna. In so doing, we offer relatively complete checklists for 4 separate riparian herpetofaunas in southeastern Arizona.

Methods

We used a combination of sampling types to assemble data on the presence and relative abundance of amphibians and reptiles at three intensive study sites, and we compared the results to historical data for a fourth site. The three intensive study sites were San Bernardino National Wildlife Refuge (NWR), Leslie Canyon NWR, and Las Ciénegas National Conservation Area (NCA) in the Empire-Cienega Valley. We compared these to the originally rich streamside and riparian herpetofauna of the Santa Cruz River at San Xavier del Bac and Tucson. Environmental comparisons are given in table 1.

Study Locality Descriptions

San Bernardino NWR, first created as a native fish refugium, protects a mesic bottomland 1.0–3.4 km across and separated by low rocky and stony scarps (10–24 m) on both sides from surrounding semi-desert uplands dominated by tobosa grass, mesquite, and whitethorn acacia. This bottomland system continues into the Mexican portion of land grant; its entire length is on the order of 6 km. The bottomlands (see Hendrickson and Minckley 1985 and Lanning 1981) have a long and colorful history of use and modification, followed by the creation of the refuge in 1982. Original conditions included broad, rich sacaton grassland bottoms punctuated by springs issuing into

Table 1—Summary of southeastern Arizona lowland riparian study site characteristics. Estimated areas are based on width of riparian bottomlands plus width of adjoining strip included in samples. Categories are explained in text under "Methods."

	Leslie Canyon NWR	San Bernardino NWR	Las Ciénegas NCA	Tucson and San Xavier
Reach length (km)	14.2	3.8	26.2	26.9
Approximate area studied (km^2)	23	15	126	129
Elevational midpoint (m)	1,466	1,161	1,280	758
Elevational range (m)	183	58	244	102
Site type	Canyon	Valley	Valley	Valley
R (Riparian-associated at site)	12	13	15	18
RO (Riparian obligate at site)	4	8	11	11
Species in moderate to high abundance	24	25	30	38
Species seen rarely or entering peripherally	10	13	7	4
Species total	38	38	37	42
Potential species total	50	48	56	51
Potential species total (native)	48	46	54	49

marshy ciénegas, and scattered stands of willow, cottonwood, and mesquite. The broad, level bottomland plain was the source of San Bernardino Creek. Current conditions include a deeply incised creek (now called "Black Draw"), greatly reduced sacaton, recovering agricultural fields, and extensive mesquite bosques punctuated by artesian-fed ponds and ciénegas. Exotic fishes (Hendrickson et al. 1980) were replaced by natives following the creation of the refuge, except in Black Draw, where some exotics persist. Black Draw now supports a cottonwood-willow gallery forest, mesquite, Johnson grass, an ephemeral steam, and a mature ciénega-stream with deep pools.

Leslie Canyon NWR protects a short perennial stream that rises from a sacaton bottomland basin at the base of the Pedrogosa Mountains and cuts through mixed Chihuahuan desertscrub, grassland, and thornscrub in a rocky canyon in the Swisshelm Mountains. Narrow bottomland flats support sacaton, mesquite, and other grasses and thorny shrubs, while the riparian zone supports a dense, shady forest dominated by Arizona ash. The canyon bottom ranges from <0.05 km to 0.2 km across, while the sacaton basin above it is over 0.5 km across. The site was modified in the 1930s by creation of a low dam separating the sacaton basin from the canyon-bound creek. Semi-perennial, fishless pools exist above the dam, while the pools and stream below it support native longfin dace (*Agosia chrysogaster*) and a Yaqui chub (*Gila purpurea*) population that was translocated from Black Draw (Astin Spring) in 1969 (Minckley 1973). The refuge was established in 1988, and has expanded to include additional areas in the Swisshelm Mountains, but in this report we confine our consideration to the canyon proper, as described above.

Las Ciénegas NCA protects the most intact lowland ciénega-stream in Arizona. Ciénega Creek is a marshy, boggy, stream with dense herbaceous vegetation, deep pools, and a gallery forest dominated by willow and cottonwood. Its surrounding bottomland supports extensive sacaton flats, with some natural ponds and pools, mesquite shrubland, and mature bosque. Although the ciénega-stream bottom is generally less than 50 m wide, the bottomlands are 0.4–1 km across, except at the lowermost part of the study area, at the Narrows. Uplands consist of sandy-gravelly semi-desert grassland heavily occupied by mesquite and burrow weed (*Isocoma tenuisecta*). The Empire-Cienega ranches were not established until the 1880s. In the mid 1990s cattle were excluded from most of the riparian areas. Downstream of the mostly perennial reach on the study area is a 14 km dry reach followed by 10 km of mostly perennial stream and ciénega-stream.

The area from San Xavier Mission, the ancient site of the Tohono O'odham village of "Bac" (W:ak—"where the water rises") to current downtown Tucson was a rich mix of mesquite forest, riparian gallery forest, desert stream, acequia-based agriculture, xeroriparian and upland desertscrub, ciénega, and sacaton (Betancourt 1990; Logan 2002; Turner 2003) surrounded by desertscrub flats dominated by creosotebush. This formerly fabulous area (Brandt 1951, and references therein) adjoins rocky desert in a few areas, and was visited by early naturalists, including Ruthven (1907) and Van Denburgh and Slevin (1913). For purposes of this report, the study area includes the Santa Cruz River floodplain from the south boundary of the San Xavier District of Tohono O'odham to a north line in historic Tucson at St. Mary's Road. Although the area is currently heavily degraded, this report is based upon historic information.

Sampling and Museum Survey

For San Bernardino NWR, field data for this study are from 1985–1999, while for Leslie Canyon NWR, data from that period were supplemented by intensive study in 2000–2003. At Las Ciénegas NCA, limited data from 1985–2001 were supplemented by intensive aquatic trapping and terrestrial sampling during 2002–2004. In each area we focused on aquatic species using intensive search and a variety of trapping methods (see Schwalbe and Rosen 1988; Rosen and Schwalbe 1995), and made general efforts to capture and mark a variety of riparian and terrestrial species. At Leslie Canyon NWR and San Bernardino NWR, we also used pitfall traps (3 square 25 trap grids with 5 gal buckets covered loosely with plywood lids) to sample upland habitats during 1997–1999, and at Leslie we used terrestrial drift fences with funnel traps in 2000–2003. At all sites, road observations within the site were also used, cover was turned to search for animals, and immediately adjacent areas were included as indicated in table 1.

A database of 36,925 locality records from Pima, Santa Cruz, and Cochise Counties, Arizona, was assembled from museums throughout the United States. Each record was classified into a set of geographic sub-regions, and the sub-regions included around the 4 study areas were further classified to isolate records that applied only to the riparian bottomlands and immediately adjoining uplands. Records were excluded if they could not be reasonably determined to fall within the defined study areas, except that desert rock slopes adjoining the Tucson-San Xavier bottomlands were excluded. Records labeled "Tucson" were not included except if they were specified in Ruthven (1907) or Van Denburgh and Slevin (1913). After a first round of classification, these data were re-studied to eliminate ambiguous or misclassified records.

The entire museum database was studied to estimate the sub-region-specific geographic (and inferred habitat) ranges for species, and this was combined with field experience near study areas to define the macrohabitat niche of the species within the sub-region that includes each study area. Species were classified as "RO" (locally riparian obligate) if they only were found and collected within or adjacent to the riparian bottomlands; "R" (riparian associated) if they were found primarily in the riparian bottomlands, but also occurred with some regularity away from it; "C" (common) if they were abundant but not numerically associated with riparian bottomlands; and "p" (present) if they occurred as an occasional record at lower than expected frequency for the taxon.

The final species list for each area was the combined field and museum records available for each species. For the San Xavier-Tucson site, only museum records were included, as recent field data under highly degraded conditions differ markedly from the original conditions found in the literature and museum records. We computed a coefficient of similarity among sites according to the formula $\% \ Similarity = 100 \ X \ 2C/(N_1 + N_2)$, where C is the number of species in common between the sites, and N_i is the number of species at each site.

Results

The number of species confirmed per site was relatively consistent at 37–42, with 24–38 species being recorded in numbers, as more than a lone specimen or occasional observation. At each site, 12–18 species tended to be numerically associated with the bottomland environments, with 4–12 being riparian bottomland obligates in the sub-region for each site (table 1). Riparian obligate species were more prominent in lowlands than in the mountain canyon site. Leslie Canyon NWR had the most divergent herpetofauna, while San Bernardino NWR and Las Ciénegas NCA were most similar (table 2); the San Xavier-Tucson fauna was similar to other lowland sites, despite being within the Sonoran Desert and supporting 9 desert species not found elsewhere.

Discussion

The lowland riparian herpetofauna of southeastern Arizona has a distinctive core of associated species including ranid frogs, *Kinosternon sonoriense*, *Sceloporus clarkii*, *S. undulatus*, *Crotalus atrox*, *Lampropeltis getula*, *Tantilla hobartsmithi*, *Thamnophis eques*, *T. marcianus*, and either *Masticophis flagellum* or *M. bilineatus* (or both). These systems may also include a number of species that are not typically thought of as riparian, and are not otherwise expected under lowland desert conditions, such as *Aspidoscelis burti stictogramma*, *Bufo woodhousii*, *Diadophis punctatus*, *Elgaria kingii*, and *Terrapene ornata*. *Gastrophryne olivacea* is also represented in one of our lowland riparian systems, and elsewhere it joins other unique species such as *Kinosternon arizonense*, *Pternohyla fodiens*, and *Bufo retiformis* in lowland bottoms originally grown to tobosa grass within the Arizona Upland. It is of interest that lowland sites show such affinity despite the transition from Chihuahuan Desert and Semi-desert Grassland environs at San Bernardino NWR and Las Ciénegas NCA to Sonoran Desert environs at Tucson-San Xavier.

Certain species habitats as presently understood may reflect a lack of knowledge about early conditions. Although the pygmy owl has lately been known in isolated bajada localities, it was originally (late 1800s) a lowland riparian-centered species (Johnson et al. 2003). The Santa Cruz pupfish, *Cyprinodon arcuatus*, was taken at Tucson, but may have already been gone by 1904 (Minckley 1999), perhaps disappearing with the early degradation of ciénega habitat. Analogously, although *Elgaria kingii* was not recorded in the Tucson riparian, we found it in 2002 in the only intact ciénega remnant on the basin floor (Rosen, personal observation). Although Ruthven (1907) characterized the Tucson lowland riparian herpetofauna with *A. b. stictogramma*, *A. sonorae*, and *S. clarkii*, these are now nearly forgotten as lowland species; Van Denburgh and Slevin (1913) found *S. undulatus* abundant at Tucson, where we found one, perhaps the last, in 1995 (Rosen, personal observation). Van Devender et al. (1994) report a locality for the tropical brown vine snake (*Oxybelis aeneus*) as "south

Table 2—Similarity coefficients based on species presence at the four study areas.

	LCNWR	SBNWR	Las Ciénegas NCA	San Xavier-Tucson
	-----	percent	-----	-----
LCNWR	100	68	64	44
SBNWR		100	85	72
Las Ciénegas NCA			100	73
San Xavier-Tucson				100

outskirts of Tucson," which at the time (1880s) could best be interpreted as the floodplain of the Santa Cruz River. Similarly, *B. retiformis* is reported from a large artificial tank adjoining the floodplain of the Santa Cruz River (Sullivan et al. 1996), and could originally have occurred under natural conditions at floodplain wetlands. The herpetofauna of the lowlands may have been richer than we can adequately document, although it retains high α-diversity.

The richness of the lowland riparian biota presents a paradox for current conservation efforts. While conservation efforts are ongoing, they are focused most effectively on land purchases in upland desertscrub and semi-desert grassland. Lowland bottomlands are still being degraded by urbanization. There are few solid plans to incorporate natural biodiversity into the urban riparian corridors, although this would seem at least possible. In this paper, we have tried to illustrate the importance that could be attached to the lowland riparian biota, and the richness it has to offer.

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Appendix A—Herpetofaunal records for SBNWR, LCNWR, Las Ciénegas NCA (field data only), and historic Tucson - San Xavier (museum data only). Introduced, non-native species are indicated with (I).

	SBNWR				LCNWR							
Species	Pitfall traps	Other field methods	Museum records	Total	Pitfall traps	Other 1985-1999	Drift fences	Museum records	Total	Las Ciénegas total	Tucson - San Xavier total	Grand total
Ambystoma tigrinum (I)					4	10	3		17			17
Arizona elegans											6	6
Aspidoscelis burti										61	28	912
Aspidoscelis sonorae					43	23	190	3	259	61	7	77
Aspidoscelis tigris											46	46
Aspidoscelis uniparens	144	407	13	564			5	4	9	733		733
Bufo alvarius		21	2	23						2	28	53
Bufo cognatus			3	3			54		54		50	107
Bufo debilis			5	5			20		20			25
Bufo punctatus			1	1						1	2	4
Bufo woodhousii			1	1							3	4
Callisaurus draconoides											42	42
Chilomeniscus cinctus											7	7
Coleonyx variegatus										1	43	44
Cophosaurus texanus			1	1						13		14
Crotalus atrox		71	2	73		11	2		13	15	9	110
Crotalus molossus						13	6	1	20			20
Crotalus scutulatus		1	1	2		1			1	4	5	12
Crotaphytus collaris	1	2	2	5						4		9
Diadophis punctatus		3		3		2	10	1	13	2	2	20
Elgaria kingii		14		14	3	2	86	1	92	8		114
Eumeces obsoletus					5		29		34			34
Gambelia wislizenii			1	1							6	7
Gastrophryne olivacea											1	1
Heloderma suspectum		6		6		1	1		2	2	7	17
Heterodon nasicus						2		1	3	1		4
Holbrookia maculata	55	56	15	126			1	3	4	62	4	196
Hypsiglena torquata	2	6		8		1	1		2	3	3	16
Kinosternon sonoriense		488	5	493		1			1	373	32	899
Lampropeltis getula		44	2	46						1	16	63
Leptotyphlops dulcis							2		2			2
Leptotyphlops humilis											5	5
Masticophis bilineatus		1		1		13	61		74	7		82
Masticophis flagellum		90		90		0	1		1	2	10	103
Micruroides euryxanthus		1		1		1			1			2
Phrynosoma cornutum		1	4	5								5
Phrynosoma hernandesi							1		1			1
Phrynosoma solare		3	2	5						8	19	32

	SBNWR				LCNWR							
Species	**Pitfall traps**	**Other field methods**	**Museum records**	**Total**	**Pitfall traps**	**Other 1985-1999**	**Drift fences**	**Museum records**	**Total**	**Las Ciénegas total**	**Tucson - San Xavier total**	**Grand total**
Phyllorhynchus browni											23	23
Phyllorhynchus decurtatus											16	16
Pituophis catenifer		49	1	50		3	7		10	8	8	76
Rana blairi								1	1			1
Rana catesbeiana (I)	1	9,085	32	9,118						347	2	9,467
Rana chiricahuensis			6	6		538	2	3	543	162		711
Rana yavapaiensis		50		50						5	99	154
Rhinocheilus lecontei		12	2	14						1	7	22
Salvadora hexalepis		19	1	20		1	2	1	4	2	4	30
Scaphiopus couchii		7	9	16	1	1	51		53	9	41	119
Sceloporus clarkii		36	10	46	11	2	85	1	99	46	63	254
Sceloporus magister											7	7
Sceloporus slevini										26		26
Sceloporus undulatus	10	14	4	28						41	28	97
Senticolis triaspis						1	2	1	4			4
Spea multiplicata			9	9			139		139	1	3	152
Tantilla hobartsmithi	4	5	6	15			9		9	2	14	40
Tantilla yaquia							2		2			2
Terrapene ornata		4	3	7	1	2	2		5	5	2	19
Thamnophis cyrtopsis						16	30	8	54			54
Thamnophis eques		148	21	169						37	9	215
Thamnophis marcianus		974	10	984						1	15	1,000
Trimorphodon biscutatus						1	5		6			6
Urosaurus ornatus	27	72	17	116		1	68	2	71	208	119	514
Uta stansburiana											15	15
Total	100	11,690	178	12,125	68	647	877	31	1,623	2,057	856	16,66

A Preliminary Floristic Inventory in the Sierra de Mazatán, Municipios of Ures and Mazatán, Sonora, México

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Abstract—*Presently, the flora of the Sierra de Mazatán contains 357 species of vascular plants distributed in 248 genera and 80 families. The families with the most species are Asteraceae (48), Fabaceae (45), Poaceae (28), Euphorbiaceae (18), and Acanthaceae, Cactaceae, Scrophulariaceae, and Solanaceae (11 each). The results show that the flora of the Sierra de Mazatán is diverse. However, with additional collections, the number of species could double. For the future, it would be necessary to collect sites that were not sampled; in different habitats, especially on the north side, and in Cerro Prieto, on the extreme southwest part of the Sierra.*

Introduction

The Sierra de Mazatán is, according to the Commission for the Use and Understanding of Biodiversity (CONABIO, Comisión para el Uso y Conocimiento de la Biodiversidad), an "island" of temperate biodiversity surrounded by the arid landscape of the Sonoran Desert (Arriaga 2000). The Sierra de Mazatán is located 70 km east of Hermosillo, Sonora, along the highway to Sahuaripa (figure 1), reaching 1,545 m elevation, in the municipios of Mazatán and Ures, between the coordinates 29°02'35" and 29°10'30" N, and 110°08'17" and 110°16'30" W.

Presently, it does not belong to the "sky islands" of Northwestern Mexico and Southwestern United States; however, it is found only 80 Km to the south of Sierra de Aconchi, the southernmost element of the Madrean Archipelago. The Sierra Mazatán belongs to the Northwestern Coastal Plain physiographic region, and the Sierra Madre Occidental subprovince (Rzedowski 1981).

The Sierra de Mazatán is a granitic range that originated from the Tertiary period (Navarro 1985). The rock composition includes mainly metamorphic rocks, although Cerro Prieto, located on the southwest rim of the Sierra, is made up of limestone.

Climate is hot toward the southeastern portion, with an annual median temperature of 23.8 °C; while on the high portion of the Sierra, the climate is milder with cool winters with the lowest temperature under 18 °C (Morales-Abril and Parra-Salazar 1994). The Sierra de Mazatán functions as a biological corridor, since it allows the interactions between the biota of the Sonoran Desert with that of the Sierra Madre Occidental (Arriaga 2000).

Vegetation Types

Although there are small grass-dominated areas in clearings in the oak woodland, as well as local areas of mesquite bosque near the base of the Sierra, we recognize only three main vegetation types in the Sierra de Mazatán: foothills thornscrub, tropical deciduous forest, and oak woodland.

Foothills thornscrub (Búrquez 1999) is found from the lower plains well up the slopes of the Sierra, on the west side in the Rancho Viejo area and between 600 and 1,100 m elevation. The vegetation is dominated by tree and shrub species like *Acacia cochliacantha*, *Acacia russelliana*, *Agave angustifolia*, *Bursera fagaroides* var. *elongata*, *Bursera lancifolia*, *Bursera laxiflora*, *Coursetia glandulosa*, *Croton alamosanus*, *Diphysa suberosa*, *Eysenhardtia orthocarpa*, *Fouquieria macdougalli Guajacum coulteri*, *Havardia mexicana*, *Ipomoea arborescens*, *Jatropha cordata*, *Lantana hispida*, *Lysiloma divaricatum*, *Opuntia gosseliniana*, *Pachycereus pecten-aboriginum*, *Randia obcordata*, *Randia sonorensis*, *Sebastiania bilocularis*, *Senna pallida*, and *Stenocereus thurberi.* Between 1,100 and 1,200 meters, the transition zone to oak woodland begins, with a combination of low trees and shrubs like *Acacia angustissima*, *Lysiloma watsonii*, *Quercus chihuahuensis*, and *Tecoma stans*.

The tropical deciduous forest is restricted to deep shady ravines that descend from the Sierra; this type of vegetation reaches to 1,300 meters on the south side of the Sierra. At Cañada Agua de Don Luis, the elements form tropical deciduous forest with foothills thornscrub such as *Acacia cochliacantha*, *Bursera fagaroides* var. *elongata*, *Bursera laxiflora*, *Ceiba acuminata*, *Croton flavescens*, *Erythrina flabelliformis*, *Ficus petiolaris*, *Ficus pertusa*, *Ipomoea arborescens*, *Jacquinia macrocarpa* subsp. *pungens*, *Jatropha cordata*, *Lysiloma divaricatum*, *Pachycereus pecten-aboriginum*, *Plumeria rubra*, *Senna atomaria*, *Stenocereus thurberi*, and *Vitex mollis*. At Cañada El Carrizo, *Ayenia jaliscana, Esenbeckia hartmannii*, *Euphorbia colletioides*, *Ficus petiolaris*, *Ficus pertusa*, *Guazuma ulmifolia*, *Hintonia latiflora*, *Ipomoea bracteata*, *Iresine calea*, *Justicia californica*, *Justicia candicans*, *Pisonia capitata*, *Sebastiania pavoniana*, *Senna atomaria*, and *Vitex mollis* are present. In the ravines, in the transition zone to oak woodland, about 1,300 meters, there are populations of *Dioon sonorae*

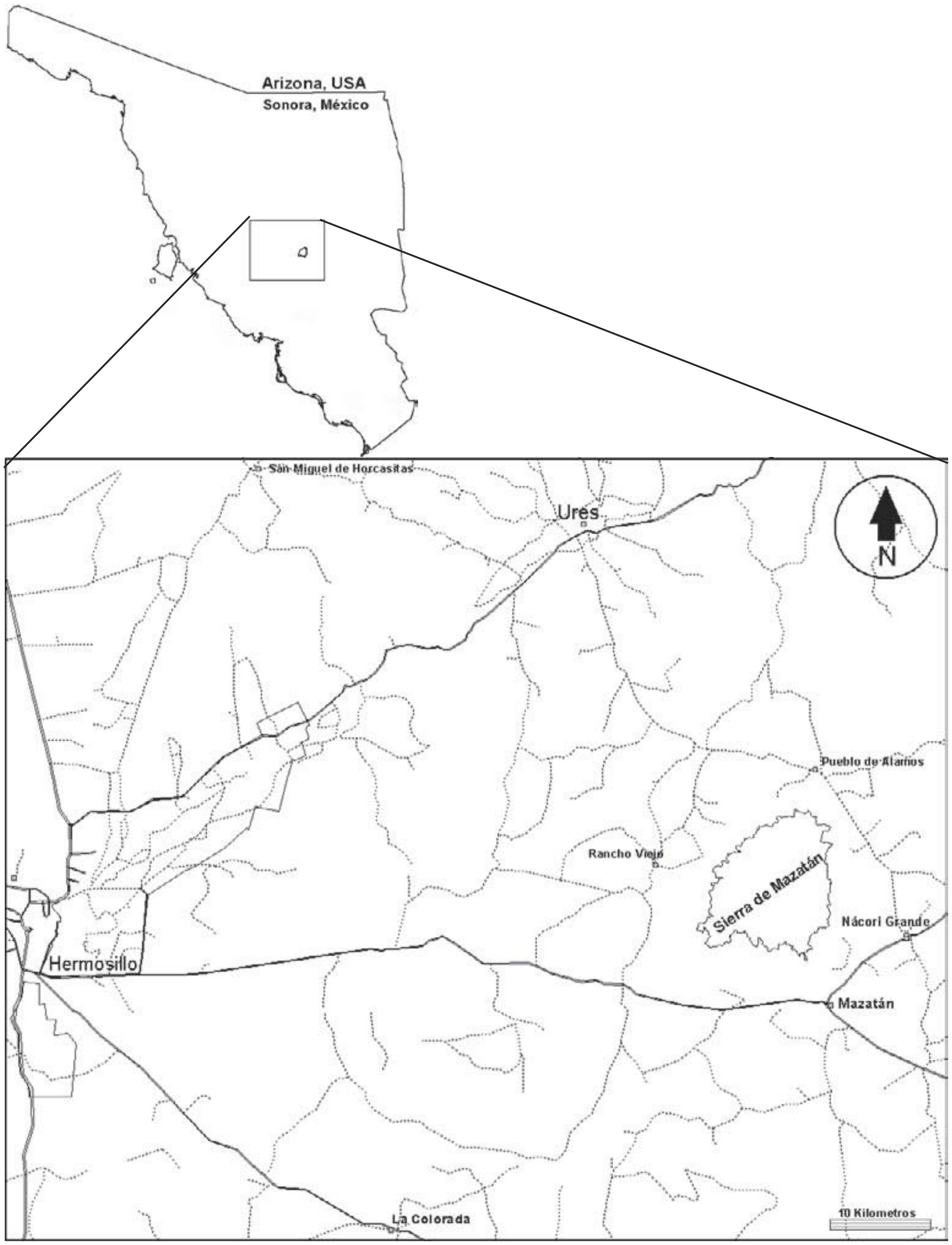

Figure 1—Location map of the Sierra de Mazatán, Sonora, Mexico.

associated with *Ceiba acuminata*, *Dasylirion wheeleri*, *Quercus tuberculata*, and *Tecoma stans* var. *angustata.* The flora on the north side of the Sierra is still relatively unknown although we found *Diphysa suberosa*, *Ceiba acuminata*, *Sideroxylon occidentale*, and *Zanthoxylum fagara* between the base and 850 meters elevation.

On the west side, oak woodland starts with *Quercus chihuahuensis* at 1,200 meters, and *Quercus oblongifolia* and *Quercus viminea* join *Quercus chihuahuensis* at 1,300 meters. On the eastern rim, we found a young tree determined as *Quercus perpallida* (R. Spellenberg, personal communication, 2004) that needs acorns to be securely identified.

Flora

The first study on the flora and vegetation of the Sierra Mazatán was about 1984, and recorded 137 plants (Navarro 1985); however, the herbarium specimens for this study were not found.

In this work, the collections were made during a seven month period, between the summer of 2003 and the spring of 2004. The sampling area was within13 km radius centered at ranch El Bachán. The sampled sites were located mostly on the high part of the sierra, and along the south and west slopes, concentrating at sites like the ranches El Bachán, Palo Bonito, La Tinaja, El Carrizo, La Flauta, and El Repecho; also along ravines like El Yugo, La Loba, La Tigra, and Los Mimbres; as well as several localities along roads on the east and west slopes. This flora is almost totally based on our collections (40 records are from the collections of Thomas Van Devender and Ana Lilia Reina-Guerrero from 2004), with a total of 562 samples, 507 of which were classified at least to the level of species. It is estimated that the flora of the Sierra can reach near 700 species. The samples collected were deposited at the University of Sonora Herbarium (USON) in Hermosillo, Sonora. A set of duplicates were deposited at the University of Arizona Herbarium (ARIZ) in Tucson, Arizona. A third set of duplicates was used to establish a regional mini-herbarium at the CBTA 53 high school in Mazatán, Sonora.

Presently, the flora contains 357 species of vascular plants distributed in 248 genera and 80 families (appendix 1). The families with the most species are Asteraceae (48 species), Fabaceae (45 species), Poaceae (28 species), Euphorbiaceae (18 species), and Acanthaceae, Cactaceae, Scrophulariaceae, and Solanaceae (11 each).

Outstanding among the important Sierra de Mazatán collections are four species of oak: *Quercus chihuahuensis*, *Quercus oblongifolia*, *Quercus viminea*, and *Quercus tuberculata. Dioon sonorae*, named locally as "peine," is the northernmost population of a cycad, which the Mexican government has classified as endangered. Other plants of conservation concern are cabeza de viejo (*Coryphanta recurvata*), ironwood (*Olneya tesota*), guayacán (*Guajacum coulteri*), and saya (*Amoreuxia palmatifida*).

Some plants are of economic importance for the local people, for example, chiltepín or bird pepper (*Capsicum annuum* var. *aviculare*) is used as a spicy seasoning in Sonoran cuisine and has a very high market price. Agave (*Agave angustifolia*) is used to make "bacanora," a very popular Sonoran mescal (alcoholic drink). Guayabilla (*Acacia russelliana*) is a tropical tree that is rarely found in the area today because it has been used as fence poles and house beams in ranches.

Some of the Sierra de Mazatán collections were important north or south extensions. Previously the northernmost record of jumping beans (*Sebastiania pavoniana*) was in the Sierra San Javier and Tepoca (Felger 2001). Another species, *Ipomopsis thurberi*, extends its southern distribution limit to the Sierra de Mazatán.

Some uncommon species in the sierra are restricted to the slopes and bottom of ravines including *Ficus pertusa*, *Celtis reticulata*, *Euphorbia colletioides*, *Sebastiania pavoniana*, and *Dioon sonorae*. Other species are restricted to the riparian areas in the oak woodland at the higher locations including *Salix exilifolia*, *Prunus serotina*, and *Lotus alamosanus.* Plants only found in the oak woodland include *Senecio carlomasonii*, *Tephrosia thurberi*, *Dalea exserta*, *Stevia* sp., and *Ipomoea longifolia.*

Although 28 species of grasses were recorded, many more are expected. In clearings of the oak woodland at rancho El Bachán, several grasses were collected: *Bothriochloa barbinodis*, *Bouteloua hirsuta*, *Chloris virgata*, *Echinochloa colona*, *Echinochloa crusgalli*, *Eragrostis mexicana* var. *mexicana*, *Eragrostis pectinacea* var. *pectinacea*, *Heteropogon melanocarpus*, *Muhlenbergia arizonica*, *Muhlenbergia rigens*, *Panicum bulbosum*, and *Setaria pumila*.

In the foothills thornscrub, other grasses were collected including *Aristida adscensionis*, *Bouteloua aristidoides*, *Bouteloua barbata* var. *barbata*, *Cathestecum brevifolium*, and *Leptochloa panicea* subsp. *Brachiata. Aristida ternipes* var. *ternipes*, *Lasiacis ruscifolia*, and *Setaria liebmannii* were found in the tropical deciduous forest ravines.

We recorded 16 non-native species (table 1), which represent only 4.5% of the flora. Of these exotic species, *Pennisetum ciliare*, *Melinis repens*, and *Nicotiana glauca*, are among the most important in terms of invasiveness.

The results we obtained during seven months of collection show that the flora of the Sierra de Mazatán is diverse. However, with additional collections, the number of species could double. For the future, it would be necessary to collect sites in different habitats, that were not sampled especially on the north side, and in Cerro Prieto, on the extreme southwest part of the Sierra.

Human Activities

Cattle raising is the traditional and predominant productive activity in the Sierra de Mazatán area. Cheese production, which occurs on on a small scale, is a very important supplementary economic activity for ranches. Sheep raising on rancho Palo Bonito on top of the sierra is a recent activity according to local ranchers. It is important to monitor this activity in the future, given the great capacity that sheep have to disturb natural habitats. In the past, mining on a small scale was another economic activity in the Sierra. Now all these mines are abandoned and there are no plans to reopen them in the short term.Tourism is an occasional activity, especially during vacations when the area attracts some visitors to the oak woodland on top of the Sierra. Lastly, there is an annual event in the Sierra de Mazatán, where many bikers cross the sierra from west to east with little effect on the flora.

Conservation and Management

The Sierra de Mazatán belongs to the System of Natural Protected Areas of the State of Sonora (SANPES). It was proposed as a Zone Subject to Ecological Conservation Sierra de Mazatán (ZSCESM) (Morales-Abril y Parra-Salazar 1994) but was never officially decreed as a reserve by the State government. Nonetheless, the Natural Resources Department of the State of Sonora, Instituto del Medio Ambiente y Desarrollo Sustentable del Estado de Sonora (IMADES), is planning to reactivate the SANPES program (Víctor Suárez, personal communication, 2004). At the present, and as a result of this work, there exists a great interest to establish an ecological reserve, and the formation of the Committee for Conservation of the Sierra de Mazatán has been proposed, integrated by local people and school teachers from the area, as well as scientists and conservationists (Sánchez-Escalante 2004, information unpublished). Through CONABIO, the Mexican government

Table 1—Non-native species in México (a) recorded in Sierra de Mazatán, Sonora, México.

Brassica campestris L.
Sisymbrium irio L.
Ricinus communis L.
Melilotus indicus (L.) All.
Malva parviflora L.
Pennisetum ciliare (L.) Link
Cynodon dactylon (L.) Pers.
Chloris virgata Swartz
Dactyloctenium aegyptium (L.) Richt.
Echinochloa colonum L.
Echinochloa crusgalli (L.) Beauv.
Eragrostis cilianensis (All.) Vignolo ex Janch.
Melinis repens (Willd.) Zizka
Phalaris minor Retz.
Polygonum aviculare L.
Nicotiana glauca Gram.

[a] Villaseñor and Espinosa-García, 2004.

also has classified the Sierra de Mazatán as a Priority Terrestrial Region for conservation (Arriaga 2000).

A decade ago, the threats to the area included cattle raising, poaching, and fires (Morales-Abril y Parra-Salazar 1994). The situation with respect to cattle has not changed significantly. During the field work, evidence of disturbance by cattle could be observed in only a few areas. Besides cattle raising, other threats have been identified but at low levels of magnitude. First, two important exotic invasive species were found: buffelgrass (*Pennisetum ciliare*) and natal grass (*Melinis repens*). Two decades ago presence of the buffelgrass was not reported for the Sierra de Mazatán (Navarro 1985). The possibility that buffelgrass could present problems by habitat destruction was mentioned 10 years ago (Morales-Abril y Parra-Salazar 1994). Today, a clear, although moderate, trend in expansion of buffelgrass from lower elevations toward the higher parts of the Sierra has been observed. Buffelgrass was noted at the unusually high elevation of 1,420 meters. With respect to natal grass, in 1985 a small amount of this grass was reported on the east side of the Sierra, at about 1,050 meter elevation (Navarro 1985). Although this grass has increased, this aggressive plant does not yet represent a threat, but should be watched.

Like in other rural areas of Sonora, the lack of adequate garbage disposal is a problem that appears frequently. In places near human settlements or ranches in the Sierra, clandestine domestic waste disposal sites have affected small areas of the natural surroundings.

Another activity that has caused disturbance in the oak woodland is the installation of infrastructure for communications on top of the Sierra including numerous radio and cellular phone antennae.

One of the activities that affects the natural habitat, although in a lesser degree in this region, is cutting of trees. Evidences of this practice can be observed at the summit of the Sierra where, apparently, the domestic use of oak wood has impacted the woodland. At the north base of the Sierra, where mesquite is the dominant species, some disturbance of the riparian and desert vegetation was observed, especially near arroyo El Bamuco. Clearing of vegetation is not a common practice in this region and was only observed on rancho La Tinaja, 7 km west of Mazatán, and in a few areas in oak woodland in the Sierra.

Fire is a potential threat that fortunately has not been frequent in the Sierra de Mazatán. The last event recorded occurred during the mid 1960s, and it was observed on the eastern slopes of the Sierra at about 1,300 meters elevation (Navarro 1985). No evidence of recent fires was noted during this work; however, due to the prolonged drought of the last years, the fire risk is very high for the region.

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Appendix 1—Checklist of the flora of the Sierra de Mazatán, Sonora, México. This list is based primarily on specimens collected by the authors between 2003 and 2004. Non-native species are indicated by an asterisk (*).

ACANTHACEAE
Anisacanthus andersonii T.F. Daniel
Carlowrightia arizonica A. Gray
C. pectinata Brandegee
Dicliptera resupinata (Vahl) Juss.
Dyschoriste decumbens (A. Gray) Kuntze
Elytraria imbricata (Vahl) Pers.
Henrya insularis Nees
Justicia californica (Benth.) D. Gibson
J. candicans (Nees) L. Benson
Tetramerium abditum (Brandegee) T.F. Daniel
T. nervosum Nees

AGAVACEAE
Agave shrevei Gentry ssp. *matapensis* Gentry

AIZOACEAE
Mollugo verticillata L.

AMARANTHACEAE
Alternanthera stellata (S. Watson) Uline & Bray
Amaranthus albus L.
A. graecizans L.
Gomphrena nitida Rothr.
G. sonorae Torr.
Iresine calea (Ibáñez) Standl.

APIACEAE
Daucus pusillus Michx.

ARALIACEAE
Aralia humilis Cav.

ASCLEPIADACEAE
Asclepias angustifolia Schweig.
A. elata Benth.
Cynanchum ligulatum (Benth.) Woodson
Marsdenia edulis S. Watson
Matelea tristiflora (Standl.) Woodson

ASTERACEAE
Acourtia thurberi (A. Gray) Reveal & King
Ageratum corymbosum Zucc.
Ambrosia ambrosioides (Cav.) W.W. Payne
A. confertiflora DC.
A. cordifolia (A. Gray) W.W. Payne
Artemisia ludoviciana Nutt.
Baccharis thesioides H.B.K.
Bidens bigelovii A. Gray var. *angustiloba*
B. odorata Cav.
Brickellia betonicifolia A. Gray
B. coulteri A. Gray
B. eupatorioides (L.) Shinners var. *chlorolepis*
Cosmos parviflorus (Jacq) Kunth
Eclipta prostrata (L.) L. Mart.
Erigeron arisolius Nesom
Eupatorium collinum DC.
Galinsoga parviflora Cav. var. *parviflora*
G. parviflora Cav. var. *semicalva* A. Gray
Gamochaeyta sphacilata (Kunth) Cabrera
Guardiola platyphylla A. Gray
Laennecia sophiifolia (Kunth) G.L. Nesom
Lagascea decipiens Hemsl.
Lasianthaea fruticosa (L.) K.M. Becker var. *occidentalis*
Machaeranthera tagetina Greene
Malacothrix sonorae W.S. Davis & P.H. Raven
Melampodium longicorne A. Gray
Milleria quinqueflora L.
Parthenium tomentosum DC. var. *stramonium* (Greene) Rollins
Pectis filipes var. *filipes* [Harv.& Gray]
Perityle californica Benth.
P. leptoglossa Harv. & A. Gray
P. microglossa var. *microglossa* Benth.
Porophyllum macrocephalum DC.
Pseudognaphalium canescens (DC.) W.A. Weber
Senecio carlomasonii B. L. Turner & T. M. Barkley
Stevia serrata Cav.
Tagetes micrantha Cav.
T. palmeri A. Gray
T. subulata Cerv.
T. triradiata Greenm.
Thymophylla anomala (Canby & Rose) Strother
T. concinna (A. Gray) Strother
Trixis californica Kellogg var. *californica* Kellogg
Viguiera dentata (Cav.) Spreng.
V. longifolia (B.L. Rob. & Greenm.) S.F. Blake
Wedelia greenmanii B.L. Turner
Xanthium strumarium L.
Zinnia zinnioides (H.B.K.) Olorode & Torres

BIGNONIACEAE
Tecoma stans (L.) Juss. ex Kunth *var. angustatum* Rehder

BOMBACACEAE
Ceiba acuminata (S. Watson) Rose

BORAGINACEAE
Cordia sonorae Rose
Cryptantha angustifolia (Torr.) Greene
Heliotropium wigginsii I.M. Johnst.
Plagiobothrys jonesii A. Gray

BRASSICACEAE
* *Brassica campestris* L.
Lepidium lasiocarpum Nutt. ex Torr. & A. Gray
* *Sisymbrium irio* L.

BROMELIACEAE
Tillandsia recurvata L.

BUDDLEJACEAE
Buddleja parviflora H.B.K.
B. sessiliflora Kunth

BURSERACEAE
Bursera fagaroides (H.B.K.) Engl. var. *elongata* McVaugh & Rzed.
B. lancifolia (Schlecht.) Engl.
B. laxiflora S. Watson

CACTACEAE
Coryphantha recurvata (Engelm.) Britton & Rose
Echinocereus rigidissimus (Engelm.) Hort. F.A. Haage
Mammillaria macdougalii Rose
M. standleyi (Britton & Rose) Orcutt
Opuntia gosseliniana F.A.C. Weber
Opuntia sp.
O. thurberi Engelm.
O. wilcoxii Britton & Rose
Pachycereus pecten-aboriginum (Engelm.) Britton & Rose
Stenocereus alamosensis (J.M. Coult.) A.C. Gibson & K.E. Horak
S. thurberi (Engelm.) F. Buxbaum

CAMPANULACEAE
Lobelia endlichii (F. Wimmer) Ayers

CLUSIACEAE
Hypericum moranense Kunth

COCHLOSPERMACEAE
Amoreuxia palmatifida Sesse & Moç. ex DC.

COMMELINACEAE
Commelina dianthifolia Delile
C. erecta L.
Tradescantia sp. nov.

CONVOLVULACEAE
Evolvulus alsinoides L.
E. arizonicus A. Gray
Ipomoea arborescens (Humb. & Bonpl.) G. Don
I. bracteata Cav.
I. cristulata Hallier f.
I. longifolia Benth.
I. purpurea (L.) Lam.
Jacquemontia agrestis (Choisy) Meisner
Operculina pteripes (G. Don.) O'Donnell

CUCURBITACEAE
Sicyosperma gracile A. Gray

CYCADACEAE
Dioon sonorae (De Luca, Sabato & Vázq. Torres) Chemnick, T.J. Greg. & Sales-Mor.

CYPERACEAE
Cyperus squarrosus L.

CHENOPODIACEAE
Chenopodium ambrosioides L.
C. watsonii A. Nelson

DRYOPTERIDACEAE
Dryopteris cinnamomea (Cav.) C. Chr.

EUPHORBIACEAE
Acalypha aliena Brandegee
A. californica Benth.
A. neomexicana Muell. Arg.
Cnidosculus angustidens Torr.
Croton alamosanus Rose
C. ciliatoglandulifer Ortega
C. flavescens Greenman var. *brandegeanus* Croizat
C. sonorae Torr.
Dalechampia scandens L.
Ditaxis neomexicana (Muell. Arg) Heller
Euphorbia colletioides Benth.
E. heterophylla L.
E. hirta L.
E. indivisa (Engelm.) Tidestrom
Jatropha cordata (C.G. Ortega) Muell. Arg.
* *Ricinus communis* L.
Sebastiania bilocularis S. Watson
S. pavoniana Muell. Arg.

FABACEAE
Acacia angustissima (Mill.) Kuntze
A. cochliacantha Humb. & Bonpl.
A. farnesiana (L.) Willd.
A. occidentalis Rose
Acacia pennatula (Cham. & Schlecht.) Benth.
A. russelliana (Britton & Rose) Lundell
Aeschynomene fascicularis Schltdl.
Caesalpinia pulcherrima (L.) DC.
Calliandra eriophylla Benth.
Coursetia glandulosa A. Gray
Crotalaria pumila Ort.
Chamaecrista absus (L.) H.S. Irwin & Barneby
C. nictitans (L.) Moench var. *pilosa* (Benth.) H.S. Irwin & Barneby
Dalea albiflora A. Gray
D. exserta (Rydb.) Gentry
D. mollis Benth.
Desmodium retinens Schltdl.
D. scopulorum S. Watson
Diphysa suberosa S. Watson
Erythrina flabelliformis Kearney
Eysenhardtia orthocarpa (A. Gray) S. Watson
Havardia mexicana (Rose) Britt. & Rose
H. sonorae (S. Watson) Britton & Rose
Indigofera jamaicensis Spreng.
Lotus alamosanus (Rose) Gentry
Lysiloma divaricatum (Jacq.) Macbr.
L. watsonii Rose
Macroptilium atropurpureum Urban
M. gibbosifolium (Ortega) A.Delgado
* *Melilotus indicus* (L.) All.
Mimosa dysocarpa Benth.
Nissolia schottii (Torr.) A. Gray
Parkinsonia aculeata L.
P. microphylla Torr.

P. praecox (Ruiz & Pav.) J. Hawkins
Phaseolus filiformis Benth.
Piscidia mollis Rose
Rhynchosia precatoria (Will.) DC.
Senna atomaria (L.) Irwin & Barneby
S. covesii (A. Gray) Irwin & Barneby
S. hirsuta (L.) H.S. Irwin & Barneby
S. pallida (Vahl) H.S. Irwin & Barneby
Sesbania herbacea (Mill.) McVaugh
Tephrosia thurberi (Rydb.) C.E. Wood
Zornia reticulata Sm.

FAGACEAE
Quercus cf. *perpallida* Trel.
Q. chihuahuensis Trel.
Q. oblongifolia Torr.
Q. tuberculata Liebm.
Q. viminea Trel.

FOUQUIERIACEAE
Fouquieria macdougalii Nash
F. splendens Engelm.

GENTIANACEAE
Centaurium calycosum (Buckl.) Fernald

HYDROPHYLLACEAE
Cryptantha barbigera (A. Gray) Greene
Eucrypta chrysanthemifolia (Benth.) Greene
Nama hispidum A.Gray
N. jamaicense L.
Phacelia gentryi Const.

IRIDACEAE
Nemastylis tenuis (Herb.) Benth. ex Baker

KRAMERIACEAE
Krameria erecta Willd. ex Schultes.

LAMIACEAE
Hedeoma nana (Torr.) Briq. ssp. *nana* (Torr.) Briq.
Hyptis albida Kunth
Monarda citriodora Cerv. ex Lag.
Salvia lasiocephala Hook. & Arn.
S. misella Kunth in H.B.K.
S. setosa Fernald
S. townsendii Fernald
Stachys coccinea Jacq.

LILIACEAE
Echeandia flavescens (Schult. & Schult. f.) Cruden
Milla biflora Cav.

LOASACEAE
Mentzelia asperula Wooton & Standl.
M. multiflora (Nutt.) A. Gray

LORANTHACEAE
Psittacanthus sonorae (S. Watson) Kuijt
Struthanthus palmeri Kuijt

LYTHRACEAE
Cuphea wrightii A. Gray

MALPIGHIACEAE
Callaeum macropterum (DC.) D.M. Johnston
Janusia californica Benth.
J. linearis Wiggins

MALVACEAE
Abutilon abutiloides (Jacq.) Garcke ex. Britt. & Wilson
A. incanum (Link) Sweet
Anoda cristata (L.) Schlecht
Gossypium thurberi Todaro
Herissantia crispa (L.) Brizicky
Hibiscus acicularis Standl.
* *Malva parviflora* L.
Sida alamosana S. Watson
S. hyalina Fryxell
S. rhombifolia L.

MARTYNIACEAE
Proboscidea parviflora (Woot.) Woot. & Standl.

MORACEAE
Ficus pertusa L. f.
F. petiolaris H.B.K.

NOLINACEAE
Nolina microcarpa S. Watson

NYCTAGINACEAE
Allionia incarnata L.
Boerhavia coccinea Mill.
B. erecta L.
Commicarpus scandens (L.) Standl.
Pisonia capitata (S. Watson) Standl.

ONAGRACEAE
Epilobium canum (E. Greene) P.H. Raven ssp. *latifolium* (Hook.) P.H. Raven
Gaura parviflora Douglas
Ludwigia octovalvis (Jacq.) P.H. Raven
L. peploides (H.B.K.) P.H. Raven
Oenothera kunthiana (Spach) Munz

OROBANCHACEAE
Orobanche cooperi (A. Gray) A. Heller

PALMAE (ARECACEAE)
Brahea brandegeei (Purpus) H.E. Moore

PAPAVERACEAE
Argemone ochroleuca Sweet.
Eschscholzia californica Chamisso ssp. *mexicana* (Greene) C. Clark

PASSIFLORACEAE
Passiflora arizonica (Killip) D.H. Douglas
P. foetida L. var. *gossypiifolia* (Ham.) Mast.

PLANTAGINACEAE
Plantago ovata Forsk.
P. virginica L.

PLUMBAGINACEAE
Plumbago scandens L.

POACEAE
Aristida adscensionis L.
A. ternipes var. ternipes Cav.
Bothriochloa barbinodis (Lag.) Herter
Bouteloua aristidoides (H.B.K.) Grisb.
B. barbata var. *barbata* Lag.
B. hirsuta Lag.
B. repens Scribn. & Merr.
Cathestecum brevifolium Swallen
* *Cynodon dactylon* (L.) Pers.
* *Chloris virgata* Swartz
* *Dactyloctenium aegyptium* (L.) Richt.
* *Echinochloa colonum* (L.) Link
* *E. crusgalli* (L.) Beauv.
* *Eragrostis cilianensis* (All.) Vignolo ex Janch.
E. mexicana (Hornem.) var. *mexicana* (Hornem.)
E. pectinacea (Michx.) Nees var. *pectinacea* (Michx.) Nees
Heteropogon melanocarpus (Ell.) Benth.
Lasiacis ruscifolia (H.B.K.) Hitchc.
Leptochloa panicea (Retz.) Ohwi ssp. *brachiata* (Steud.) N. Snow
* *Melinis repens* (Willd.) C.E. Hubbard
Muhlenbergia arizonica Scribn.
M. microsperma (DC.) Kunth.
M. rigens (Benth.) Hitchc.
Panicum bulbosum H.B.K.
* *Pennisetum ciliare* (L.) Link
* *Phalaris minor* Retz.
Setaria liebmannii Fourn.
S. pumila (Poir.) Roem. & Schult.

POLEMONIACEAE
Ipomopsis sonorae (Rose) A. Grant
I. thurberi (Torr. ex A. Gray) V. E. Grant
Loeselia glandulosa (Cav.) G. Don

POLYGALACEAE
Polygala alba Nutt.
P. glochidiata H.B.K.

POLYGONACEAE
Antigonon leptopus Hook. & Arn.
* *Polygonum aviculare* L.

PONTEDERIACEAE
Heteranthera limosa (Swartz) Willd.

PORTULACACEAE
Portulaca suffrutescens Engelm.
P. umbraticola Kunth
Talinum paniculatum (Jacq.) Geartn.

PTERIDACEAE
Astrolepis sinuata (Lag. ex Sweet) Benham & Windham
Bommeria hispida (Kuhn.) Underw.
Cheilanthes bonariensis (Willd.) Proctor
C. kaulfussii Kunze
C. lindheimeri (J. Smith) Hook.
C. wrightii Hook.
Pellaea ternifolia (Cav.) Link ssp. *arizonica* Windham

RANUNCULACEAE
Thalictrum fendleri Engelm. ex A. Gray

RHAMNACEAE
Condalia globosa var. *globosa* I.M. Johnston
Gouania rosei Wiggins
Karwinskia humboldtiana (Roem. & Schult.) Zucc.

ROSACEAE
Prunus serotina Ehrh.

RUBIACEAE
Bouvardia ternifolia (Cav.) Schltdl.
Galium proliferum A. Gray
Hintonia latiflora (Sess. & Moç.) Bullock
Mitracarpus hirtus (L.) DC.
Randia obcordata S. Watson
R. sonorensis Wiggins

RUTACEAE
Esenbeckia hartmannii Rob. & Fern.
Zanthoxylum fagara (L.) Sarg.

SALICACEAE
Salix exilifolia Dorn

SAPINDACEAE
Cardiospermum corindum L.
Dodonaea viscosa Jacq.

SAPOTACEAE
Sideroxylon occidentale (Hemsl.) Pennington

SCROPHULARIACEAE
Antirrhinum costatum Wiggins
Conobea intermedia A. Gray
Linaria canadensis (L.) Dum. Cours.
Lindernia dubia (L.) Pennell
Mecardonia vandellioides (H.B.K) Pennell
Mimulus floribundus Dougl.
M. guttatus Fisch. ex DC.
Penstemon dasyphyllus A. Gray
Russelia sonorensis var. *sonorensis* Carlson
Stemodia durantifolia (L.) Sweet
Veronica peregrina L.

SCHIZAEACEAE
Anemia tomentosa (Sav.) Swartz. var. *mexicana* (C. Presl) Mickel

SELAGINELLACEAE
Selaginella rupincola Underw.

SOLANACEAE
Capsicum annuum L. var. *aviculare* (Dierb.) D'Arcy & Eshbaugh
Datura lanosa Barkeley ex Bye
Lycium andersonii A. Gray
* *Nicotiana glauca* Graham
N. obtusifolia Mart. & Gal.
Physalis acutifolia (Miers.) Standl
P. pubescens L.
Solanum adscendens Sendtn.
S. elaeagnifolium Cav.
S. nigrescens Mart. & Gal.
S. tridynamum Dunal

STERCULIACEAE
Ayenia filiformis S. Watson
A. jaliscana S. Watson
Guazuma ulmifolia Lam.

THEOPHRASTACEAE
Jacquinia macrocarpa Stahl. ssp. *pungens* (A. Gray) B. Ståhl

ULMACEAE
Celtis pallida Torr.
C. reticulata Torr.

UMBELLIFERAE
Eryngium heterophyllum Engelm.
E. nasturtiifolium Juss. ex F. Delaroche

URTICACEAE
Parietaria floridana Nutt.

VERBENACEAE
Aloysia gratissima (Gill. & Hook) Troncoso
Glandularia gooddingii (Briq.) Solbrig
Lantana camara L.
L. hispida H.B.K.
Verbena neomexicana (A. Gray) Small
V. tenuisecta Briq.
Vitex mollis H.B.K.

VISCACEAE
Phoradendron californicum Nutt.
P. serotinum (Raf.) M.C. Johnst. ssp. *tomentosum* (DC.) Kuijt

VITACEAE
Vitis arizonica Engelm.

ZYGOPHYLLACEAE
Guajacum coulteri A. Gray
Kallstroemia californica (S. Watson) Vail
K. grandiflora Torr.

Refugia, Biodiversity, and Pollination Roles of Bumble Bees in the Madrean Archipelago

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***Abstract**—Eight species of bumble bees (Hymenoptera: Apidae:* Bombus*) are present within five major Sky Island mountains of southern Arizona. Another four species exist in the nearby large mountainous region stretching from the Arizona White Mountains to Flagstaff. The distribution and number of bumble bee species within the individual Sky Island mountains varies from six in the Catalina and Chiricahua Mountains to only one in the Santa Rita Mountains. The overall distribution of species within the Sky Island region is consistent with the theory of island biogeography advanced by MacArthur and Wilson (1967) and indicates that bumble bee survival in these small fragile areas is tenuous. Based on their importance as pollinators and their susceptibility to extinction, bumble bees could be important keystone species for the ecology of the Sky Island region and a reflection of its health.*

Introduction

Bumble bees are large roundish bees sporting coats of bright combinations of yellow, orange, red, or white fur on black. They are social and live in colonies ranging from 50 to perhaps a thousand bees, depending upon the species. In temperate climates, colonies start with an overwintered queen who establishes a colony in the spring, often in a rodent burrow, lines her nest with fur, feathers, or other soft material, and forages on flowers to collect nectar and pollen to feed her young. She makes wax pots in which the pollen and honey are stored and the offspring are reared. All of this is done alone until the first brood of small workers emerges and begins helping. Throughout the summer and fall, the colony expands in population and eventually new males and queens are reared. As fall and winter approach the queen dies, the worker population dwindles, the males and young queens mate, and the colony disintegrates (Heinrich 1979).

Bumble bees are among the most diverse and successful pollinators known. Worldwide, over 239 species are known, and in North America at least 50 species are present (Williams 1998; Krombein et al. 1979). They range from the frigid arctic coast to tropical rainforests in Amazonia. They are particularly cold hardy, being able to survive arctic winters. We have observed them foraging at temperatures of 5-7 ^{o}C on the windy peak at Eagle Summit in Alaska, on the 4,328 m summit of Mt. Evans in Colorado, and commonly at flowers on days far too cold for honey bees to fly. They are capable of pollinating a dazzling variety of flower types, and, as pollinators, they have several advantages over honey bees, stingless bees, and most small-bodied bees. Chief among these are the possession of long tongues for reaching deeply into flowers to collect nectar, and the ability to sonicate, or "buzz," and pollinate difficult flowers. Sonication is achieved by decoupling the flight muscles from wing movement and thereby vibrating and releasing pollen from within cavities of floral anthers. The result is similar to touching a tuning fork to the anthers: the pollen comes flying out the pore and onto the bee's fur where it can be collected by the bee, with some that is transferred to the next flower effecting pollination. Floral sonication is necessary for effective pollination of many flowers, including most species in the large family Solanaceae. Bumble bees are classified as "long-tongued" bees (Michener 2000). That property gives them the ability to pollinate flowers including many species of clover (*Trifolium*) whose nectar is too deep in the flower corolla to attract short-tongued bees or honey bees (Free 1993). Bumble bees also have long life spans and flight seasons, and are among the most extreme of generalists (polyleges) in their selection of flowers to visit (Heinrich 1979). These combined traits make bumble bees among the best and most abundant pollinators in much of nature.

Bumble bees are important pollinators and contributors to the ecology of southern Arizona. The Sky Islands of southern Arizona, and presumably northern Chihuahua and Sonora, provide a cool refreshing refuge for these bees in this part of the world. At the end of the last ice age, southern Arizona had a cooler, moister climate complete with coniferous trees and lots of habitat for bumble bees. As the climate dried and warmed, many plants and animals were displaced from the area and their ranges retreated either northward or up the slopes of the Sky Islands (Van Devender 1990). All but one species of bumble bee retreated along with many other animal and plant species, leaving the desert floor to carpenter bees, digger bees, leaf cutter bees, sweat bees, and a host of other bees. The theory of island biogeography predicts that isolated Sky Island populations should suffer increasing rates of species extinctions as "island" area decreases, that isolated Sky Islands should accumulate species from adjoining species reservoirs at a rate dependent upon the distance from the reservoir and the dispersal and recolonization abilities of species, and that current species presence on any given island is a reflection of the relative effect of time plus these two forces (MacArthur and Wilson 1967).

The purpose of the investigation reported here was to survey the species diversity of bumble bees in the isolated Sky Island mountain ranges of the Madrean Archipelago and to compare the Sky Island bee diversity with the diversity present in the nearby large mountainous reservoir for bumble bees. A goal was to determine if bumble bees might have suffered local extinctions in accord with island biogeography theory and to estimate the likelihood of recolonization of populations lost from the Sky Islands by dispersal of bees from the mountainous region running from the Arizona White Mountains to Flagstaff.

Materials and Methods

Isolated mountain areas were considered to be Sky Island refugia for bumble bees if peak mountain elevations were greater than 2,500 m and low points in all surrounding directions were 1,500 m or less. The reason for these criteria is that, with one exception, all bumble bee species require or greatly benefit from the forested relatively moist areas provided by high mountain tops. They do not tend to forage or disperse readily through the drier and warmer more open areas generally present at 1,500 m (personal observations). Moreover, if the peak of a mountain range does not reach at least 2,500 m, the areas around the peak and even the peak itself, generally are not sufficiently high and moist to produce suitable habitat for bumble bees. Five mountain areas in southeastern Arizona met these criteria: the Catalina Mountains (Mt Lemmon, 2,791 m); the Pinaleno Mountains (referred to as the Graham Mountains, Mt. Graham, 3,265 m); the Chiricahua Mountains (Flys Peak, 2,946 m); the Huachuca Mountains (Miller Peak, 2,885 m); and the Santa Rita Mountains (Mt. Wrightson, 2,881 m). The Galiuro and Baboquivari Mountains, two other interesting potential ranges, were excluded for two reasons: (1) their highest elevations were somewhat low, around 2,350 m; and (2) access to these areas is difficult.

Several methods of survey were used. Over a 10-year period, one of us (JS) conducted numerous collecting trips to these mountain areas to directly survey the bumble bees. In addition, extensive analysis of the insect collections of the Department of Entomology of the University of Arizona and of R. S. Jacobson yielded many good records from both modern collectors and those of the previous century. Finally, literature data and the personal experiences of RJ and Robbin Thorp (Thorp et al. 1983; Thorp, personal communication) completed the search. Identifications were confirmed by one of the authors (RJ) and sometimes also by Robbin Thorp (personal communication). Specimens are placed in the collections of the authors and at the University of Arizona.

Results

The large contiguous northern mountainous region of the Madrean Archipelago stretching from the Arizona White Mountains along the Mogollon Rim and highlands to Flagstaff contains 10 known species of bumble bees (table 1). All of these species have extensive ranges in nearby areas of California, Utah, Colorado, and New Mexico, and often considerably further north and east in North America (Thorp et al. 1983; Krombein et al. 1979). One species in the table, *Bombus sonorus*, is absent from the White Mountain-Flagstaff region. This species is generally characterized as being a member of the Mexican fauna and thrives in arid regions of the Chihuahuan and Sonoran Deserts, and in dry, warm areas of southern coastal and central California. This species nests in the lower slopes and desert below the Sky Islands and forages from those areas up to and including the peaks of the Sky Islands. As such, it is the only southern and desert species in the Arizona Madrean area and is not a true inhabitant of the Sky Islands, only a foraging visitor to the islands.

Table 1—Bumble bee species present in the mountainous region of Arizona stretching from the White Mountains to Flagstaff and in individual Sky Island Mountains of southern Arizona.

	Mountains					
Species	**Flagstaff—White**	**Catalina**	**Chiricahua**	**Graham**	**Huachuca**	**Santa Rita**
Bombus sonorous		X	X	X	X	X
B. morrisoni	X	X	X	X	X	
B. huntii	X	X	X			
B. fervidus	X	X	X			
B. centralis	X			X		
B. melanopygus	X	X				
B. (Ps.) variabilis	X		X			
B. (Ps.) insularis	?	X	X	X	X	
B. occidentalis	X					
B. rufocinctus	X					
B. flavifrons	X					
B. nevadensis	X					

The five Sky Islands in table 1 can be loosely categorized two ways—island size, and island position. The Catalina, Graham, and Chiricahua Mountains are large mountains compared to the other two. The Catalina and Graham Mountains are more northerly, and closer to the contiguous northern mountain region than are the other three mountain islands. The Catalina and Chiricahua Mountains each contain 6 species of bumble bees, 5 in common. The Graham Mountains have 4 species, three in common with the Catalinas and Chiricahuas and one unique to that range. The Huachuca Mountains have only 3 species, all in common with those in the Catalinas, Chiricahuas, and Grahams. The Santa Rita Mountains have the fewest species, only one—*Bombus sonorus*. In a sense, this range has no recorded species that would be expected to nest and inhabit the highest elevations.

A key to the species of bumble bees in the Sky Islands of the southern Arizona Madrean Archipelago is presented in figure 1. The key was developed to use minimal scientific terminology and to require only a hand lens at most for seeing sufficient detail for successful identification. It is intended to be ideal for specimens collected in the southeastern Arizona desert or the Sky Islands region and northern Sonora and northwestern Chihuahua. The key might not work as well outside those regions because additional species are likely present and color pattern variation among populations within species becomes a problem.

Discussion

One of the surprises in this study was the discovery of a species entirely unknown to southern Arizona. This species is the social parasite, *Bombus* (*Psithyrus*) *insularis*. Queens of this species invade colonies of other bumble bee species, displace the original queen, and lay eggs in her place. We had difficulty identifying this unusual bumble bee. Not only had it not been recorded in our area, but also it was very much lighter in color, being almost white-yellow instead of rich yellow and with more areas that are dark, and it possessed much thinner pelage of setae. Its status remains uncertain until more investigations are conducted to determine if the species is a color variation of *B. insulari*s or a new species.

At present, eight species of bumble bees are known from the Sky Islands of southern Arizona. These are listed in the table along with their distribution in various mountain ranges. Several observations emerge from these data. Although *Bombus sonorus* is the only species present in all listed mountain ranges, it would be misleading to assume it is a true Sky Island inhabitant. Rather, it is the one species specifically adapted to life in the desert and lower mountain slopes, and that is typically where it is found. Exceptions do occur—for example, two young queens were caught on the top of Mt Lemmon at the Stewart Observatory on September 28, 1994. These individuals probably had flown there from a lower elevation in an attempt to find flowers still in bloom. *Bombus morrisoni* is the most widespread of the true Sky Island bumble bees. It is known from mid and upper elevations of four ranges. *Bombus huntii* and *B. fervidus* are known from two ranges, while three other species, *B. centralis*, *B.* (*Ps.*) *variabilis*, and *B. melanopygus*, are each known from only one range. The last species was also a new record for State.

Many questions remain. Why are three of the eight species found on only one of the Sky Islands and another two species only on two islands? Could these be the result of random extinction processes operating independently on each Sky Island and on each bumble bee species? The occurrence of local extinctions of species as predicted by island biogeography theory is generally consistent with the overall species distribution. As observed, the larger Sky Islands, the Catalina, Chiricahua, and Graham Mountains, would be expected to have lower extinction rates than the two smaller Sky Islands. Moreover, should an extinction event occur, those Sky Islands nearer the extant populations in the Arizona highland areas would be expected to be the first to be recolonized. Accordingly, the Catalina and Graham Mountains would be expected to be recolonized first. The observation that the Catalina Mountains have the most species (along with the Chiricahua Mountains) fits the prediction, but the somewhat lower species number in the Graham Mountains does not. The Huachuca and Santa Rita Mountains, being both smaller in peak area and more distant from the reservoir of bee populations for recolonizations, would be expected to have the fewest species, in accord with observations. Thus, the Sky Islands of southern Arizona appear to be acting as true islands vis-à-vis bumble bee extinctions and potential recolonizations. They are true, albeit fragile, refugia in the desert for many species of bumble bees, pollinators whose presence or absence could profoundly affect the ecology of entire mountaintops.

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Figure 1—Key to the bumble bees of the Sky Islands. Although the first segment (the propodeum) of the abdomen is fused with the thorax; the remainder of the abdomen forms a unit distinctly hinged to the thorax; this is called the gaster. References to numbered segments in the key indicate those of the gaster from front to back (i.e., the hinged segment is regarded as the first one). Although the exoskeleton of the bee is entirely black, color descriptions refer to the hair.

1a. Gaster having six visible segments; sting present (but often retracted within the rather pointed sixth segment); usually having pollen baskets on the broadened tibia of hind legs ....2 (females)

1b. Gaster having seven visible segments; sting absent; tip of gaster rather blunt; never having pollen baskets.. 110 (males)

2a. Lacking pollen baskets on hind legs ....9 (*Bombus Psithyrus*))

2b. Pollen baskets always present ....3 (nonparasitic *Bombus*)

3a. Segments two and three of gaster black ....*Bombus melanopygus* Nylander

3b. Segments two and three light colored 4

4a. Segment three orange 5

4b. Segment three yellowish, similar to all other light-colored segments of gaster 6

5a. Segments two and three both orange; segments one and four yellow....................*Bombus huntii* Greene

5b. Segments three and four both orange (may be faded on senescent specimens); segments one and two yellowish ....*Bombus centralis* Cresson

6a. Segments one, two and three yellow; segment four black; distinct black band between wings present .... *Bombus sonorous* Say

6b. Coloring otherwise 7

7a. Segments one, two and part or all of segment three yellow; segment four black; band between wings completely absent ....*Bombus morrisoni* Cresson

7b. Segments one through four yellow 8

8a. Face with black hair ....*Bombus fervidus* (Fabricius)

8b. Face with considerable yellow hair....................*Bombus centralis* Cresson

9a. At least some yellow hair present on segments four, five and six ....*Bombus* (*Psithyrus*) *insularis* (Smith)

9b. Segments four, five and six entirely black .... *Bombus* (*Psithyrus*) *variabilis* (Cresson)

10a. Segments one and two entirely black; clypeus black ....*Bombus* (*Psithyrus*) *variabilis* (Cresson)

10b. Light hair on at least segment one......... 11

11a. Segment three and most or all of segment two black....................*Bombus melanopygus* Nylander

11b. Segment three with light hair 12

12a. Segment three orange 13

12b. Segment three yellowish, similar to all other light-colored segments of gaster 14

13a. Segments two and three both orange; segments one and four yellow....................*Bombus huntii* Greene

13b. Segments three and four both orange (may be faded on senescent specimens); segments one and two yellowish ....*Bombus centralis* Cresson

14a. Segments one through four yellow; segment five black; distinct black band between wings present .... *Bombus sonorous* Say

14b. Coloring otherwise 15

15a. Segments one through three and anterior part segment four yellow; segment five black; band between wings completely absent; compound eyes enlarged .... *Bombus morrisoni* Cresson

15b. Segments one through five yellow; compound eyes reduced (i.e., as in females) 16

16a. Lower part of face (clypeus) extensively yellow....................*Bombus centralis* Cresson

16b. Clypeus black or at most with few light hairs....................17

17a. Top of head (vertex) with yellow hairs when viewed from above ....*Bombus* (*Psithyrus*) *insularis* (Smith)

17b. Vertex black when viewed from above ....*Bombus fervidus* (Fabricius)

First Records of Two Species of Mammals in the Huachuca Mountains: Results of Ecological Stewardship at Fort Huachuca

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Abstract—*We report the first voucher of the cliff chipmunk (*Neotamias dorsalis*) and observations of Brazilian free-tailed bats (*Tadarida brasiliensis*) from the Huachuca Mountains, Arizona, where these species had not been documented. While presence of* T. brasiliensis *was expected on Fort Huachuca,* N. dorsalis *was a surprise after a century of unexpected absence. The chipmunk carcass from a cave on the Fort in 2003 suggests recent dispersal from other mountain islands.*

Introduction

The presence or absence of species in an area is inherently interesting, in part, because it is a first step in understanding nature. Such data from mountain islands, like the Madrean Archipelago, have numerous applications. For example, datasets of montane species diversity are used to test insular theory, to test models of competition, to model extinctions following environmental degradation by humans, and to set management priorities on public lands (Lomolino et al. 1989; McDonald and Brown 1992). Reasons why some species are present or absent, however, can be the subject of debate (Lomolino et al. 1989).

The Huachuca Mountains are a sky island in the Madrean Archipelago with high species richness. The range extends approximately 40 km across southwestern Cochise County, Arizona, and continues into north-central Sonora, Mexico (Brown and Lowe 1983; Hoffmeister and Goodpaster 1954). The Huachucas rise from Chihuahuan desertscrub on the east along the San Pedro River drainage at 1,525 m elevation, to Miller Peak at 2,889 m in mixed conifer forest (Hoffmeister and Goodpaster 1954). A large portion, 29,675 ha, of these mountains is the Fort Huachuca Military Reservation. During recent fieldwork on the Fort, we documented presence of two species not previously included in the faunal richness of the Huachucas.

To understand the significance of finding two additional species, it is necessary to know that the Huachuca Mountains have been well studied. Formal surveys for mammals were first conducted in the 1890s (Mearns 1907) as part of an inventory of the international border region. Later, Hoffmeister and Goodpaster (1954) surveyed the Huachucas specifically and thoroughly for mammals, obtaining and preparing 842 museum specimens. Later still, Howe and Lackey (1975) mist netted for bats on Fort Huachuca. More recently, within the past two decades, the Army has promoted responsible stewardship and provided for independent survey, monitoring, and research activities to protect the diversity of vegetation and wildlife on Department of Defense lands (e.g., Chace et al. 2000; Hass 2002; Morrison et al. 1995; Sidner 2000).

Methods

During survey efforts on Fort Huachuca, Sidner (with Russell Davis) netted bats in riparian areas in five canyons. We set multiple mist nets over small pools in forests and over large ponds in Woodcutter, Garden, and Tinker Canyons at elevations from 1,500-1,640 m on 11 nights during June-September 1993 and May-August 1994. Nets were tended from sundown until nearly sunup. Bats were removed from nets, identified to species, measured, photographed, and released. Sidner visited 6 caves and one mine during summers of 1989-2003 to locate roosting bats. In addition, Sidner identified bat carcasses at the Arizona State Health Lab in Tucson, including those from Fort Huachuca, sent in for routine rabies testing from 2000-2003.

On 04 November 2003, we descended 38 m into a vertical cave pit in a mixed conifer forest south of Scheelite Canyon, Fort Huachuca, at 2,562 m, to inventory vertebrates and invertebrates. This cave is part of a limestone outcrop where we observed the following species: mountain treefrogs (*Hyla eximia*), mountain patch-nosed snake (*Salvadora grahamiae*), mountain spiny lizard (*Sceloporus jarrovii*), a mountain snail (*Sonorella* spp.), cave little brown bat (*Myotis velifer*), rock squirrel (*Spermophilus variegatus*), and Mexican spotted owl (*Strix occidentalis lucida*). We recorded, sampled, and photographed species, including a decomposing chipmunk carcass at the bottom of this cave. Because cave air at the internal base is ≤8 ºC and >95% RH, conditions that slow decomposition, we could not determine how long the carcass had been there, but it had not been present during a previous visit in September 2002 (R. Toomey, personal communication). Pelage appeared fresh and was in good condition. On May 7, 2004, we returned to retrieve the skeleton and remaining hairs after further decomposition. We measured the skull with a Fowler caliper (0.05 mm increments) and compared ours with measurements given by Hoffmeister (1986).

Results and Discussion

Brazilian Free-Tailed Bats

We netted 146 bats on Fort Huachuca during 1993-1994, including 12 female and 13 male Brazilian free-tailed bats (*T. brasiliensis*). Captured free-tailed bats were identified by forearm measurements between 41.2-44.5 mm and by complete basal separation of ears at the forehead. Even though not previously documented in the Huachuca Mountains, the species was the second most common bat we caught after *Eptesicus fuscus*. Other species captured in the same nets as *T. brasiliensis* included *E. fuscus*, *Lasiurus blossevillii*, *L. cinereus*, *Lasionycteris noctivagans*, *Leptonycteris curasoae*, *Myotis auriculus*, *M. thysanodes*, *M. velifer*, *M. volans*, and *Pipistrellus hesperus*. We saw no *T. brasiliensis* in any of the caves and mine on Fort Huachuca that were monitored for 14 y. However, *T. brasiliensis* was the most common species of bat from Fort Huachuca sent to the Arizona State Health Lab in Tucson for routine rabies testing during 2000-2003 (41 of 72 bats; Sidner, lab notes). This pattern indicates that the species now roosts in buildings on post as was predicted by Hoffmeister and Goodpaster (1954).

Absence of *T. brasiliensis* in previous surveys was of interest, in part, because it is one of the most common and abundant bat species in Arizona. Other attempts to document the species in the Huachucas have been inconclusive or incorrect. Duncan and Sidner (1990) reported two *T. brasiliensis* in regurgitation pellets of Mexican spotted owls (*Strix occidentalis lucida*) from a canyon on Fort Huachuca, but these prey may have been obtained outside the Huachucas and carried in. A specimen misidentified as *T. mexicana* (= *T. brasiliensis*) from the Huachucas in the Chicago Natural History Museum is a *M. velifer* (Hoffmeister and Goodpaster 1954). The other literature reference to Brazilian free-tailed bats in the Huachucas refers to a locality, now called Pyeatt Ranch, and associated cave (Hoffmeister and Goodpaster 1954), probably Pyeatt Cave or Manila Mine/Cave, which is now on Fort Huachuca property. This reference is from Vernon Bailey's 1924 field notes that "*Nyctinomys mexicanus* [= *T. brasiliensis*] …occupy one cave at [Pyeatt Ranch]…Much guano has been taken out of these caves and they are very smelly and full of bats" (Hoffmeister 1986). Because there is no specimen to verify Bailey's observation, and because there are no *T. brasiliensis* in those sites today, but rather, one is occupied by a large aggregation of *M. velifer*, Bailey's notation must be questioned.

It is likely that *T. brasiliensis* was not collected before simply because it was missed. Biologists often net bats over small water pools for convenience (Howe and Lackey 1975). Freetails, however, prefer to fly over relatively large bodies of water, and we purposely selected large bodies for our netting surveys. Hoffmeister and Goodpaster (1954) collected bats by shooting over ponds at dusk or by "searching several thousands of feet" of tunnels. Thus, its prior absence in field surveys suggests the possibilities that *T. brasiliensis* arrived only recently, or was present before in lower numbers than now. Brazilian free-tailed bats are a crevice-dwelling species (Hoffmeister 1986). Current human land use in the Huachucas would encourage and sustain new arrivals. Humans have increased artificial habitat for bats by building structures with small crevices and by creating new water sources that provide moist foraging areas in an arid environment.

Cliff Chipmunk

The chipmunk carcass found in the pit cave in November 2003 was identifiable by its facial stripes. We identified the species *N. dorsalis* (Baker et al. 2003) by body size, by color pattern showing a distinct mid-dorsal dark line with relatively indistinct other body lines, and because only the cliff chipmunk is known from southern Arizona (Hoffmeister 1986). Cranial measurements of our specimen (with average measurements of *N. d. dorsalis* from the Pinaleno and Chiricahua Mountains by Hoffmeister, 1986:149) were: condylobasal length, 32.6 (32.2); palatilar length, 15.0 (14.8); postpalatal length, 13.0 (13.2); least interorbital breadth, 9.1 (8.1); postorbital breadth, 12.0 (11.4); zygomatic breadth, 19.6 (19.8); cranial breadth, 17.3 (16.5); bullae length, 8.7 (8.4); maxillary toothrow, 5.7 (5.7); and cranial depth, 14.5 (14.5). Because there can be overlap in cranial and external measurements between *N. dorsalis* and three other species of chipmunks in northern Arizona, we used Hoffmeister's (1986:159) scattergram that graphically separates the species using 3 cranial characters: cranial breadth, palatilar length, and postpalatal length. A point on that scattergram that represents our measurements of the skull from Fort Huachuca falls entirely within the range of *N. dorsalis* and out of the range of skull dimensions of the other species.

While *N. dorsalis* occurs in nearby Santa Catalina, Rincon, Pinaleno, and Chiricahua Mountains, it had not been documented in the Huachucas. Mearns' (1907) borderlands survey in the 1890s did not find cliff chipmunks in the Huachucas despite many weeks of survey and trapping in appropriate habitat. Mearns observed and trapped the species to the north and east, and his descriptions show that he knew the species well. Mearns (1907) commented, "The absence of any species of chipmunk from the Huachuca Mountains is remarkable." This absence was later supported by Cockrum (1960), Hall (1981), Hoffmeister (1986), and Hoffmeister and Goodpaster (1954).

The absence of *N. dorsalis* in earlier surveys in the Huachucas was of interest because the species, like *T. brasiliensis*, is otherwise common in Arizona in appropriate habitats and is common in nearby mountains (Hoffmeister 1986). Cliff chipmunks are most often found in canyons in the vicinity of large rocks, rocky outcrops, and cliffs in woodlands and forest habitats, but range lower into scrub in the presence of permanent water (Hart 1992; Hoffmeister 1986). The species occurs from southern Idaho and Wyoming, south to Durango, with isolated subspecies in western coastal Sonora and Coahuila (Hall 1981). The subspecies, *N. d. dorsalis*, is widely distributed in mountains of central and southeastern Arizona, east to western New Mexico, and south through Chihuahua to northern

Durango (Findley et al. 1975; Hall 1981; Hoffmeister 1986). In proximity to the Huachucas, *N. d. dorsalis* is also known from the Peloncillo and Animas Mountains in southwestern New Mexico (Findley et al. 1975), and the Sierra San Luis and Sierra Madre Occidental in Chihuahua (Hall 1981). A specimen from Sonora, in the vicinity of the Sierra del Tigre, and sight records from the west slope of the Sierra Huachinera are known (Caire 1978).

When a species is discovered initially in a montane area of the Southwest, one assumes either that it was present but missed previously, or that the species only recently moved into the area. The former explanation suggests relictual presence, that is, the species has been present and remained undetected since the Pleistocene (Davis et al. 1988). If this were the case for *N. dorsalis*, then the implication is that chipmunks in the Huachucas have been missed by biologists for 100 years. We think it unlikely that these chipmunks have been missed by the cadre of many biologists visiting the Huachucas, reviewing the work of others, and making judgments about where to draw distribution lines on range maps (Hall 1981; Hoffmeister 1986) because this is a visible and vocal species (Dunford 1974). An alternative possibility we do not accept is that this specimen was dropped by a raptor after being carried 78 km from the nearest source, the Rincon Mountains. Neither do we think chipmunks were released into the area by humans. Ground squirrels are difficult to capture, maintain, and transport. It is not clear what purpose would be served by transporting and releasing chipmunks. A fourth possibility is that the species may have arrived recently as a result of natural dispersal. However, the Huachucas are separated from other sky islands where cliff chipmunks do occur, to the north by semidesert grasslands, to the east by desertscrub and a small grassland bridge via the Mule Mountains. Differences in quality and quantity of separation between mountain ranges undoubtedly affect dispersal capabilities of a small, relatively non-vagile species. Yet there must be much plasticity in environmental tolerance in this species. The subpopulation of cliff chipmunks living along the coast of Mexico at Guaymas in Sonoran desertscrub are found to nest in woodpecker holes in cardon cactus (Callahan and Davis 1977).

There is no way to know for certain when these squirrels first arrived, but at the present time, while not common, there is evidence that chipmunks are successfully established. Besides our specimen, Mark Pretti (naturalist with The Nature Conservancy and frequent hiker in Ramsey Canyon) has observed chipmunks on four occasions in the summers of 1997-2002 at elevations of 2,440 to 2,530 m in the upper Ramsey Canyon drainage and the south face of Carr Peak. However, as new colonizers, cliff chipmunks may be present in low numbers in the Huachucas. We have no other reports of observations, although we have asked other biologists who have conducted intensive animal surveys in the vicinity (e.g., mammalogist C. Hass and ornithologist J. Martin, personal communication).

The "discovery" of *T. brasiliensis* in the Huachucas is not surprising given the vagility of bats. For a small, nonvolant mammal, however, new presence of a species on a montane island is more exciting. Most ecologists accept the possibility of range expansion within suitable habitat, but dispersal by a species across seemingly unsuitable habitat to colonize new territory is a troubling alternative to some (Davis et al. 1988). However, dispersal through such habitats does occur. Colonization by Abert's squirrels from pine forest of one mountain to another across gaps consisting of lower elevation woodlands and grasslands (Davis and Brown 1989), and range expansions northward by yellow-nosed cotton rats in the Madrean Archipelago (Davis and Dunford 1987) are recent examples. It appears that cliff chipmunks have provided another example of recent dispersal from one mountain to another in sky islands of the region.

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Historical Biogeography of Longhorn Cactus Beetles: The Influence of Pleistocene Climate Changes on American Desert Communities

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Abstract—*Mitochondrial sequence data from three species of flightless cactus beetles,* Moneilema gigas, M. armatum, *and* M. appressum, *were analyzed. The coalescent models implemented in the program FLUCTUATE were used to test the hypothesis that these species experienced range changes following the end of the last glacial period. The two desert species* M. gigas *and* M. armatum *both showed significant evidence of population growth, particularly in northern populations; however, the montane species* M. appressum *did not show evidence of range fragmentation and population decline as predicted from paleoclimate data.*

Introduction

The arid regions of the intermontane American West experienced dramatic changes following the end of the most recent glacial period. Many desert plants and animals experienced range changes to higher elevations where they had been absent during glacial periods, and many cool-climate organisms that previously dominated these regions retreated to isolated mountaintops, including the Madrean Sky Islands (Van Devender 1990a,b). The range changes seen in these cases are among the best-documented examples of plant responses to Pleistocene climate changes, and have prompted a number of phylogeographic studies that looked for genetic signatures of these events (Barber 1999; Maddison and McMahon 2000; Masta 2000; Smith 2003; Sullivan 1994). Although these studies have revealed much about population structure in species within these regions, evidence for a direct impact of late Pleistocene climate changes on biogeography or demography is still lacking.

The flightless cactus beetles *Moneilema* are an appropriate place to look for evidence of such an impact. *Moneilema* spp. are large, black, flightless beetles distributed throughout the North American deserts. They feed exclusively on cacti, their larvae burrowing into the pads, where they complete their development (Linsley and Chemsak 1984). Previous research has demonstrated that these extremely sedentary animals show significant biogeographic structure (Smith 2003), and retain genetic signatures of past range changes.

There are three species of *Moneilema* that occur in the Madrean Sky Islands and the surrounding deserts. *M. gigas* LeConte occurs in the Sonoran Desert below ca 1,500 meters, and is distributed from central Arizona southwards to northern Sinaloa. *M. armatum* LeConte occurs in the Chihuahuan Desert below 1,500 meters from western New Mexico, east to the Gulf of Mexico, and southward to Central Mexico. Finally, *M. appressum* LeConte is a sky islands endemic that occurs above 1,300 meters elevation in semi-desert grassland and oak woodlands throughout Arizona, New Mexico, Texas, Sonora, and Chihuahua, and exists in sympatry with each of the two desert species at lower elevations in the western and eastern edges of its range, respectively.

Given the packrat midden evidence for changes in the distribution of desert organisms following the end of the last ice age (Van Devender 1990a,b), we might expect that these organisms would have undergone similar range shifts, and that that history might be retained in their population genetic structure. Indeed, previous phylogenetic and Nested Clade analyses suggest that the two desert species, *M. gigas* and *M. armatum*, have undergone progressive northward range expansions, from source populations in southern Sonora, and the Bolson de Mapimi in Coahuila, into the northern edge of their current distribution (Smith 2003; Smith and Farrell, in review). Likewise, Nested Clade Analysis suggests that the Sky Island species, *M. appressum*, has undergone a range fragmentation, leading to local differentiation of isolated populations (Smith 2003). However, coalescent and molecular-clock-based estimates suggest that in all three species these dramatic range changes on a continental scale occurred between 0.3 and 2 million years ago, long before the end of the last glacial period (Smith and Farrell, in review).

Clearly, these flightless animals record biogeographic history over very deep time, but we also wanted to look at range changes on a smaller time scale. It is possible that superimposed on these large scale distribution patterns, there may have been more subtle, local range changes as certain desert organisms expanded from local refugia and moved into higher elevations throughout the last 40,000 years. In order to test this hypothesis, we examined mitochondrial DNA sequences drawn from multiple populations in each of theses species. We used coalescent models to test the hypothesis that populations of the two desert species, *M. gigas* and *M. armatum*, have undergone recent growth, and that populations of the sky island species, *M. appressum*, have undergone recent decline.

Methods

Specimens of *Moneilema* spp. were collected from across the range of the Sonoran and Chihuahuan Deserts, and from across the Madrean Sky Islands Archipelago. The coordinates of each collection locality were recorded using a hand-held Garmin GPS 12, or E-map GPS unit (see tables 1, 2, and 3). Collection sites were chosen by consulting previous collections data in published accounts (Linsley and Chemsak 1984; Raske 1966) and by examining museum specimens at the Museum of Comparative Zoology at Harvard, the University of Arizona insect collection, the Essig Museum at University of California-Berkeley, the California Academy of Sciences, and the Instituto de Biologia at the Universidad Nacionál Autónoma

Table 1—Populations and collection localities information for *M. gigas*.

Population	Collection localities	Location	Coordinates	Individuals sequenced
Rio Mayo	Alamos Monte	Southeast of Alamos, Sonora, on the road towards the Rio Cuchijaqui	26 59 00 N 108 54 12 W	3
Rio Sonora	San Carlos	In the town of San Carlos, Sonora	27 50 00 N 110 54 00 W	6
	Las Guásimas	Mexico Hwy 15 East of Guaymas, Sonora, Mexico	27 54 24 N 110 34 24 W	2
	Playa Del Sol	Mexico Hwy 15, 20 Km East of Guaymas, Sonora, Mexico	27 54 24 N 110 45 00 W	1
	San Nicolas, Sonora	260 Km Southeast of Hermosillo, Sonora, Near Intersection with Road to Ciudad Obregon	28 25 00 N 109 15 00 W	3
	Moctezuma Sonora	160 Km Northeast of Hermosillo, Near Moctezuma River	29 30 00 N 109 30 00 W	4
	Ures Son	60 Km Northeast of Hermosillo	29 30 00 N 110 30 00 W	6
	Mazocahui Sonora	104 km North east of Hermosillo, Near Road to Cananea	29 31 43 N 110 09 15 W	1
	Km 100	Mexico Hwy 15, 100 KM north of Hermosillo, Sonora, Mexico	30 00 00 N 111 08 00 W	5
Rio Bavispe	Husabas Sonora	200 Km Northeast of Hermosillo, Sonora near Rio Bavispe	29 50 00 N 109 25 00 W	4
Cholla Bay	Cholla Bay	Cholla Bay, west of Puerto Peñasco, Sonora, Mexico	31 15 00 N 114 40 00 W	7
Ajo Mountains	Sonoita	Off Mexico Hwy 2, Just east of Sonoita, Sonora, Mexico	31 41 18 N 112 50 48 W	5
	Bull's Pasture	Bull's Pasture in the Ajo Mountains, Organ Pipe National Monument, Pima County, Arizona	32 00 55 N 112 41 36 W	3
	Table Mts	South of Interstate 8, Near Table Top Wilderness, Pinal County, Arizona	32 39 54 N 112 12 36 W	3
Altar Valley	Black Mt	Black Mountain, South of Ajo, Pima County, Arizona	32 20 32 N 112 44 30 W	2
	Baboquivari	Brown Canyon, East of Baboquivari Mountain, Pima County, AZ	31 45 00 N 111 30 00 E	2
	Altar Valley	Intersection of Arizona Hwy. 86 and 286 Pima County, AZ	32 03 00 N 111 19 00 W	2
	Sheriff's Mesa	Between Amado and Arivaca on Batamote Rd., Santa Cruz County, Arizona	31 45 00 N 111 11 00 W	2
Santa Rita Mts	Florida Canyon	Santa Rita Mountains, Above Santa Rita Experimental Range Station, Santa Cruz County, Arizona	31 46 00 N110 51 00 W	7
	Box Canyon	Box Canyon Road between Greaterville and the Santa Rita Experimental Range Station, Santa Cruz County, Arizona	31 47 00 N 110 50 18 W	10
Santa Catalina Mts	Catalina State Park	Catalina State Park Group Use Area, Pima County, Arizona	32 26 00 N 110 55 00 W	3
	Biosphere II	Biosphere II Center, Pinal County, Arizona	32 34 20 N 110 51 30 W	3
	Oracle, Arizona	Arizona Trail off Mt. Lemon Road, Oracle, Pinal County Arizona	32 36 30 N 110 45 00 W	2
	Tiger Mine	Off AZ HWY 77, North East of Oracle, Arizona, Pinal County, Arizona	32 38 18 N 110 44 20 W	1
	Willow Springs Rd	Off AZ Hwy 77, West of Oracle, Arizona.	32 44 54 N 110 53 50 W	5

Table 2—Populations and collection localities information for *M. armatum*.

Population	Collection localities	Location	Coordinates	Individuals sequenced
Gulf Coast	China	Mexico Hwy 40, Near China Reservoir, Nuevo Leon, Mexico	25 41 00 N 99 13 60 W	2
	Reynosa	Mexico Hwy 40, 10 km south of Reynosa, Tamaulipas	26 01 00 N 98 13 00 W	2
	Monterrey	Mexico Hwy 53, 7 KM Northwest of Monterrey, Nuevo Leon, Texas	25 40 00 N 100 19 00 W	2
East of Rio Grande	Cox Mts	Off County Hwy 1111, North of Sierra Blanca, Hudspeth County, Texas	31 16 45 N 105 13 48 W	4
	Franklin Mts	Franklin Mountains in County Road 375 Loop, North of El Paso, El Paso County, Texas	31 52 33 N 106 29 34 W	5
	Hueco	County Road 001 and US 180, Near Hueco, Hudspeth County, Texas	31 58 00 N 105 58 00 W	2
	Bernalillo	Interstate 25 at exit 242, Bernalillo, Sandoval County, New Mexico	35 18 58 N 106 31 54 W	5
	Doña Ana Mts	Doña Ana Peak, off County road 64, North of Las Cruces, Doña Ana County, New Mexico	32 28 24 N 106 45 54 W	3
	Valley of Fire	Off US 380, Northeast of Carrizozo, Lincoln County, New Mexico	33 40 55 N 105 55 05 W	3
Pecos River Valley	Correo	Interstate 40, Exit 126 Near Correo, New Mexico, Cibola County, New Mexico	34 59 27 N 107 05 54 W	6
	Bear Mt	Davis Mountains, Texas, Jeff Davis County	30 43 27 N 104 13 32 W	2
	Medley Draw	Texas Rt 166 near windfarms east of Fort Davis, Jeff Davis County, Texas	30 31 50 N 104 11 59 W	1
Continental Divide	Old Hachita	Old Hachita Road and New Mexico Hwy 9, West of Hachita, Grant County, New Mexico	31 55 48 N 108 24 12 W	1
	Granite Gap	Arizona/New Mexico State Line at NM Hwy 80. Hidalgo Cty, New Mexico	32 05 20 N 108 58 25 W	4
	Antelope	New Mexico Hwy 9, east of Animas, New Mexico near Continental Divide, Hidalgo Cty, New Mexico	31 55 30 N 108 43 00 W	4
	Tres Hermanas	Near Tres Hermanas Mountains off New Mexico Hwy 11, South of Deming, Luna County, New Mexico	31 57 15 N 107 45 40 W	9
	Sierra Las Uvas	Off New Mexico Hwy 185, South of Hatch, Doña Ana County, New Mexico	32 32 29 N 107 07 38 W	2

de México (UNAM). Additionally, biotic communities maps (Brown 1994) and published accounts of paleovegetation in the region (Elias and VanDevender 1992; Van Devender 1990a,b; Van Devender and Bradley 1994) were consulted to identify potential new populations and determine which would be most informative in reconstructing Pleistocene climate changes.

Approximately 1,000 base pairs of mitochondrial DNA sequence data from the Cytochrome Oxidase 1 (COI) gene was obtained by PCR and thermal cycle sequencing using the methods described in Smith (2003) from 59 individuals of *M. appressum*, 57 individuals of *M. armatum*, and 92 individuals of *M. gigas*. Sequence data were easily aligned by eye using MacClade version 4.03 (Maddison and Maddison 2001).

Coalescent modeling of changes in population size were performed using the program FLUCTUATE (Kuhner et al. 1998). Samples were grouped into populations based on previous estimates of migration rates between collection localities (Smith 2003) obtained from the program MDIV (Nielsen and Wakeley 2001); if there was evidence of significant migration between collection localities, these localities were combined and analyzed as a single population (see tables 1 through 3). FLUCTUATE was used to estimate the parameters "Θ" (= $2N\mu$) and "g" (= the exponential rate of population growth or decline relative to the neutral mutation rate) for each species. We set the program to compute the Watterson estimate of theta, and allowed the population to change in size, with an initial value for "g" set to 0.1. We used 10 short Markov Chain Monte Carlos of 200 generations each, and two long Markov Chain Monte Carlos of 20,000 generations each. The probability that "g" is different from zero was determined by referring to plots of the likelihood surface and the confidence intervals about g and theta output by FLUCTUATE.

Results

FLUCTUATE found evidence of population growth in all three species, in most of the populations (table 4). Estimates of "g" were positive for all populations analyzed, but were generally low, with per-generations growth rates between 1.0 x 10^{-4} and 1.0 x 10^{-7}. Estimates of "g" were significantly greater than zero ($p < 0.05$) in all but four populations.

Discussion

Both of the desert species show evidence of population growth as we had predicted. Additionally, as we might expect, the most dramatic rates of population growth were seen in populations on the northern periphery of the range of *M. gigas* (i.e., the Catalina Mountains, Altar Valley, and Ajo Mountains,

Table 3—Populations and Collection Localities information for *M. appressum*.

Population	Collection localities	Location	Coordinates	Individuals sequenced
East of Rio Grande	Bernalillo	Interstate 25 at exit 242, Bernalillo, Sandoval County, New Mexico	35 18 58 N 106 31 54 W	2
	Organ, NM	US 70 Between Las Cruces and White Sands Missile Range. Doña Ana Cty, New Mexico	32 24 51 N 106 37 53 W	5
Continental Divide	Mt Riley	East Portillo Mts. Cty Road A005 north of Cty Road A003 near US/Mexico Border. Doña Ana Cty, New Mexico	31 52 55 N 107 05 45 W	4
	Old Hachita	Old Hachita Road and New Mexico Hwy 9, West of Hachita, Grant County, New Mexico	31 55 48 N 108 24 12 W	3
	Saddlerock Canyon	Big Burro Mts. Saddlerock Canyon Rd. off US 180 west of Silver City, Grant Cty, New Mexico	32 47 04 N 108 29 48 W	1
	Las Playas Valley	Las Playas Valley Rd. South of Intersection w/ NM Hwy 9 Hidalgo Cty, New Mexico	31 51 21 N 108 37 09 W	4
	Antelope	New Mexico Hwy 9, east of Animas, New Mexico near Continental Divide, Hidalgo Cty, New Mexico	31 55 30 N 108 43 00 W	3
	Granite Gap	Arizona/New Mexico State Line at NM Hwy 80. Hidalgo Cty, New Mexico	32 05 20 N 108 58 25 W	4
	Skeleton Canyon	Peloncillo Mts. Skeleton Canyon	31 35 25 N 109 03 48 W	3
	Tollhouse Canyon	Peloncillo Mts. Hwy 191 west of Clifton, Greenlee Cty, Arizona	33 46 25 N 109 18 41 W	2
	San Simon	Pinaleño Mts. Hwy 191 South of Safford, Graham Cty, Arizona	32 32 58 N 109 40 31 W	1
	Willcox Playa	Railroad Avenue, Southwest of Willcox, Cochise Cty, Arizona	32 12 05 N 109 52 02 W	5
	Cochise Stronghold	Dragoon Mts. Ironwood Rd, East of Cochise Ranger Station, Cochise Cty, Arizona	31 56 55 N 109 55 59W	9
	Dragoon	Dragoon Mts. Forest Service Rd 795, North of Intersection w/ Ironwood Rd. Cochise Cty, Arizona	31 58 36 N 109 57 50 W	1
Santa Cruz River Valley	Oracle, Arizona	Arizona Trail off Mt. Lemon Road, Oracle, Pinal County Arizona	32 36 30 N 110 45 00 W	3
	Greaterville	Santa Rita Mts. Greaterville Rd. West of AZ Hwy 83	31 46 31N 110 45 06 W	2
	Nogales, Arizona	Pajarito Mts. Forest Service Rd 222 Near Arizona Hwy 289, east of Interstate 19. Sta Cruz Cty. Arizona	31 23 34 N 110 48 57 W	4
	Box Canyon	Box Canyon Road between Greaterville and the Santa Rita Experimental Range Station, Santa Cruz County, Arizona	31 47 00 N 110 50 18 W	3

where post-glacial range changes in desert organisms were greatest), whereas three populations from Sonora, including one on the Sea of Cortez (i.e., putative desert refugia) did not show rates of population growth that were significantly different from zero. Although this latter observation may in part be an artifact of small sample size, the geographic component, and the fact that "g" was of similar sign and magnitude across all populations offer further support for a common extrinsic cause of these demographic changes.

It should be noted, of course, that population growth per se and range expansion are certainly distinct processes, but barring dramatic changes in population density, the one would seem to require the other. Additionally, while it is not possible to accurately infer when these demographic changes occurred, they must have been recent enough that the genetic signatures of these events have not been lost through genetic drift. We therefore view these results as compelling evidence that the two desert insects have undergone recent range expansions, which may have been a response to climate changes since the end of the last glacial period.

However, The montane species *M. appressum* not only does not show evidence of population decline as we had predicted, but in fact indicates strong evidence of population expansion in two of the three populations analyzed. It is possible that grouping sequences from different localities could produce erroneous estimates of coalescent parameters, particularly if demographic histories differed between localities, or if geographic sampling were uneven. However, in this case, there was still significant evidence of population expansion when the data from particular collection localities were analyzed separately (C. Smith, unpublished). Additionally, we suspect that if grouping populations were to have biased our results at all, it would have produced lower estimates of "g" on average because sampling multiple populations should increase the mean time to coalescence in our sample.

So, it appears that the evidence of population expansion in *M. appressum* is not an artifact of the analysis. This result is somewhat confusing, however, as both phylogenetic and Nested Clade analyses indicate that this species has undergone range fragmentation, albeit much longer ago than the end of the last glacial period (Smith 2003). One possible explanation might be that more recent demographic changes have erased any evidence of prior population decline. Alternatively, it may be that this species simply did not respond to post-Pleistocene climate changes by undergoing significant range fragmentation. It has long been known that particular plants and animals responded idiosyncratically to climate change following the end of the last ice age, rather than responding en-masse as an

Table 4—Exponential growth rates estimated by FLUCTUATE.

Species	Population	Theta	g (t=1/μ)	r (t= 2Ne)	r (t=1 generation)	p
Gigas	Alamos	0.31	155.3	48.1	2.33×10^{-06}	>0.05
	Rio Sonora	0.54	80.1	43.2	1.20×10^{-06}	<0.01**
	Rio Bavispe	0.03	99.5	3.0	1.49×10^{-06}	>0.5
	Cholla Bay	0.03	117.4	3.5	1.76×10^{-06}	>0.5
	Ajo Mts	0.12	238.5	28.6	3.58×10^{-06}	<0.05*
	Altar Valley	0.6	402.1	241.2	6.03×10^{-06}	<0.01**
	Santa Ritas	0.8	203.8	163.04	3.06×10^{-07}	0.05*
	Catalinas	0.49	935.7	463.2	1.40×10^{-05}	<0.01**
Armatum	Continental Divide	0.08	201.8	16.1	3.03×10^{-06}	0.01**
	Gulf Coast	0.718	608.1	436.6	9.12×10^{-06}	<0.05*
	Pecos River	0.25	404.1	101.0	6.06×10^{-06}	<0.01**
	Rio Grande	0.18	38.8	7.0	5.82×10^{-07}	<0.01**
Appressum	East of Rio Grande	0.0435	47.681	2.1	7.15×10^{-07}	>0.5
	Continental Divide	0.83	190.6	157.6	2.86×10^{-06}	<0.01**
	Santa Cruz River	0.37	376.8	138.6	5.65×10^{-06}	<0.01**

entire community (VanDevender 1990a). Although many pine and oak woodland species did retreat to higher elevations, it may be that *M. appressum* and their hosts remained in place as the environment changed around them.

Conclusions

The results for all three of these species suggest a complex biogeographic history in which recent range changes have been overlaid on an older biogeographic history. Previous studies suggest that the desert species, *M. gigas* and *M. armatum*, have been undergoing progressive northward expansion throughout the Pleistocene, but the evidence presented here suggests that populations from across the range of both of these species have also experienced local demographic changes and population growth following the end of the last ice age. Conversely, whereas previous studies suggest that the montane species *M. appressum* underwent significant range fragmentation in the past, the evidence presented here suggests recent expansion in some populations.

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Biogeography of Amphibians and Reptiles in Arizona

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Abstract—*We examined patterns of species richness for amphibians and reptiles in Arizona and evaluated patterns in species distribution between ecoregions based on species range size. In Arizona, the Sonoran Desert has the highest herpetofauna diversity, and the southern ecoregions are more similar than other regions. There appear to be distinct low- and mid-elevational faunas. There was no difference in elevational measures or species range sizes between species groups. However, species widespread in one ecoregion tended to have larger distributions in other ecoregions. Relating similarity indices to phylogenies and paleontological information will help us better understand the patterns of colonization and speciation that make Arizona such a herpetologically diverse place.*

Introduction

Arizona has long fascinated herpetologists. Beginning with the early railroad-related surveys and continuing to the present with the herpetofauna-as-pets upsurgence, Arizona has long been a Mecca for both amateurs and professionals in the field (e.g., Kauffeld 1957; Kauffeld 1969; Bartlett 1987). Only in a few other States can one observe such a diversity of reptiles and amphibians and experience such a wide range of habitats in which they occur. Among these animals, Arizona has species that are greatly modified for sand-swimming (*Chilomeniscus cinctus*) and arboreal foraging (*Oxybelus aeneus*); or that are venomous (*Micruroides euryxanthus*, *Crotalus* spp.), toxic (*Bufo alvarius*), cryptic (*Phrynosoma* spp.), alert and speedy (*Draconoides callisaurus*, *Cnemidophorus* spp., *Masticophis* spp.), slow and deliberate (*Gopherus agassizii*), or visually stunning (*Lampropeltus pyromelana*). One of only 2 venomous lizards occurs here (*Heloderma suspectum*), and there are more rattlesnake species here than anywhere else in the United States.

Given the diversity of species, and the attention received from professional and amateur herpetologists, it is surprising that no Statewide biogeographic analysis of Arizona's herpetofauna exists. Gloyd (1937) defined faunal areas in southern Arizona according to the distribution of its herpetofauna, but paid no attention to northern Arizona. Stewart (1994), Lowe (1994), and Morafka and Reyes (1994) assessed the herpetofaunas of the Mojave, Sonoran, and Chihuahuan Deserts, respectively. More locally, Lowe (1992) made the case for a north-south boundary line demarcating northern and southern species near Tucson, and assessed differences in faunas at Saguaro National Park by elevation. Lastly, Duellman and Sweet (1999) included Arizona in a comprehensive biogeographic analysis of the amphibians of North America: reptiles were not included. However, to our knowledge there is no Statewide analysis that relates the distribution of all Arizona herpetofauna to faunistic provinces or biogeographic regions.

Inspired by recent re-readings of *The Vertebrates of Arizona* (Lowe 1964), we initiated a biogeographic analysis of Arizona's herpetofauna. The objective of our paper is to use quantitative biogeographic techniques and GIS to determine similarities between regional herpetofaunas in Arizona and to characterize the uniqueness of these taxonomic groups in Arizona.

Methods

Using methods similar to those of Duellman and Sweet (1999), we digitized 125 species distribution maps found in Stebbins (1985) with ARC/view for all herpetofauna species whose ranges occur at least partially in Arizona. We digitized only at the species level; species containing more than one subspecies in Arizona were only considered at the species level. Among amphibians, there are 24 anurans and one salamander (excluded from further analyses). Among reptiles, 50 are snakes, 41 are lizards, and 4 are turtles after excluding introduced species.

We analyzed amphibian and reptile distributions according to Omernik's (1987) ecoregions (table 1), which may be considered as faunistic provinces, defined primarily by the species present and the ecological differences between regions (figure 1). We assigned presence/absence status to each species for each ecoregion and used the entire extent of each ecoregion rather than truncating the species' range at the Arizona border. We excluded established introduced species from our analysis (*Hemidactylus turcicus*, *Rana catesbeiana*, *Xenopus laevis*, *Rana berlandieri*, *Apalone spinifera*, and *Trachemys scripta*, as well as *Ambystoma tigrinum*, whose native range in Arizona is confounded by introductions of non-natives). Two species, *Kinosternon arizonense*, *and Chrysemys picta belli*, have been recently described for Arizona and are not included

Table 1—The size and elevational range of the 6 ecoregions that occur in Arizona (Omernik 1987).

Ecoregion	Total area (km^2)	Area in AZ (km^2)	Area in AZ (%)	Elev. range (m)
Arizona Mountains Forests	109,135	61,760	56.6	1,370 – 3,000
Chihuahuan Desert	513,427	32,160	6.23	600 – 1,500
Colorado Plateau Shrublands	326,765	89,929	27.5	1,500 – 4,000
Mojave Desert	131,271	15,039	11.5	0 – 2,000
Sierra Madre Occidental Pine-oak Forests	223,435	6,902	3.09	1,500 – 3,000
Sonoran Desert	222,982	88,729	39.8	0 – 1,500

in this analysis. A consequence of using Stebbins (1985) for this analysis was that we had to use an older taxonomy than is currently recognized, which may underestimate the currently accepted number of species in Arizona by approximately 9% (Averill-Murray, personal communication).

Because the scale of maps in Stebbins (1985) is large and generalized, we proofed species presence/absence according to elevation range (according to Stebbins 2003) and commonly accepted distribution (e.g., *Crotalus lepidus* not known to occur north of the Santa Rita Mountains, *Dipsosaurus dorsalis* not known from Chihuahuan Desert). In ambiguous cases we took a conservative approach and considered a species as present. To determine the degree of similarity between ecoregions, we calculated the Coefficient of Biogeographic Resemblance (Duellman 1990) between each pair, where

Faunal Similarity = $[2C/(N_1 + N_2)][100]$.

Here, C is the number of species common to the two regions, N_1 is the number of species in the first ecoregion, and N_2 is the number of species in the second ecoregion. By multiplying that term by 100 we express similarity as a percentage. Lastly, we estimated each species' distribution in hectares within the 6 ecoregions and compared species range size between ecoregions.

Results

The Sonoran Desert has the most species-rich herpetofauna in Arizona (99 species), followed by the Chihuahuan Desert (94 species) (table 2). The Mojave Desert has the lowest diversity (56 species). The Chihuahuan Desert and Sierra Madre Occidental Pine-oak Forests share the highest percentage of species (94.1%), followed by the relationship between Arizona Montane Forests and Colorado Plateau Shrublands, at 91.0% (table 2). The least relationship between faunas is between the Mojave Desert and Sierra Madre Occidental Pine-oak Forests, which share 49.7% of their faunas.

In Arizona, amphibians and reptiles occur from approximately sea level to the highest elevations; however, the mean elevation occupied is 1,380 m. We found no difference between amphibians and reptiles in mean elevation occupied (t-test, $t_{113} = 0.89$, $p = 0.38$; amphibians-mean = 1,512 m, 95% CI = 1,182 – 1,841 m; reptiles-mean = 1,346 m, 95% CI = 1,177 – 1,515 m), and we found no difference in mean elevation occupied between anurans, lizards, and snakes (ANOVA, $F_{2,112} = 0.390$, $p = 0.678$; anurans-mean = 1,512 m, 95% CI = 1,181 – 1,843 m; lizards-mean = 1,349 m, 95% CI = 1,096 – 1,602 m; snakes-mean = 1,343 m, 95% CI = 1,114 – 1,573 m).

The distribution of the lowest elevational limit for species' ranges is distinctly bimodal, showing peaks at 0 m and 900 m, with a long right tail (figure 2). We found no difference in lowest elevation occupied by amphibians and reptiles (ANOVA, $F_{1, 113} = 0.213$, $p = 0.656$; amphibians-mean = 634 m, 95% CI = 431 – 838 m; reptiles-mean = 687 m, 95% CI = 583 – 792 m). Also, we found no difference between anurans, lizards, and snakes (ANOVA, $F_{2, 112} = 0.114$, $p = 0.892$; anurans-mean = 634 m, 95% CI = 430 – 839 m; lizards-mean = 696 m, 95% CI = 539 – 852 m; snakes-mean = 681 m, 95% CI = 540 – 823 m).

Thirty-three species may be considered ubiquitous, occurring in all 6 ecoregions, and 4 species can be considered endemic to a given ecoregion. *Chionactis palorostris* and *Uma notata* occur only in the Sonoran Desert, *Hyla regilla* is endemic only to the Mojave Desert, and *Rana blairi* occurs only in the Chihuahuan Desert.

The mean species distribution size between all ecoregions was 7,003,718 ha (95% CI = 6,207,660 – 7,799,777 ha). Range size did not differ between class (t-test, $t_{712} = -1.209$, $p = 0.227$; amphibians-mean = 6,028,612 ha, 95% CI = 4,256,603 – 7,800,622 ha; reptiles-mean = 7,250,061, 95% CI = 6,359,404 – 8,140,716 ha), or between anurans, lizards, and snakes (ANOVA, $F_{2, 687} = 1.132$, $p = 0.323$; anurans-mean = 6,028,612 ha, 95% CI = 4,244,086 – 7,813,138 ha; lizards-mean = 6,965,385, 95% CI = 5,600,058 – 8,330,711 ha; snakes-mean = 7,677,135, 95% CI = 6,440,778 – 8,913,490 ha). Those species that had larger ranges in one ecoregion generally had large ranges in adjacent ecoregions (table 3). In pairwise comparisons of distribution size between ecoregions, those pairs that did not have significant positive relationships were usually between lower elevation deserts and adjacent higher elevation ecoregions (table 3). In the lower-elevation deserts, species occupied a larger proportion of the entire ecoregion than in the higher-elevation mountain ranges and shrublands (linear contrast, $t_{684} = -2.94$, $p = 0.003$).

Discussion

Arizona is indeed herpetologically diverse; however, the pattern of diversity is perhaps more complex than generally recognized. Surprisingly, Arizona is only in the top 25th percentile of all the United States for overall herpetofauna diversity,

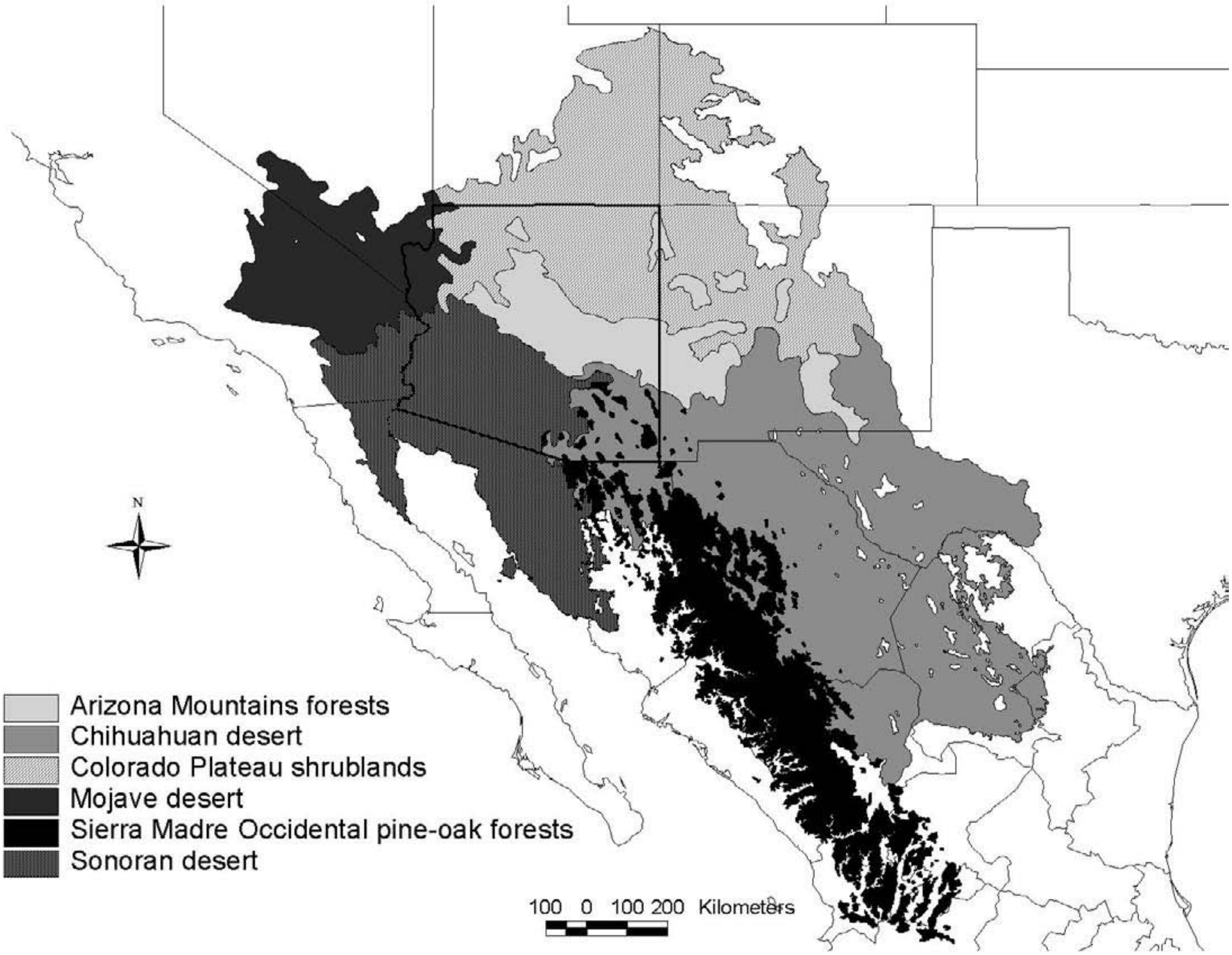

Figure 1—The 6 ecoregions as they occur in Arizona.

but second in the nation for reptile diversity (Stein 2002). Amphibian fauna is relatively depauperate, with Arizona in the lower 50th percentile of all the United States (Stein 2002). Clearly, the generally hot, dry conditions that characterize Arizona's ecoregions are not ideal for animals that have biphasic lifestyles and permeable skins, true toads (Bufonidae) and spadefoots (Pelobatidae) notwithstanding.

Herpetofauna diversity is greatest in the southeastern corner of Arizona (Sonoran Desert, Chihuahuan Desert, Sierra Madre Occidental Pine-oak Forests, in that order), the reasons for which are two-fold. First, in the continental United States, species richness is higher to the south than to the north. Secondly, 4 ecoregions meet here, each with their own assemblage. Sierra Madre Occidental Pine-oak Forests enter Arizona from the south, bringing middle- and high-elevation species from Mexico. Near Tucson, these isolated mountain ranges meet the Arizona Mountains Forests to the north (considered the southern extent of the Colorado Plateau), the Sonoran Desert to the west, and the Chihuahuan Desert to the east. This "hot-spot" of herpetofauna diversity has long been recognized (Gloyd 1937; Lowe 1964; Lowe 1992).

Patterns of greatest herpetofauna similarity involved either the Sierra Madre Occidental Pine-oak Forests (relationship with the Chihuahuan Desert, or with the Sonoran Desert), or the Arizona Mountains Forests (relationship with Colorado Plateau Shrublands). As discussed above, the Sierra Madre Occidental Pine-oak Forests reach their northern terminus where it meets 3 other distinct ecoregions. Here, the definition of elevational range for an ecoregion is undoubtedly somewhat arbitrary, and many species, whether considered "low elevation" or "high elevation," apparently have broad enough physiological tolerances to span across ecoregions where they grade from one to another. A similar effect may be shared between the Colorado Plateau Shrublands and Arizona Mountains Forests, which overlap in elevational range.

The patterns of similarity we found between the Sierra Madre Occidental Pine-oak Forests, the Chihuahuan Desert, and the Sonoran Desert are similar to the patterns recognized for amphibians only by Duellman and Sweet (1999). However, in their analysis, amphibian faunal similarity was greatest between Sierra Madre Occidental Pine-oak Forests and the Sonoran Desert (Coefficient of Biogeographic Resemblance = 64.3%)

Table 2—Relationship of herpetofauna by ecoregion. Number of species shared between ecoregions is in upper right, coefficient of biogeographic resemblance is in italics, lower left, and number of species in each region is in shaded common cell. Highest value is marked with an asterisk (*) and lowest value is underlined. AMF = Arizona Mountains Forests, CD = Chihuahuan Desert, CPS = Colorado Plateau Shrublands, MD = Mojave Desert, MSI = Sierra Madre Occidental Pine-oak Forests, and SD = Sonoran Desert.

	AMF	CD	CPS	MD	MSI	SD
AMF	82	71	71	46	67	68
CD	0.807	94	61	38	88	79
CPS	0.910	0.726	74	47	57	59
MD	0.667	0.507	0.723	56	37	50
MSI	0.766	0.941*	0.682	<u>0.497</u>	93	82
SD	0.751	0.819	0.761	0.645	0.854	99

Table 3—Pairwise correlations between ecoregions for species range size. For pairs that had positive correlations between them, widespread species in one ecoregion were also widespread in the other. Upper right cells represent probability, -- = no relationship, + = p<0.05, ++ = p<0.001. Cells in lower left represent correlation coefficient, N = 115 AMF = Arizona Mountains Forests, CD = Chihuahuan Desert, CPS = Colorado Plateau Shrublands, MD = Mojave Desert, MSI = Sierra Madre Occidental Pine-oak Forests, and SD = Sonoran Desert.

	AMF	CD	CPS	MD	MSI	SD
AMF		++	++	--	+	--
CD	0.4801		++	+	++	++
CPS	0.7897	0.3587		+	--	+
MD	0.1292	0.2162	0.2675		--	++
MSI	0.2741	0.3206	0.0597	-0.0788		--
SD	0.1581	0.3190	0.2023	0.7836	-0.0018	

and second greatest between Coefficient of Biogeographic Resemblance and the Chihuahuan Desert (56.3%). It appears that Duellman and Sweet (1999) took a more liberal approach to assigning species absence to their natural regions (comparable in scale to our ecoregions) than did we. Our ecoregions typically had 2-4 more species than did theirs.

A confounding factor might be the scale at which we performed this analysis. Shaded distribution maps are often not intended for analyses such as ours (Lowe 1994): the broad-scale and conservative approach we took may have obscured some differences between faunas. However, for determining general patterns, we believe our approach is sound and supported by previous biogeographic work (Duellman and Sweet 1999).

Although there were no differences in elevational range between reptiles and amphibians, or between anurans, lizards, and snakes, the emergence of 2 distinct lower-elevational limits (figure 2) is interesting and suggests that species can be clearly categorized by elevation. Lower-elevation species tended to be Mojavean animals with adaptations for fine sand (e.g., *Uma* spp., *Chilomeniscus cinctus*, *Crotalus cerastes*) or saxicoly (e.g., *Sauromalus obesus*, *Lichanura trivergata*), whereas middle-elevation species tended to be those associated with the Chihuahuan Desert or Madrean Sky Islands. A long right tail in figure 2 also indicates the presence of true montane species, those that occur only above 1,300 m.

Our estimate of the number of ubiquitous species seems reasonable. Many species are widely distributed but found only in patches, where habitat is available. Thus, Arizona has species like *Diadophis punctatus*, a wide-spread North American species generally occurring in more mesic areas, showing up in all ecoregions. However, we have probably underestimated local endemism. Some species known to be very limited in distribution, such as *Rana onca*, did not show as endemics in our analysis. In this specific case, *Rana onca* had a geographic range that spanned across the Mojave Desert and Colorado Plateau Shrublands border. It may be that the species actually occurs on the ecotone between the two regions; however, at the large scale of our distribution maps, the range of this and other animals with very small ranges was surely over estimated.

Related to ubiquity and local endemism, animals that occupied a large proportion of one ecoregion were also widespread across ecoregions. This pattern held especially true for lower elevation "desert" species, which occupied higher proportions of those lower ecoregions.

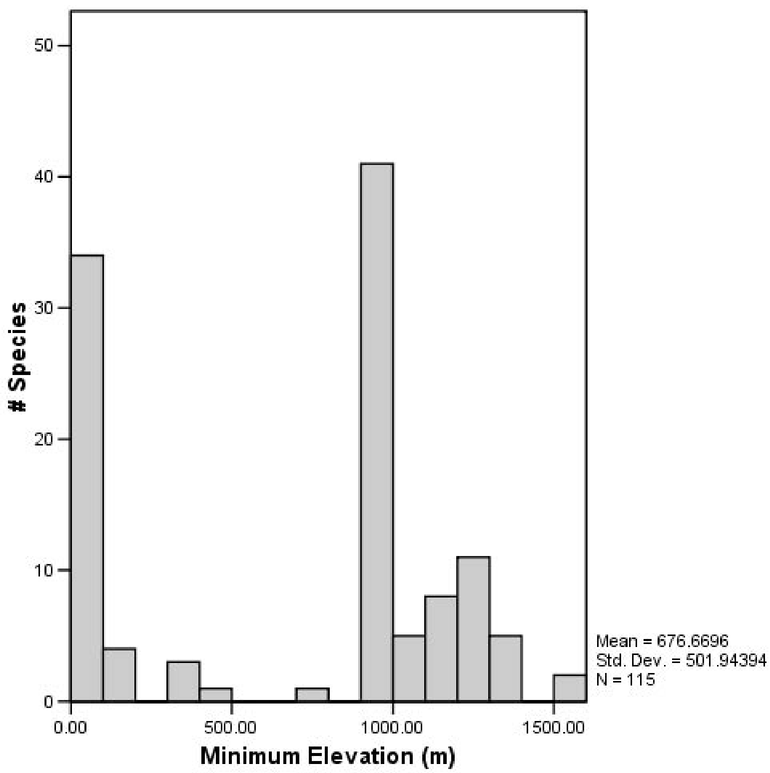

Figure 2—The lower elevational limit for herpetofauna in Arizona

The distribution of herpetofauna in Arizona continues to be a fascinating subject with many questions left to answer. The driving force for studies such as ours is to understand the patterns of colonization and speciation that have led to currently observed diversity. Analyses of faunal similarity between regions is a first step in such an endeavor. Future work should use molecular-based phylogenies and paleontological findings to help reconcile relationships between faunas and ecoregions. These, combined with more detailed analyses of present day faunal distributions including environmental correlates such as annual precipitation and temperature patterns, should provide a deeper understanding of the historical and current distribution of herpetofauna that makes Arizona so unique.

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The Arizona Striped Whiptail: Past and Present

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Abstract—*We surveyed historic and nearby collecting localities for* Aspidoscelis *(=* Cnemidophorus*)* arizonae *in Cochise and Graham Counties, Arizona, during spring and summer, 2000-2003.* Aspidoscelis arizonae *was present at or nearby all but one of the historic sites (seven of eight) that we surveyed located near Willcox (within 15 km), but not the type locality 65 km to the west at Fairbank, Cochise County, nor the Whitlock Valley 65 km to the northeast in Graham County. The Desert Grassland Whiptail,* A. uniparens*, was present at most sites unoccupied by* A. arizonae*, including the type locality; three sites were occupied by both taxa. Cattle grazing was apparent at virtually all sites occupied by either species;* A. arizonae *was associated with relatively open grasslands, whereas* A. uniparens *was often found in habitats with numerous invader shrubs (e.g., mesquite), regardless of grazing activity.*

Introduction

The Arizona Striped Whiptail, *Aspidoscelis arizonae*, has enjoyed a complex taxonomic history. Originally described by Van Denburgh (1896) based on a single specimen labeled "Fairbank, Cochise County, Arizona," it was relegated to synonymy with *A. perplexa* (= *inornata*) by Van Denburgh (1922) and noted as extirpated from the type locality some twenty years after its initial collection (Van Denburgh and Slevin 1913). Wright and Lowe (1965) rediscovered *A. arizonae* at Willcox Playa, Cochise County, Arizona, in 1962, and since that time it has been known from only a handful of localities near Willcox, and in the Whitlock Valley, Graham County, Arizona (Mitchell 1979; Wright and Lowe 1993; Rosen et al. 1996). Wright and Lowe (1965) recognized *A. arizonae* as a subspecies of the widely distributed Little Striped Whiptail, *A. inornata*; however, most recent workers have recognized *A. arizonae*.

Wright and Lowe (1965) and Rosen et al. (1996) suggested that *A. arizonae* was historically a desert grassland form distributed widely in southeastern Arizona that declined following alteration and reduction of habitat due to overgrazing and drought that began in the late 1800s. They also indicated that *A. arizonae* may have been replaced in these altered habitats by the unisexual form, *A. uniparens*, concordant with theoretical expectations about the reproductive advantage of parthenogenesis (e.g., Hulse 1981). Herein we report on surveys for whiptails in Cochise and Graham Counties during 2000, and 2002-2003. Presence of *A. arizonae*, *A. uniparens*, and other whiptails, as well as habitat characteristics in relation to grazing impacts were assessed for all historic collecting localities and nearby sites.

Materials and Methods

We obtained information about historic collecting sites for *A. arizonae* from publications (e.g., Wright and Lowe 1965) and museum records (i.e., Arizona State University, University of Arizona, and Museum of Vertebrate Zoology, University of California, vertebrate collections). Fieldwork was conducted during April through September 2000-2003. Sites near Willcox were visited and the following information recorded: (1) precise location (UTM; Garmin GPS 12 XL unit); (2) temperature (air temperature approximately 1.5 m above ground in shade); (3) time and duration of survey; (4) cloud cover; (5) general habitat characteristics (soil color and texture; numerically dominant perennial plants; apparent condition vis a vis grazing by cattle and sheep); and (6) all reptiles observed during survey efforts (typically 30 minutes per site). Sites were visited repeatedly within and across years to document consistency in presence/absence of *A. arizonae* and *A. uniparens*.

During surveys all individual lizards were followed closely until the observer obtained a clear visual image for identification (following Wright and Lowe 1993). We captured up to 15 specimens at each site in order to confirm visual taxonomic assignments and obtain tissues for future genetic analysis.

At 25 survey sites in Cochise and Graham Counties, Arizona, grazing impacts were assessed by surveying plants and cattle sign (dung) using modified belt transects (50 m by 2m width) in which substantive plants (greater than 10 mm stem diameter) were recorded using the criteria listed in appendix I. Grazing activity was assessed directly using dung pile counts along the plant survey transects. Specifically, all dung piles were scored along each plant transect (regardless of size or shape). All habitat assessment transects were completed between April 18 and July 10, 2003.

Results

Many specimens listed in various museum collections as *A. inornata* from Cochise County are likely misidentified *A. uniparens* (John Wright, personal communication). We examined all *A. inornata* (= *arizonae*) from Cochise County held at the MVZ (UC Berkeley), and found that only 7 of 29 were in fact *A. arizonae*. All of these were from within 5 km of Willcox; the remainder were *A. uniparens*. Interestingly, many *A. uniparens* were collected by Law (at MVZ) in 1919 along state route 186 southeast of Willcox, revealing that this taxon has been present at sites within 10 km of Willcox for at least 80 years rather than having recently colonized these areas following overgrazing and habitat disturbance. Virtually all specimens of *A. arizonae* in the ASU and UA collections were properly identified, and from within 10 km of Willcox (appendix II).

Historically, *A. arizonae* has been collected primarily along the eastern and northern edges of the Willcox Playa (ASU, UA, and MVZ collections). Only two historic sites are more than about 15 km from Willcox: the type locality at Fairbank (Van Denburgh 1896) about 65 km to the southwest, and the Whitlock Valley (discussed by Wright and Lowe 1993; a single specimen is housed at UA) about 65 km to the northeast.

A total of 111 person hours was spent surveying on a total of 25 days from April 20 through September 5, 2000; similarly, 41 person hours on eight days from June 24 through September 1, 2002, and 53 person hours on 12 days from April 18 through August 30, 2003. A total of 81 independent sites were surveyed in Cochise and Graham Counties. The majority of sites were heavily grazed, with ample sign (e.g., droppings, active trails, grazed shrubs and grasses) of persistent, recent grazing by cattle. Overall, *A. arizonae* were present at 12 sites, *A. uniparens* were present at 45 sites, *A. tigris* were present at 15 sites, and no whiptails were observed at the remaining 15 sites. Three sites were occupied by both *A. arizonae* and *A. uniparens*.

We observed *A. arizonae* at 10 sites, including all but one of the eight historic localities, in the vicinity of Willcox, and at two sites roughly 35 km to the north, near Bonita, Graham County (figure 1). One historic collecting locality, roughly 13 km north of Willcox, is now occupied by a housing development, and no whiptails were observed. Relatively large numbers of *A. arizonae* were observed at three sites: Twin Lakes Golf Course three km southwest of Willcox; along state route 186, seven km southeast of Willcox; and near Bonita, Graham County. At each of these sites more than 10 *A. arizonae* were visually confirmed within 30 minutes of field survey activity on several occasions. Like other collectors (e.g., Van Denburgh and Slevin 1913; Wright and Lowe 1965), we documented only *A. tigris* and *A. uniparens* at Fairbank, the type locality. The northern Whitlock Valley was occupied exclusively by *A. tigris* when surveyed in 2000, 2002, and 2003; it may be that other areas in this valley that were not accessible (private holdings) contain suitable habitat that we could not access (e.g., we could not access the precise locality near the Hackberry Ranch for the single *A. arizonae* in the UA collection, taken in 1983).

At one site (7 km southeast of Willcox), recognized as "area I" by Mitchell (1979), we found only *A. arizonae* (12 of 12 individuals captured) and no *A. uniparens*, just as Mitchell documented in 1975. We observed *A. uniparens* at a number of sites to the west, south, and north of Willcox Playa, and at many localities in eastern Cochise County. However, we found no evidence that *A. uniparens* was present at sites historically occupied by *A. arizonae* (except for the type locality, Fairbank; see below). *Aspidoscelis tigris* was found at rocky sites with creosote and other shrubs, rarely with *A. uniparens* and never with *A. arizonae*.

Habitat surveys were conducted at nine sites occupied by *A. arizonae* (one of the nine sites also had *A. uniparens*) and at one additional site occupied by *A. uniparens* and hybrids between *A. arizonae* and *A. uniparens* (table 1). Fifteen nearby additional sites (most were within 10 km of a site occupied

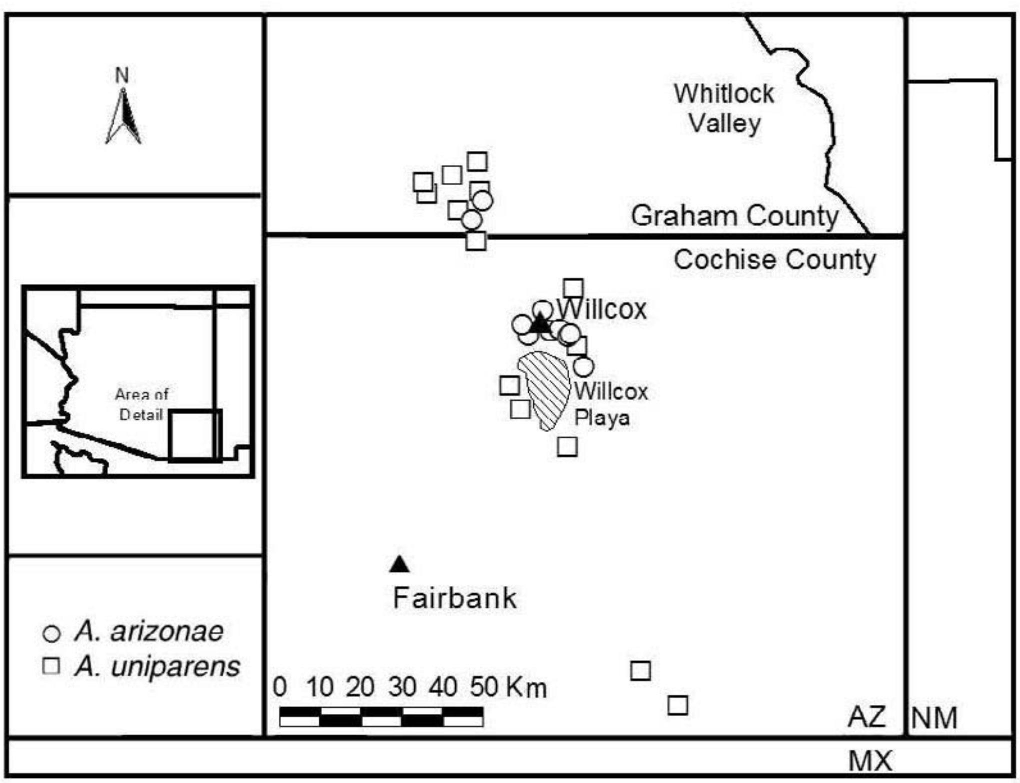

Figure 1—Sites surveyed for habitat characteristics in Cochise and Graham Counties, Arizona, in 2003 (see tables 1 and 2 for additional data from these sites). Sites for *Aspidoscelis arizonae* (circles) represent all known localities surveyed; sites for *A. uniparens* (squares) represent only 15 of 45 sites.

Table 1—Habitat survey scores for sites occupied by *Aspidoscelis arizonae* (sites 1-8); only *A. uniparens* and hybrids were present at site 9, and both *A. arizonae* and *A. uniparens* were present at site 10. Grass = index (1-5) based on criteria in appendix 1; Mesquite, shrubs and dung represent counts. N = number of 50 X 2 m belt transects recorded at each site. Sites are plotted in figure 1.

UTM	Grass	Mesquite	Shrubs	Dung	N
1: 596467 E; 3597780 N	2	0	13	1	2
2: 594203 E; 3593212 N	2	3	4	9	2
3: 609018 E; 3571324 N	5	3	1	0	3
4: 606019 E; 3565061 N	3	0	4	4	4
5: 610680E; 3566457 N	5	0	4	10	4
6: 612521 E; 3566861 N	5	2	5	0	2
7: 614376 E; 3565044 N	5	0	1	7	2
8: 614824 E; 3565459 N	4	1	5	5	3
9: 617576 E; 3557783 N	5	3	0	3	4
10: 604809 E; 3567878 N	4	4	2	0	4

by *A. arizonae*) with only *A. uniparens* were surveyed for comparative habitat characteristics (table 2). Sites occupied by *A. arizonae* were significantly higher in grass cover indices (MW U = 116.5, P = 0.019), and lower in both mesquite (MW U = 45.0, P = 0.09) and invader shrub counts (MW U = 35.0, P 0.026) than sites occupied by *A. uniparens*. However, the sites did not differ in current grazing index scores (i.e., dung counts; MW U = 72.5, P = 0.888).

Discussion

We documented the presence of *A. arizonae* at ten sites (including seven of eight historic sites) we visited within 10 km of Willcox, and discovered two disjunct populations approximately 37 km north of Willcox, near Bonita, Graham County (figure 1). Further, we found no evidence that *A. uniparens* has increased in abundance at a site (rte 186, 7 km southeast of Willcox) close to an area of sympatry studied by Mitchell in the 1970s (Mitchell 1976, 1979). With the exception of the type locality at Fairbank, we documented the presence of *A. arizonae* at (or nearby) most all of the historic localities near Willcox that we visited during each survey year (2000-2003). We were unable to confirm the presence of *A. arizonae* at the disjunct site in the Whitlock Valley 60 km to the northeast (discussed in Wright and Lowe 1993), although we did document previously unrecorded populations about 37 km north of Willcox near Bonita, Graham County, Arizona.

The observation that the (single) type specimen of *A. arizonae* was collected at Fairbank (approximately 65 km southwest of Willcox), a site where it does not occur today, is central to the hypothesis that *A. arizonae* was historically more widespread in southeastern Arizona (Wright and Lowe 1965). However, there is reason to suspect that the collecting locality for the type specimen was assigned in error. The

Table 2—Habitat survey scores for sites occupied by *Aspidoscelis uniparens*. Grass = index (1-5) based on criteria in appendix 1; mesquite, shrubs and dung represent counts. N = number of 50 X 2m belt transects recorded at each site. Sites are plotted in figure 1.

UTM	Grass	Mesquite	Shrubs	Dung	N
1: 615356 E; 3577106 N	1	2	15	4	2
2: 602564 E; 3553288 N	3	10	11	0	2
3: 604798 E; 3547324 N	1	4	25	6	2
4: 638296 E; 3475562 N	5	3	1	3	2
5: 630466E; 3483931 N	3	4	5	0	2
6: 595206 E; 3607484 N	2	1	13	1	4
7: 595953 E; 3600345 N	2	2	9	1	2
8: 585197 E; 3599891 N	3	3	5	3	4
9: 584312 E; 3602417 N	5	0	0	15	4
10: 590114 E; 3604199 N	1	2	12	4	2
11: 595296 E; 3588058 N	2	5	4	0	2
12: 595296 E; 3588058 N	1	1	16	4	3
13: 591540 E; 3595647 N	1	4	30	8	2
14: 616443 E; 3563040 N	4	1	6	11	3
15: 614629 E; 3538446 N	4	4	4	4	3

W. W. Price expedition used Fairbank as a base in southeastern Arizona in 1894; many other herpetological specimens (e.g., exclusively high elevation, montane forms) likely collected elsewhere were labeled "Fairbank" (Phil Rosen, personal communication). Additionally, the creosote/acacia dominated community near Fairbank, although presumably altered relative to its historic state, is not a habitat typically occupied by *A. arizonae*. We are aware of no other historic collecting localities in which *A. uniparens* has replaced *A. arizonae*. The evidence reviewed here, including consistent distributions among these taxa, indicates that if wide-spread decline of *A. arizonae* with replacement by *A. uniparens* occurred, it was prior to 1900, and that their current distributions in Cochise County appear relatively stable at least over the past fifty years.

Rosen et al. (1996) suggested that *A. uniparens* might be competitively superior to *A. arizonae*. Mitchell's (1976, 1979) analysis indicated that these two taxa are nearly identical with respect to diet, and thus if resources are limiting, and the unisexual *A. uniparens* has a reproductive advantage (Hulse 1981), then it might replace the bisexual *A. arizonae* over time in zones of overlap. Rosen et al. (1996) observed sympatric populations of *A. arizonae* and *A. uniparens* west of Willcox in 1993. Although we focused primarily on simple assessments of presence and absence, we could find no evidence that *A. arizonae* has declined and been replaced by *A. uniparens*; it appears that *A. arizonae* is persisting in historic localities identified in the 1960s (e.g., sites 3-7 km west and southwest of Willcox). Independent of high levels of grazing apparently maintained throughout the region, our simple surveys suggest that *A. arizonae* is at least as abundant at the twelve sites where we observed it in 2000-2003 as *A. uniparens* is at the nearby sites it occupies. Perhaps most significantly, the continued presence of *A. arizonae* at a "pure" site surveyed by Mitchell (1976) adjacent to an area occupied by *A. uniparens*, in spite of heavy grazing throughout the region, indicates a lack of competitive exclusion of *A. arizonae* by *A. uniparens* in some grazed habitats. Interesting, the collections by Law held at the MVZ, obtained in 1919, reveal the long-standing presence of *A. uniparens* in this area 8-25 km southeast of Willcox, which is certainly ample time for this taxon to have expanded and replaced nearby populations of *A. arzionae*.

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Appendix I.

Criteria for scoring habitat characteristics of sites (per 50 X 2 m transect). (1) Grass cover index: 1 = no bunch grasses present; 2 = 1-10 bunch grasses (primarily *Sporobolus* spp.) present; 3 = 11-49 bunch grasses present; 4 = 50-99 bunch grasses present; 5 = Æ 100 bunch grasses present. Each individual grass "clump" was counted, regardless of diameter, height, or condition; (2) Mesquite counts: number of plants. Each plant with any above ground vegetative part within the two m belt was counted; (3) Creosote counts: number of plants. Each plant with any above ground vegetative part within the two m belt was counted; (4) Invader shrub (primarily *Gutierrezia* spp., *Hymenoclea* spp., and *Isocoma* spp.) counts: number of non-mesquite/creosote shrubs. Each plant with any above ground vegetative part within the two m belt was counted; (5) Current grazing index: number of dung piles. Each discrete pile (i.e., contiguous), regardless of size, was counted.

Appendix II.

Specimens examined (MVZ, UA, ASU): MVZ: 7894-7898, 7900-7909, 7911-7918, 49852, 61753, 67091, 67093, 149966, 206988; UAZ: 05421-05440; 05444-05451; 05460-05462; 05476-05488; 06719-06721; 10915-10918; 13695-13722; 15553; 16818-16832; 18547; 18584; 19087; 19421; 23588; 25350-25351; 25361-25365; 25370-25372; 25389-25400; 25406; 25408-25414; 25501-25518; 33041-33044; 44628; 44638-44723; 50052-50053; 5212

In Search of the Madrean Line: Biogeography of Herpetofauna in the Sky Island Region

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Abstract—*In 1992 Charles H. Lowe proposed a major partition in the distribution of the herpetofauna of southern Arizona and New Mexico between the Madrean Archipelago and the Rocky Mountains along a line that parallels the present-day Interstate 10. We categorized species by elevation and geographic region and used spatial analysis to explore the existence and location of a Madrean Line. We found a difference in area occupied by species north and south of Interstate 10, and located a clear boundary where Lowe's predicted line occurs. In addition, we found a very strong east (Chihuahuan Desert) and west (Sonoran/Mojave Desert) pattern.*

Introduction

In a paper presented during a symposium on research at Saguaro National Park in 1992, the eminent herpetologist Charles H. Lowe proposed the existence of a major biogeographic boundary in the Sky Island area of the southwestern United States (Lowe 1992). Lowe called this line the Madrean Line, and declared that it was "as sharp as the world's most famous one, Wallace's Line" (Lowe 1992). Wallace's Line, named for the great British naturalist Alfred Russell Wallace, separates the Asian-dominated fauna of the northwestern islands of Indonesia and the Australian-dominated fauna of the southeastern islands (Wallace 1860).

Lowe's paper, which appears in the symposium proceedings, contains a number of ideas that he developed over more than 50 years of activity as a passionate herpetologist and ecologist of the Southwestern United States and Northern Mexico. For herpetologists, Lowe's biogeographic analysis is of greatest interest. Herpetologists are drawn to southern Arizona both for the region's diversity and the many tropical species that occur at the northern edge of their range. A recurring theme of amphibians and reptiles in the area is that a species may be plentiful in one mountain range, but absent at the same elevation in an adjacent range. The differences between Saguaro National Park (Rincon Mountains) and the Santa Rita Mountains, for example, are striking. Although the 1,800 m contours of each range are separated by <25 km, 5 snakes, 3 frogs, and 3 lizards that occur in the Santa Ritas are absent in the Rincons.

So what are the patterns of distribution, and why do they exist? Using montane rattlesnakes as an example, Lowe (1992) established his Madrean Line along the route where today's Interstate 10 (I-10) runs generally east-west across eastern Arizona and western New Mexico. His paper concludes that the northern distribution of the Madrean species is primarily limited by climatic factors, particularly lower temperatures and lower summer rainfall.

Several detailed herpetological inventories have occurred in the Arizona Sky Islands since Lowe's paper (e.g., Turner et al. 2003; Swann and Schwalbe 2002), and genetic research is greatly improving our understanding of the biogeography within species (e.g., Zumudio et al. 1997). In addition, geographic information systems (GIS) allow us to quickly map and analyze distributional patterns. The major objective of this paper was to use spatial analysis to explore whether a north-south biogeographic boundary for herpetofauna occurs in the Sky Island region, and where it is located. A second objective was to explore east-west distribution patterns and other aspects of the biogeography of reptiles and amphibians in the area.

Methods

We used published species distribution maps (Stebbins 1985) to categorize and compare distributions for amphibians and reptiles that occur in the Sky Islands. Range maps are problematic because all species distributions are patchy to some degree, but Stebbins (1985) has the advantage of being particularly detailed for southern Arizona, in part because of the author's collaboration with Charles Lowe. For consistency with range maps we also used Stebbins' (1985) species classification with one exception, the Arizona black rattlesnake (*Crotalus oreganus cerberus*) due to recent taxonomic revision (Pook et al. 2000; Douglass et al. 2002) and its importance in Lowe's paper. Range maps for all species present in southern Arizona were digitized using the GIS mapping software ArcView 3.3.

Species were categorized by local elevation range (above 1,524 m only, and all species) and biogeographic province (east/Chihuahuan, south/Madrean, west/Sonoran-Mojave, north/Rocky Mountain, and others). We assigned species to elevation range categories using published sources (e.g., Lowe et al. 1989) in combination with our experience and knowledge of local experts (C. R. Schwalbe and R. Repp). We recognized that categorizing species by elevation is problematic because individuals are occasionally found well outside of areas where they are most common. We determined biogeographic province based on whether the major area of a species distribution occurred east, west, north, or south of the Arizona Sky Islands. We were conservative in this categorization and excluded species that have ranges that are localized, disjunct, or distributed in more than one direction from our study area.

We defined our study area as a rectangle of approximately 60,000 km^2 centered roughly around the north end of the Dragoon Mountains east of Wilcox, Arizona (figure 1). This is only a portion of the region considered the "Sky Islands" as defined in this volume but includes nearly all the species north of Mexico (where species distributions are less well-documented) and approximately the same area north and south of Interstate 10. We calculated each species' range falling within this region and totaled the distribution of all species. We used a 2-tailed t-test (Zar 1996) to determine whether the ranges of species north and south of 1-10 were significantly different. We created contour maps of species distributions by biogeographic province by combining species ranges. We considered the location of the Madrean Line to be the zone of overlap of 50% contours of the north/Rocky Mountain and south/Madrean biogeographic provinces, and conducted a similar analysis for the geographic boundary between west/Sonoran-Mojave and east/Chihuahuan herpetofauna.

Results

Montane Species

North-south distributions for 12 high-elevation species are summarized in table 1. Nine have largely Madrean ranges; of these, seven do not occur north of I-10, while two occur in the Pinelenos and one occurs in the Galiuros. We categorized only one montane species, the Arizona black rattlesnake, as having a predominantly northern distribution. It occurs in all the major ranges in our study area north of I-10, and does not occur south of it. Two species, the Sonoran mountain kingsnake (*Lampropeltis pyromelana*) and the short-horned lizard (*Phyrnsoma douglassii*) occur in all of the Sky Islands and range well to the north and south. For montane species, we found a significant difference in range occupied north and south of the current route of I-10 ($t_{11} = -2.366$, $p = 0.037$).

All Species Combined

We categorized 83 species in our study area. We considered four species to be northern or Rocky Mountain in distribution,

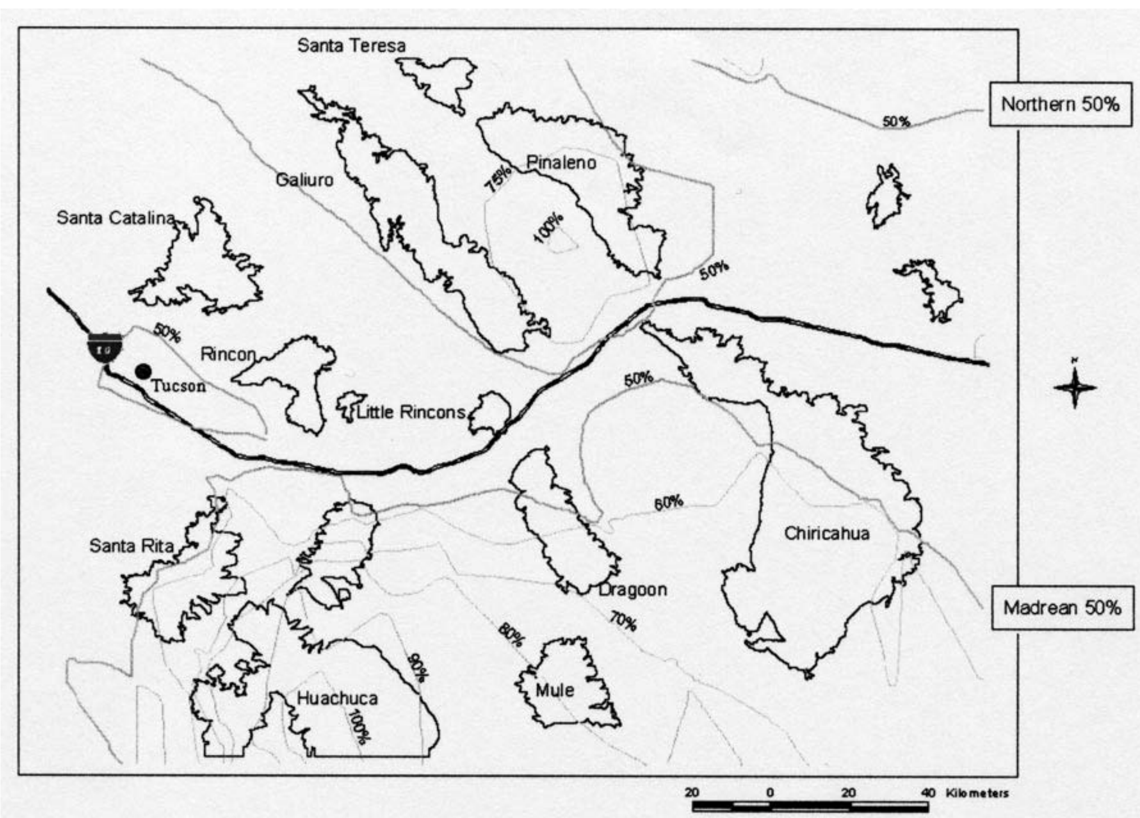

Figure 1—Contour intervals for number of species of reptiles and amphibians of southern/Madrean (n = 17) and northern/Rocky Mountain (n = 4) distributions that occur in the southeastern Arizona Sky Island region. The 50% contour for southern species runs roughly west-east of I-10 Route 10, proposed as the Madrean Line by Lowe (1992). The 50% contour for northern species is less well-defined and contains a disjunct contour island near Tucson.

Table 1—High elevation reptiles and amphibians of the major southeastern Arizona Sky Islands in relation to the "Madrean Line," proposed by Charles H. Lowe (1992) to parallel the modern route of I-10. Mountain ranges are arranged from north (top) to south (bottom). Species abbreviations: CROR = *Crotalus oreganus*, CRPR = *C. pricei*, CRWI = *C. willardi*, CRLE = *C. lepidus*, EUCA = *Eumeces callicephalus*, HYEX = *Hyla eximia*, HYAU = *Hylactophryne augusti*, SCSC = *Sceloporus scalaris*, SCVI = *S. virgatus*, SCJA = *S. jarrovii*, PHDO = *Phyronosoma douglassii*, LAPY = *Lampropeltis pyromelena*. Province abbreviations: N = North/Rocky Mountain, S = South/Madrean, W = Widespread.

North **Species**	**CROR**	**CRPR**	**CRWI**	**CRLE**	**EUCA**	**HYEX**	**HYAU**	**SCSC**	**SCVI**	**SCJA**	**PHDO**	**LAPY**
Province	**N**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**W**	**W**
Santa Theresa	X										X	X
Pinaleño	X	X								X	X	X
Galiuro	X									X	X	X
Santa Catalina	X										X	X
Rincon	X										X	X
I-10												
Dragoon				X				X		X	X	X
Whetstone			X	X				X		X	X	X
Chiricahua		X		X				X	X	X	X	X
Santa Rita		X	X	X	X		X	X		X	X	X
Huachuca		X	X	X	X	X	X	X		X	X	X
South												

17 species to be of southern or Madrean in distribution, 23 species to be of eastern or Chihuahuan distribution, and 21 to be of western or Sonoran/Mojave in distribution. For all species combined, we found a significant difference in range occupied north and south of the current route of I-10 (t_{96} = -3.239, p = 0.002). For southern species only, the 50% contour interval falls along a line that roughly parallels I-10 (figure 1). The 50% contour interval for northern species also falls in this general vicinity; in fact all but one of the four species only occurs north of I-10.

The 50% contour intervals for eastern and western species overlap in the southern half of the study area east of the Huachuca Mountains in the San Pedro River Valley (figure 2). North of I-10, the western species 50% contour runs northwest from Saguaro National Park, and the eastern 50% contour runs northeast.

Discussion

Is There a Madrean Line for Herpetofauna?

Although we humans may see clear distinctions between plant and animal communities in different areas of the earth, such boundaries are difficult to quantify. Both the existence and the position of Wallace's Line have been challenged almost since Wallace first advanced it (Mayr 1944; Whitmore 1981). Lowe (1992) focused only on four species of high elevation rattlesnakes; when all montane reptiles and amphibians are considered (table 1), the location of a major biogeographic boundary in the vicinity of I-10 appears to be largely justified, especially for species with southern distributions. Lowe considered the Pinaleños to be enigmatic, with elements of both northern and southern faunas in a presumably "mountain island outlier of the Rocky Mountain (northern) massif" (Lowe 1992). With the two Pinaleño exceptions, only one montane southern species, the mountain spiny lizard (*Sceloporus jarrovii*) in the Galiuro Mountains, occurs north I-10. On the other hand, it is clear from table 1 that distribution of montane species is variable and that none of the Sky Islands in our area contain the full complement of southern species. In addition, few reptiles and amphibians in the Sky Islands can really be considered northern in distribution. The example used by Lowe, the Arizona black rattlesnake, is the only montane species with a largely northern distribution in our study area.

Interestingly, the pattern for all species is very similar to that of montane species (figure 1), with the zone of overlap of 50% indicating a broken Madrean Line just south of I-10. The weakness of this line is the result of the low number of northern species.

Factors Limiting Distributions of Sky Island Herpetofauna

It is interesting to speculate on what factors may influence the fairly abrupt northern limit for so many reptiles and amphibians that occur in the Madrean Archipelago. Potential explanations include current or past climatic factors, such as winter low temperature and summer rainfall, geographic barriers, dispersal rates ecological factors such as competition or predation, or a combination of these. In discussing the "Pinaleño enigma" Lowe (1992) suggested that the Pinaleños were never earlier united by highlands to either the northern or southern mountains, but "witnessed the comings and goings—during the last dozen-odd glacial and interglacial faunal and floral dispersions—of Madrean taxa and Rocky Mountain taxa during the cyclical waxing and waning of their northern and southern distributional limits." While suggesting that the presence of both northern and southern rattlesnakes in the Pinalenos reflect

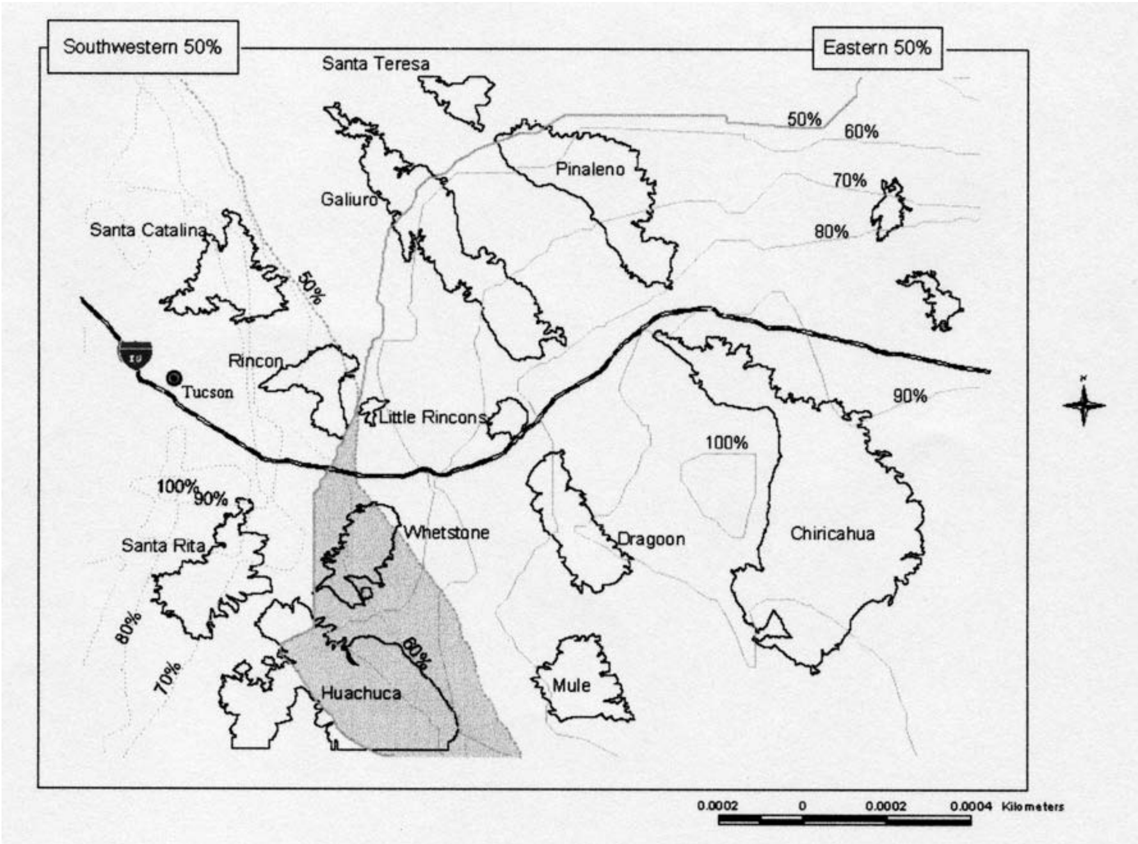

Figure 2—Contour intervals for number of reptile and amphibian species of southwestern/Sonoran-Mojave (n = 21) and eastern/Chihuahuan (n = 23) distributions that occur in the southeastern Arizona Sky Island region. The 50% contours for southwestern and eastern species overlap in the shaded area south of I-10, just east of the Huachuca Mountains in the San Pedro Valley.

the area's history, he clearly believed that the northern limits of Madrean rattlesnakes, like plants and other taxa, are primarly controlled by colder conditions and diminished summer rainfall from south to north.

General patterns of rainfall and temperature do not appear to differ significantly directly north and south of I-10, but this may be due to the lack of climatological data on the appropriate scale. Low winter temperatures could impact reptiles in a variety of ways, ranging from direct mortality to reducing prey availability. Stomach contents of mountain spiny lizards collected simultaneously by Lowe and C. R. Schwalbe in both the Sierre de los Tigres in northern Sonora and the Pinalenos indicated that only the southern population was actively feeding in winter, although individuals in the Pinalenos would take food if offered (C. R. Schwalbe, personal communication). Despite major climatic shifts since the Miocene, including periods that may have been warmer than the present, evidence is lacking that Madrean species previously ranged further north (Holman 1995).

Evidence from a variety of sources, including studies of other Sky Island taxa, suggests that current distributions of herpetofauna and other taxonomic groups in the Southwestern United States are based largely on past distributions (Van Devender 1994). Mitochondrial DNA data suggest that Sky Island populations of jumping spiders (Salticidae; Masta 2000), and mountain spiny lizards (*Sceloporus jarrovi*; Matt Kaplan, personal communication) have been genetically isolated for longer than 10,000 years. It seems possible that the northern limits for Madrean species may be the result of a combination of geography and both past and present climate, with northern distributions of southern species limited by winter temperatures during glacial periods and by geographic barriers (e.g., wide grassland and desert valleys) during interglacial periods.

The east-west pattern in our study area is even more striking than the north-south pattern, and it closely follows well-established boundaries (e.g., Brown et al. 1979) for the Sonoran and Chihuahuan Desert biogeographic provinces. Still, the transition between the two areas is quite abrupt and is interesting because the two deserts also share a large number (17 in our study area) of reptiles and amphibians. This and fossil evidence that some species once ranged further west or east than at present (Van Devender 1994; Holman 1995) suggest different explanations for the east-west pattern than for the north-south one.

Although the past may be the major contributing factor to current distributions of reptiles and amphibians in the Sky Island region, the modern world is having a growing influence. In recent years many native species have declined, and introduced species such as bullfrogs (*Rana catesbeiana*) are spreading rapidly on both sides of the Madrean Line. In 1991, Charles Lowe mourned the impending loss of the Avra Valley and regretted that it had not been included in the Tucson

Mountain District of Saguaro National Park (Lowe 1992). Our best hope is that other valleys and mountains will have their protectors, so that the rich herpetological story of this part of the world is one that future generations can experience, and not just hear about in passing.

Acknowledgments

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Floristic Comparison of an Arizona Sky Island and the Sierra Madre Occidental in Eastern Sonora: the Huachuca Mountains and the Yécora Area

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Abstract—*The floras of the "Sky Island" Huachuca Mountains, Arizona (994 taxa; 316 km²; 1,524-2,885 m elevation, 1,361 m elevational range; 31°30′N) and the "mainland" Sierra Madre Occidental near Yécora, Sonora (1,284 taxa; ca. 2,080 km²; 820-2,140 m, 1,320 m elevational range; 28°24′N) were compared. Only 6.5% and 5.1% of the floras were non-native. Compositae, Gramineae, and Leguminosae contained 39.3% and 40.2% of the taxa. The Apachian floristic element (38.8%) in the Huachuca flora best reflected the 39.9% native taxa shared with Yécora. The plant diversity in the Yécora area is much greater than in any of the Arizona Sky Islands.*

Introduction

The "Sky Island" mountain ranges in southeastern Arizona (Heald 1951) form a floristically diverse archipelago which is a northwestern extension of the "mainland" Sierra Madre Occidental in northwestern Chihuahua and northeastern Sonora. The floras of the Chiricahua, Pinaleño, Mule, Huachuca, Patagonia, Santa Rita, Pajarito, Rincon, and Santa Catalina Mountains show pronounced similarities although there are marked differences related to substrate, land use, topography, surface water, and geographic location (see discussion in Bowers and McLaughlin 1996). The local floras of these ranges are usually referred to as Madrean Floristic Province, reflecting their affinities with the Sierra Madre Occidental. The Sierra Madre Occidental is the massive *cordillera* in Western Mexico that extends 1,350 kilometers from Colima to northwestern Chihuahua and northeastern Sonora (Rzedowski 1978).

In this paper, we compare the flora of the Huachuca Mountains Sky Island in southwestern Cochise County, Arizona, with the Sierra Madre Occidental "mainland" flora in the Yécora area in east-central Sonora.

Study Areas

Huachuca Mountains

The Huachuca Mountains is a north-northeast trending range in Cochise County that extends from the International border 35 kilometers into Cochise County, Arizona. The range is in Coronado National Forest and the Fort Huachuca Military Reservation. The area is drained on the northeast and south by the San Pedro River and on the west by the Santa Cruz River, which both flow southward into Sonora. Paleozoic and Mesozoic sediments including limestone resting on a Precambrian granite base are the dominant rock types in the range. The vegetation ranges from desert grassland with Chihuahuan Desert elements to oak woodland, and pine-oak, pine, and mixed-conifer forests at higher elevations. The flora study area is an area of 316 km² with elevations from 1,524 to 2,885 m, an elevational range of 1,361 m.

Yécora

The Municipio de Yécora extends 75 kilometers from the Chihuahua border westward into Sonora in the broad Río Mayo Region of southern Sonora and adjacent Chihuahua (Gentry 1942; Martin et al. 1998). It is located 335 km southeast of the Huachuca Mountains. Mexican federal highway 16 (MEX 16) passes through the Municipio, connecting Hermosillo, Sonora, and La Junta, Chihuahua (Búrquez et al. 1992). It is the only paved highway that crosses the Sierra Madre Occidental between the Durango-Mazatlán highway (MEX 40) in southern Sinaloa and MEX 2 along the Arizona border in northern Sonora. Most of the Yécora region is in the Río Yaqui drainage with only the southeastern edge of Mesa del Campanero in the Río Mayo basin. Most of the substrates in the study area are rhyolite, andesite, or basalt.

The vegetation gradient along MEX 16 ranges from foothills thornscrub (460-550 m elevation) and tropical deciduous forest (500-1,160 m) to oak woodland (1,050-1,700 m), pine-oak forest (1,220-2,240 m), valley grassland (1,200-1,700 m), and mixed-conifer forest (1,900-2,100 m; Búrquez M. et al. 1992; Martin et al. 1998; Reina et al. 1999). Special habitats in the Municipio include riparian areas, ciénegas (Van Devender et al. 2003), and gossans. Gossans are relatively bare areas of reddish, highly acidic (pH to 4.0) soils derived from hydrothermally altered volcanic rocks with oak woodland or pine-oak forest at 820-1,000 m surrounded by tropical deciduous forest on unaltered soils (Goldberg 1982).

For comparison with the Huachuca flora, only taxa recorded in gossan woodlands, oak woodland, pine-oak forest, and grassland were compared, excluding those in foothills thornscrub and tropical deciduous forest in an area of about 2,080 km² at 820 to 2,140 m elevation, an elevational range of 1,320 meters. The lower elevation of the Yécora study area compared to the Huachuca Mountains (1,524-2,885 m elevation) reflects a well known latitudinal effect where equivalent montane vegetation types occur at different elevations (see discussion in Marshall 1957).

Methods

Huachuca Mountains

There has been interest in the flora of the Huachuca Mountains for over a century, beginning with the collections of John G. and Sara P. Lemmon in 1882. Bowers and McLaughlin (1996) reported a total of 994 taxa for the Huachuca Mountains based on University of Arizona Herbarium (ARIZ) specimens, taxa cited in Kearney and Peebles (1960), and recent collections. Between August 1990 and June 1994, Bowers, McLaughlin, and their colleagues collected 1,154 specimens including 147 species new to the flora on 41 trips to the study area between 1990 and 1994. Their specimens are in ARIZ.

Yécora

Although the intrepid Howard Gentry's book on the Río Mayo flora was published in 1942, he only made a few collections near Santa Ana and Yécora in 1958. The first plant collection in the Yécora area was made by Richard S. Felger in 1955. Between 1955 and 1994, at least a few plants were collected on 90 trips to the Yécora area, involving 102 collectors. In 1968 and 1970, Campbell W. Pennington collected 186 specimens as part of his anthropological studies of the Mountain Pima Indians. Deborah E. Goldberg made significant collections in the Santa Ana area as part of her doctoral dissertation on gossan woodlands in 1975-1977 and 1980. In his spare time, Padre Guillermo (Bill) Trauba made over 500 plant collections in the Municipio and built a personal herbarium during his Catholic missionary activities in 1996-1998. Other individuals including Mark Fishbein (326 collections), Paul S. Martin (217 collections), Richard S. Felger (129 collections), Alberto Búrquez M. (118+ collections), Thomas F. Daniel (88 collections), José Luis León de la Luz (74 collections), and Richard Spellenberg (56+ collections) made important collections in the Municipio. As part of the present inventory of the Municipio de Yécora, we made 5,450 collections (most with duplicates) on 30 field trips between May 1995 and March 2004 (Reina et al. 1999; Van Devender et al., in press). Specimens were deposited in ARIZ, the Universidad de Sonora (USON), and 15 other institutions in the United States and Mexico. Additional taxa from the Municipio were reported in Beetle and Johnson (1991) and Martin et al. (1998; mostly ARIZ specimens). Currently 1,691 taxa of vascular plants have been recorded from the Municipio.

New species have steadily been discovered and described from the Municipio de Yécora since 1989 (Henrickson and Van Devender 1999; Nesom 1998; Roalson 1999; Spellenberg 1999; Turner 1995a,b; Van Devender and Turner 1997; and others). Recent botanical studies in the Municipio include the local flora of the *Sphagnum* seep at the Ciénega de Camilo (Van Devender et al. 2003), noteworthy sedges (Roalson et al. 2002), diversity and distribution of grasses (Van Devender et al., in press), and pollen analyses and vegetation history (Ortega R. 2000).

Results

Although, the Huachuca Mountains and Yécora floras have similar vegetation types (grassland, oak woodland, pine-oak forest, and mixed-conifer forest) and elevational ranges (1,361 and 1,320 m), there are important differences in area (316 km² and ca. 2,080 km²) and substrate (sedimentary and volcanic-igneous rocks). The number of taxa recorded for the Huachucas is much less than in the Yécora flora (106 versus 124 families, 476 versus 503 genera, and 994 versus 1,284 species plus additional intraspecific taxa, 929 versus 1,220 native; table 1). Bowers and McLaughlin (1996) correlated species diversity in Sky Island mountain ranges with elevational range, a reflection of topographic and habitat diversity. A regression analysis of the number of native species against elevational range showed that the Huachuca Mountains flora (929 native taxa/1,361 m) has the greatest plant diversity in the southeastern Arizona Sky Islands. However, with 1,220 native taxa/1,320 m elevational range, the Yécora flora is much more diverse than any of the Arizona Sky Islands. Moreover, using the lower elevational limit of non-gossan oak woodland (1,050 m) raises the diversity even higher.

In general, the Huachuca and Yécora floras are similar. Both areas have 65 non-native exotic taxa, accounting for 6.5% and 5.1% of the floras. The families with the most native taxa are Compositae (168 and 224), Gramineae (96 and 139), and Leguminosae (80 and 128) in both floras. The native taxa in five other families (Euphorbiaceae, Pteridaceae, Scrophulariaceae, Labiatae, and Convolvulaceae) have more or less the same rank orders in the two floras. The taxa in these eight families in both floras account for about half (49.7% and 53.2%) of the native taxa.

A ratio of the number of Huachuca taxa divided by the number of Yécora taxa (HU/YE) provides insight into the floristic differences (table 1). The families Cruciferae, Rosaceae, and Liliaceae are clearly more important in the Huachucas than in Yécora while the Pteridaceae are equally important. The remaining nine families including Gramineae (31% more), Leguminosae (37% more), Convolvulaceae (38% more), Labiatae (51% more), and Malvaceae (61% more) are more important in Yécora.

Looking at the HU/YE ratio for genera also is insightful. Although, *Muhlenbergia* (20 taxa) is important in the Huachucas, Yécora is a major center of diversity for muhlies with 41% more taxa. One interesting shift is in the Cyperaceae with 133% more *Carex* in the Huachucas than in Yécora. However, Yécora has 48% more *Cyperus* plus six *Carex* and an additional 29 sedges in seven other genera, reflecting the greater diversity of *Carex* in temperate floras and *Cyperus* in tropical floras. *Asclepias* and *Euphorbia* (including *Chamaescyce* and *Poinsettia*) are about equally important in the two floras while

Table 1—Comparison of the floras of the Huachuca Mountains (HU), Arizona, and the Yécora area (YE), Sonora.

	Huachucas				Yécora				Shared				
Total flora	**Native taxa 929**		**Number exotics 65**	**Total taxa 994**	**Native taxa 1220**		**Number exotics 65**	**Total taxa 1284**	**Native taxa 371**		**Number exotics 25**	**Total taxa 396**	
Families	**Native taxa**	**Rank order**	**Number exotics**	**Total taxa**	**Native taxa**	**Rank order**	**Number exotics**	**Total taxa**	**Native taxa**	**Rank order**	**Number exotics**	**Total taxa**	**Native taxa HU/YE ratio**
Compositae	168	1	7	175	224	1	2	226	75	1	1	76	0.75
Gramineae	96	2	22	118	139	2	22	161	53	2	9	62	0.69
Leguminosae	80	3	6	86	128	3	3	131	42	3	1	42	0.63
Euphorbiaceae	30	4	0	30	34	5	0	34	11	5	0	11	0.88
Pteridaceae	30	5	0	30	30	7	0	30	12	4	0	12	1
Scrophulariaceae	25	6	3	28	33	6	1	34	8	7	0	8	0.76
Labiatae	17	7	1	18	35	4	3	38	6	8	2	8	0.49
Convolvulaceae	16	8	0	16	26	8	1	27	9	6	0	9	0.62
Cruciferae	15	9	3	18	7	12	6	13	4	9	2	6	2.14
Rosaceae	15	10	3	18	7	13	1	8	4	10	0	4	2.14
Liliaceae	13	11	0	13	10	11	0	10	2	13	0	2	1.3
Solanaceae	13	12	0	13	16	10	5	21	3	11	0	3	0.81
Malvaceae	7	13	0	7	18	9	1	19	3	12	0	3	0.39
Genera	**Native taxa**	**Rank order**	**Number exotics**	**Total taxa**	**Native taxa**	**Rank order**	**Number exotics**	**Total taxa**	**Native taxa**	**Rank order**	**Number exotics**	**Total taxa**	**Native taxa HU/YE ratio**
Euphorbia	21	1	0	21	22	3	0	22	7	3	0	7	0.95
Muhlenbergia	20	2	0	20	34	1	0	34	12	2	0	12	0.59
Asclepias	14	3	0	14	13	9	0	13	3	8	0	4	1.08
Carex	14	4	0	14	6	10	0	6	3	9	0	3	2.33
Cyperus	13	5	0	13	25	2	3	28	13	1	1	12	0.52
Cheilanthes	12	6	0	12	14	7	0	14	6	5	0	6	0.86
Dalea	12	7	0	12	20	4	0	20	5	7	0	5	0.6
Erigeron	11	8	0	11	14	8	0	14	6	6	0	6	0.79
Ipomoea	10	9	0	10	17	5	0	17	7	4	0	7	0.59
Salvia	3	10	0	3	15	6	0	15	1	10	0	1	0.2

four other genera (*Dalea, Erigeron*, *Ipomoea,* and *Salvia)* are from 21% to 80% more important in Yécora.

Discussion

Bowers and McLaughlin (1996) classified all native species in the Huachuca Mountains flora into floristic elements based on McLaughlin's (1989) system of floristic areas for the Western United States. He recognized five floristic provinces: Cordilleran, Intermountain, Sonoran, Californian, and Madrean. The Madrean floristic province was subdivided into Widespread, Regional, Central Arizonan, Chihuahuan, and Apachian floristic elements/districts. In this method, each species are assigned to phytogeographic floristic areas based on their frequency of occurrence in local floras rather than their actual geographic distributions. They concluded that 69.9% of the native Huachuca flora were Madrean floristic elements.

In the present comparison, 39.9% of the native Huachuca flora are shared with the Yécora flora. This is very close to the 38.8% Apachian floristic elements in the Huachuca flora. The Apachian floristic district of the Madrean phytogeographic province is centered in southeastern Arizona (McLaughlin 1989). We conclude that restricting 'Madrean' floristic province species to Apachian taxa in McLaughlin's analyses would give better predictions of the actual percentages of species shared with the Sierra Madre Occidental. As Bowers and McLaughlin (1996) pointed out, the Apachian elements were most common in the oak woodlands and pine-oak forests in the Huachucas. In these communities, many of the dominant trees and shrubs are widespread, resulting in very Sierra Madrean appearing habitats in Sky Islands even if only 40% or less of their floras actually occur in the mainland Sierra Madre Occidental.

The Huachucas have additional plants in high mixed-conifer forest (Cordilleran or Rocky Mountain), desert grassland, and Chihuahuan Desert plants, which are not found on the western slope of the Sierra Madre Occidental. Although lowland tropical plants were excluded from the comparisons, the woodlands and forests of Yécora are rich in montane tropical plants such as *Achimenes grandiflora, Begonia* spp., *Clethra mexicana, Hydrangea seemannii*, *Ilex* spp., *Pinus maximinoi, Quercus tarahumara*, *Stenorrhynchos aurantiacus*, *Tillandsia erubescens*, and *Tigridia pavoniana*, which do not occur in the Western United States.

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The Forgotten Flora of la Frontera

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Abstract—*About 1,500 collections from within 100 kilometers of the Arizona border in Sonora yielded noteworthy records for 164 plants including 44 new species (12 non-native) for Sonora and 12 (six non-native) for Mexico, conservation species, and regional endemics. Many common widespread species were poorly collected. Southern range extensions (120 species) were more numerous than northern extensions (20), although nine potentially occur in Arizona. Non-native species dispersed along highways and escaped from cultivation. The Turkish poppy (*Glaucium corniculatum*), established near Agua Prieta, may reach Arizona. African buffelgrass (*Pennisetum ciliare*) and Natal grass (*Melinis repens*) are rapidly expanding into new, higher elevation areas.*

Introduction

In northeastern Sonora, grassland and Chihuahuan desertscrub extend across the border from Arizona and New Mexico. Isolated "sky island" mountains support oak woodlands and pine-oak forests in the Apachean Highlands Ecoregion, the northwestern Madrean Archipelago extending northeast of the "mainland" Sierra Madre Occidental. Finger-like northern extensions of foothills thornscrub lie in the northern tributaries of the great Río Yaqui to within 150 km of the border in the complex transition from the New World tropics to the northern temperate zone.

Although Spanish explorers, missionaries, ranchers, and farmers were in northern Sonora for more than 350 years beginning in 1533, few descriptions of the vegetation and botanical specimens were made. The first English description of Sonora appears to have been in Hardy's (1829) account of his 1825-27 trip through Mexico where he listed cultivated and native plants he observed being used. During the Mexican Boundary Survey of 1848, six botanists including George Thurber, Charles Wright, and Heinrich W. Schott collected plants between Guadalupe Canyon, Agua Prieta, and Santa Cruz just south of the modern Arizona border (Torrey 1859), initiating real botanical exploration in the Sonoran borderlands.

In 1890, Carl Lumholtz led an archeological expedition from Bisbee, Arizona, through Fronteras and other northern Sonoran towns in route to Chihuahua (Lumholtz 1902). Robinson and Fernald (1894) described new species collected by C. V. Hartman and C. E. Lloyd on the trip. Stephen S. White led a group of botanists from the University of Michigan on three expeditions in 1938-1941 to the Río Bavispe Region in northeastern Sonora. He described the vegetation and made about 4,000 collections of 1,200 species, mostly in an area of 1,200 km² in the Sierra del Tigre within the loop of the Río Bavispe (White 1948). As part of his survey of the birds of the pine-oak woodland, Joseph T. Marshall provided lists of the dominant trees in a series of mountain ranges in southern Arizona and northeastern Sonora (Marshall 1957).

Beginning with Howard Gentry, Forrest Shreve, and Ira Wiggins in the 1930s, botanists from the United States rushed southward to the tantalizing tropical deciduous forests of the Río Mayo region of southeastern Sonora, the treasures of the Sierra Madre Occidental in eastern Sonora (Gentry 1942; Martin et al. 1998), or the scenic Sonoran Desert (Shreve and Wiggins 1964). Botanists from Mexico City 2,200 km to the southeast only occasionally visited Sonora. Solis G. (1993) and Fishbein et al. (1995) provided preliminary reports on the flora of the Sierra de los Ajos east of Cananea. In 2001, we began collecting plants in northern Sonora within 100 kilometers of the Arizona border as part of the "Pollinator Monitoring and Education in Mexico" project. In spite of the White collection, we found that even common plants had not been well collected in the Sonoran borderlands. In this paper, we present preliminary results of our floristic survey of the borderlands.

Study Areas and Methods

Between July 2001 and April 2004, botanists from the Arizona-Sonora Desert Museum, Arizona State University (ASU), the University of Arizona (ARIZ), and the Universidad de Sonora (USON) visited the border region on 20 trips. Plant collections were made between Arroyo San Bernardino (109°08'W) east of Agua Prieta and the Sásabe area (111°59'W) within 50-100 kilometers of the Arizona border in the municipios of Agua Prieta, Bacoáchi, Cananea, Cucurpe, Fronteras, Imuris, Magdalena, Naco, Nacozari de García, Nogales, Santa Cruz, Sáric, and Tubutama. Elevations ranged from 630 m at Tubutama to 1,690 m west of Cananea. The vegetation ranged from Chihuahuan (near Agua Prieta) and Sonoran (near Tubutama) desertscrub to desert grassland (Cananea-Naco, Sásabe area), plains grassland (Santa Cruz Valley), oak woodland (Nacozari, Patagonia Mountains, Sierras Las Avispas, and Los Pinitos), and cottonwood-willow riparian forests (Arroyos Planchas de Plata and San Bernardino, Cíbuta-Imuris, Tubutama,). The area is within the Apache Highlands Ecoregion of The Nature Conservancy of

Arizona and the Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora (Marshall et el. 2004). Trips were scheduled after spring and summer rains to make general collections of reproductive plants. About 1,500 plants were collected under SEMARNAT permits to Francisco Molina F. and Jesús Sánchez E. and deposited into ARIZ, ASU, USON, and many other herbaria in the United States and Mexico. Most Cactaceae specimens were deposited in to USON in Hermosillo.

Results and Discussion

Plant collections within 100 km of the Sonora border were made for 164 species with few or no previous Sonoran records. Forty-four species, including 12 introduced from the Old World, are new for Sonora. Twelve species including six introduced weeds appear to be the first records for Mexico. Collections of 120 species are southern range extensions of Chihuahuan and Sonoran desertscrub, grassland, Apachean oak woodland, and riparian plants. In contrast, 20 collections reflected northward extensions of Sonoran desertscrub, foothills thornscrub, or "mainland" Madrean oak woodland species. Selected examples of noteworthy Sonoran plant collections are presented in table 1.

An *Anoda* (Malvaceae) southwest of Cananea and a *Flaveria* (Compositae) from east of Agua Prieta appear to be undescribed species (Paul A. Fryxell and B. L. Turner, personal communication, 2002). A few collections were of Arizona-Sonora regional endemics (*Bouteloua eludens* and *Pseudabutilon thurberi*). Some new Sonoran species such as Bartram stonecrop (*Graptopetalum bartramii*), green violet (*Hybanthus verticillatus*), sandpaper oak (*Quercus pungens*), and windmill grass (*Chloris verticillata*) are southward range extensions from southern Arizona. Interestingly, three Chihuahuan Desert species including red cyphomeris (*Cyphomeris gypsophilioides*), *Ruellia parryi*, and a sunflower (*Helianthus laciniatus*) do not occur in Arizona, while *Carlowrightia texana* was recently discovered in the San Pedro Riparian National Conservation Area east of the Huachuca Mountains (Elizabeth Makings, personal communication, 2004).

A few species in the Sonoran borderlands are of conservation concern in Arizona. These include Bartram stonecrop, bigflower blue star (*Amsonia grandiflora*), and the rosewood (*Vauquelinia californica* subsp. *pauciflora*). Our 1995 collection of Gentry indigo bush (*Dalea tentaculoides*) at Cruz del Diablo near Huásabas in eastern Sonora illustrates the importance of borderlands records. It was a southeastern range extension of 250 kilometers from the population in Sycamore Canyon west of Nogales, and was used to support dropping the species as a Candidate species for listing as Threatened under the Endangered Species Act in 1998. However, in 2002 the Center for Biological Diversity petitioned the U.S. Fish and Wildlife Service to list it as Endangered because it was only known from the two Arizona and one Sonora populations. Additional information from the Sonoran portion of its range will be critical in evaluating its' status.

Many of the noteworthy Sonoran collections are common Arizona plants with a few previous collections in Sonora. These include blackspine, pancake, and Santa Rita prickly pears (*Opuntia macrocentra*, *O. chlorotica*, and *O. santa-rita*), burro grass (*Scleropogon brevifolius*), cliff rose (*Purshia stansburiana*), desert holly (*Acourtia nana*), littleleaf sumac (*Rhus microphylla*), rabbit brush (*Ericameria nauseosa*), soapberry (*Sapindus marginatus*), tarbush (*Flourensia cernua*), turpentine bush (*Ericameria laricifolia*), and many more. New records of Chihuahuan Desert plants in Sonora include dogfennel (*Thymophylla acerosa*), plains flax (*Linum puberulum*), ruda del monte (*Thamnosma texana*), sandpaper bush (*Mortonia sempervirens*), sandpaper oak, Texas shrub senna (*Senna wislizenii*), and twoleaf desert senna (*S. bauhinioides*).

A suite of Sonoran plants is found in the borderlands of Arizona from the Baboquivari Mountains southwest of Tucson east to the New Mexico border. A few examples are ball moss (*Tillandsia recurvata*), chiltepín (*Capsicum annuum* var. *aviculare*), confituría amarilla (*Lagascea decipiens*), coralbean (*Erythrina flabelliformis*), and feathertree/tepeguaje (*Lysiloma watsonii*). Our collections near the border in Sonora suggest that additional species may be discovered in Arizona. *Carlowrightia texana* (31°18'49"N) and red cyphomeris (31°13'59"N) were 2 and 5 kilometers south of the border (SOB) near Agua Prieta. Willowleaf oak (*Quercus viminea*; 31°08'31"N) was in oak woodland with the closely related Emory oak/bellota (*Quercus emoryi*) in the Sierra Las Avispas 16 km south of the border. Toji (*Struthanthus palmeri*; 22 km SOB; 31°07'06"N), a parasite on kidneywood/palo dulce (*Eysenhardtia orthocarpa*) and Emory oak, was nearby in an area where ball moss covers oaks and ocotillos (*Fouquieria splendens*). Farther west on the road to Sáric, ba'aco (*Phaulothamnus spinescens*; 17.5 km SWOB; 31°10'52"N) and bebelama (*Sideroxylon occidentale*; 27 km SOB; 31°08'59"N) grow with organ pipe cactus/pitahaya (*Stenocereus thurberi*) near La Arizona, the historic ranch for which the State of Arizona was named. Limpiatuna (*Kosteletzkya thurberi*, 45 km SOB; 30°57'21"N), a mallow with a large rose-colored flower, was found in the ciénega at Rancho Agua Caliente 19 km north of Imuris. The Sonoran Desert nopal durasnilla (*Opuntia gosseliniana*) was seen 57 km northwest of Caborca on MEX 2, 55 km southwest of the Arizona border.

Non-native Species

Of special conservation interest are the non-native species discovered in the borderlands. A lily (*Asphodelus fistulosus*) collected in Sonora for the first time north of Cucurpe is a Federal Noxious weed in the United States. A few Turkish poppies (*Glaucium corniculatum*) were first found in Mexico 4.7 km north of Santa Ana, Sonora, on MEX 15 in 1998. This annual has rough, dissected basal leaves, striking flowers with dark red petals grading into orange or yellow at the tips, and elongated, slender t-shaped fruit. In April 2004, thousands of individuals were found in broad roadside drainage areas along MEX 2 east of Agua Prieta. Considering that the border is only 2 km to the north, this attractive weed is to be expected in Arizona.

Other non-native species escape from cultivation. Individual Siberian elms (*Ulmus pumila*) have established in the Río Santa Cruz near Santa Cruz and on roadsides along MEX 2

Table 1—Selected noteworthy plants collected in the Sonoran borderlands in 2001-2003.

Native species new for Sonora
Artemisia pringlei (Compositae)
Carlowrightia texana (Acanthaceae)
Chloris verticillata (Gramineae)
Cyphomeris gypsophiloides (Nyctaginaceae)
Graptopetalum bartramii (Crassulaceae)
Helianthus laciniatus (Compositae)
Hybanthus verticillatus (Violaceae)
Kallstroemia hirsutissima (Zygophyllaceae)
Leersia oryzoides (Gramineae)
Lonicera albiflora (Caprifoliaceae)
Lotus hamatus (Leguminosae)
Lygodesmia ramosissima (Compositae)
Melampodium strigosum (Compositae)
Penstemon linarioides var. *viridus* (Scrophulariaceae)
Ruellia parryi (Acanthaceae)
Quercus pungens (Fagaceae)

Non-native species New for Sonora
Asphodelus fistulosus (Liliaceae)
Chorispora tenella (Cruciferae)
Eragrostis echinochloidea (Gramineae)
Fumaria officinalis (Fumariaceae)
Fumaria parviflora (Fumariaceae)
Glaucium corniculatum (Papaveraceae)
Herniaria hirsuta (Caryophyllaceae)
Kochia scoparia (Chenopdiaceae)
Medicago lupulina (Leguminosae)
Sinapsis arvensis (Cruciferae)
Verbascum virgatum (Scrophulariaceae)
Veronica anagallis-aquatica (Scrophulariaceae)

New records of northern species
Acourtia nana (Compositae)
Amsonia grandiflora (Apocynaceae)
Asclepias subverticillata (Asclepiadaceae)
Bahia absinthifolia (Compositae)
Chamaesaracha sordida (Solanaceae)
Cistanthe monandra (Portulacaceae)
Ericameria laricifolia (Compositae)
Ericameria nauseosa (Compositae)
Erioneuron grandiflorum (Gramineae)
Evolvulus sericeus (Convolvulaceae)
Flourensia cernua (Compositae)
Gaillardia pinnatifida (Compositae)
Gomphrena caespitosa (Amaranthaceae)
Hedeoma nanum (Labiatae)
Jatropha macrorhiza (Euphorbiaceae)
Lepidium thurberi (Cruciferae)
Linum puberulum (Linaceae)
Mortonia sempervirens (Celastraceae)
Opuntia chlorotica (Cactaceae)
Opuntia macrocentra (Cactaceae)
Opuntia santa-rita (Cactaceae)
Panicum hallii (Gramineae)
Physaria fendleri (Compositae)
Pseudabutilon thurberi (Malvaceae)
Purshia stansburiana (Rosaceae)
Rhus microphylla (Anacardiaceae)
Salvia subincisa (Labiatae)
Sapindus marginatus (Sapindaceae)
Scleropogon brevifolius (Gramineae)
Senna bauhinioides (Leguminosae)
Sphaeralcea angustifolia (Malvaceae)
Tagetes minuta (Comositae)
Thamnosma texana (Rutaceae)
Thelesperma megapotamicum (Compositae)
Thymophylla acerosa (Compositae)
Vauquelinia californica subsp. *pauciflora* (Rosaceae)

Southern species near Arizona border
Acacia occidentalis (Leguminosae)
Havardia mexicana (Leguminosae)
Kosteletzkya thurberi (Malvaceae)
Opuntia gosseliniana (Cactaceae)
Phaulothamnus spinescens (Phytolaccaceae)
Quercus viminea (Fagaceae)
Sideroxylon occidentale (Sapotaceae)
Struthanthus palmeri (Loranthaceae)
Tephrosia leucantha (Leguminosae)

and SON 117 in the Agua Prieta area. Honey locust (*Gleditzia triacanthos*), a large spiny legume with dense foliage native to the Southeastern United States, is a common shade tree near Lochiel, Arizona, and in Santa Cruz, Sonora. Scattered honey locusts in the Río Santa Cruz near Santa Cruz appear to be from the town trees and not from Lochiel as claimed by Solis et al. (2002). The Asian tree of heaven (*Ailanthus altissima*) was widely planted as an ornamental in the 1800s, especially in rural and mining towns. In Santa Cruz, it is locally called "nogal," reflecting the similarity of the leaves with the Arizona walnut/nogal (*Juglans major*). Colonies of plants were seen in several places in the Río Santa Cruz both near and away from houses and ruins. Although this tree reproduces profusely with root sprouts, hundreds of seedlings were found on roadcuts. Jujube/dátil chino (*Ziziphus jujuba*) is an ornamental tree with an edible fruit that was widely planted by Chinese immigrants. Although no Chinese presently live in San Lázaro and Santa Cruz, dátil chino is still appreciated by the mestizo residents. A stand of trees was found along MEX 2 east of Agua Prieta in an area without houses or ruins nearby. In the old mining town of Bisbee, Arizona, fennel (*Foeniculum vulgare*) is a European plant used for food and medicine that is well established in disturbed areas along streets. A collection of this plant in a similar weedy urban setting in Agua Prieta is the first record for Sonora.

Two non-native grasses are of special concern in the Sonoran borderlands. Buffelgrass/zacate buffel (*Pennisetum ciliare*) is a robust, shrub-like African grass that has been actively planted in Sonora for cattle forage. However, in Arizona and Texas, it is perceived as a threat because it introduces fire as an ecological process into fire-intolerant Sonoran and Chihuahuan desertscrub. Beetle et al. (1991) mapped it in most of central and southern Sonora in areas with 300 mm/yr or less rainfall. Their highest elevation observation for buffelgrass was 1,280 m west of Cumpas (Rogelis Alcaraz, personal communication, 2004). Recently it was seen at 1,420 m elevation in oak woodland on the Sierra de Mazatán 70 km east of Hermosillo (Jesús Sánchez E., personal communication, 2004). Our collections suggest that this savanna grass is expanding its range upward to at least 1,320 m in northern and northeastern Sonora elevation, and include the first records for the municipios of Agua Prieta, Fronteras, Imuris, and Nacozari de García; it probably also occurs in the municipios of Cananea and Naco. Noteworthy localities for buffelgrass record were in desert grassland 9.9 km north on MEX 15 (916 m) and 15 km northeast on MEX 2 (1,310 m elevation) of Imuris and in Chihuahuan desertscrub 18.3 km east on MEX 2 and 36 km south on SON 117 of Agua Prieta (1,139-1,320 m elevation).

Natal grass/zacate rosado (*Melinis repens*) is a South African species that is widespread in Sonora but reaches higher elevations than buffelgrass (Beetle et al. 1991). Our collections were the first records for the municipios de Nacozari de García and Tubutama; we expect more records for the municipios de Cananea, Fronteras, Naco, Santa Cruz, and Sáric. This species has begun to increase rapidly in the last few years. In the last six years we have noticed dramatic increases in this grass in northern Sonora south of Nogales and northeast of Imuris, as well as in easternmost Sonora in the near Yécora. At higher elevations it is replacing native grasses in desert grasslands. At 15 km northeast of Imuris on MEX 2, it is invading a unique grassland with feathertrees dominants on a south-facing slope at 1,310 m elevation. In the Guadalupe Tayopa-Tepoca area in the Municipio de Yécora, Natal grass now dominates disturbed openings in tropical deciduous forest.

In conclusion, the flora of the Sonoran borderlands is very diverse and reflects complex transitions between temperate desertscrub, grassland, and oak woodland and tropical vegetation to the south. Additional collections in the area will continue to yield many range extensions, State records for Sonora, national records for Mexico and track threats from aggressive non-native species.

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Hummingbird Conservation: Discovering Diversity Patterns in Southwest U.S.A.

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Abstract—*Using data obtained in 2002 and 2003 from sites in the Hummingbird Monitoring Network, we investigated the effect of geographic factors—latitude, longitude, and elevation—and year on hummingbird diversity patterns in Southwestern U.S.A. In California, none of these factors affected hummingbird richness but elevation significantly affected abundance. In southeastern Arizona, longitude and elevation significantly affected richness; year affected abundance. For all sites, elevation and longitude affected richness, year and elevation affected abundance. We compared these results with global hummingbird diversity patterns and suggest that the distribution of forest and rainfall patterns are likely important factors for conserving hummingbird diversity and abundance.*

Introduction

The north end of the Madrean Archipelago region of southeastern Arizona has the greatest number of hummingbird species in the United States and Canada (Johnsgaard 1983). Hummingbirds occur only in the New World and are the second most diverse family of birds there (Schuchmann 1999). Their distribution shows a strong latitudinal gradient (Greenewalt 1960) where the highest numbers of species live in the tropics. As one travels either north or south of the equator, hummingbird richness, defined as the number of hummingbird species in an area, declines (figure 1). Ecuador lies along the equator, is about the size of Colorado, and has 130 species (Ortiz Crespo 2003). Southeastern Arizona at latitudes between 31°N and 33°N has 15 regularly occurring species (Tucson Audubon Society 1995). Based upon this latitudinal distribution pattern, other regions farther south in the United States should be more likely candidates for this northern diversity center. Yet, south Texas has only nine and Big Bend National Park has ten regularly occurring hummingbird species.

In addition to richness, diversity is measured by the abundances of species in a region. This second component to diversity is poorly understood for hummingbirds (Schuchmann 1999). One reason for this missing knowledge is that techniques used to monitor other land birds fail to adequately monitor hummingbird populations (Rich et al. 2003). Two studies in southeastern Arizona (Wethington and Russell 2003; Wethington et al., in press) show that sites there support large numbers of hummingbirds, particularly during southbound migration. Thus, southeastern Arizona supports high richness and high abundance for North America. Identifying factors that make this region an important diversity center for hummingbirds is important for their conservation in the Madrean Archipelago region.

The Hummingbird Monitoring Network (HMN) is a group of scientists, citizens, land managers, and property owners who are committed to maintaining the diversity and abundance of hummingbirds. We began monitoring hummingbird populations in Arizona and California in 2002 (figure 2) with the following research goals. (1) To determine the best long-term monitoring sites for hummingbirds in Western United States and Northwestern Mexico; (2) to effectively sample their

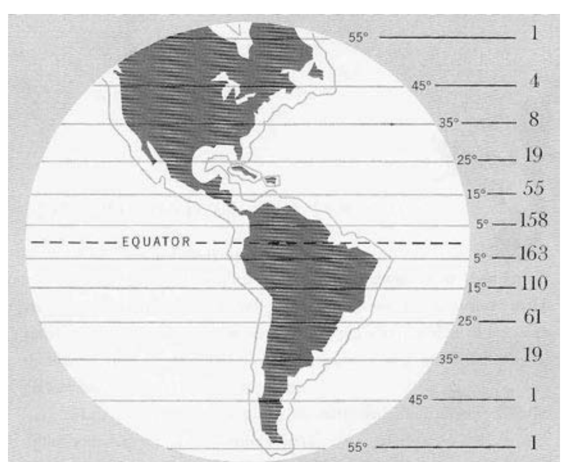

Figure 1—Map of the number of hummingbird species occurring at different latitudes (Greenewalt 1960).

Figure 2—General location of HMN's monitoring sites in California and Arizona.

populations sizes to detect trends; and (3) to use the resulting information for hummingbird conservation. Our research is a systematic banding study that generates knowledge about hummingbird diversity, abundance, productivity, and survivorship at a number of sites. We choose monitoring sites based upon geographic factors, such as elevation, longitude, and latitude, and vegetation types. Thus, HMN provides information about areas that support a high diversity and abundance of hummingbirds and that are important for breeding and migration success. HMN also tracks the timing of hummingbird occurrence and their seasonal movement patterns. This paper describes diversity patterns discovered during our first two field seasons and then discusses possible implications of these patterns.

Study Sites and Methodology

Study Sites

Table 1 describes HMN's monitoring sites. In 2002, there were nine in Arizona, two in California. In 2003, we expanded to 13 in Arizona and five in California. Six sites in Arizona and two in California were monitored during both years. Sites were classified into elevation, latitude, and longitude classes.

Monitoring Protocol

At least five commercial hummingbird feeders with a sugar solution of one part sugar to four parts water were maintained at each site while hummingbirds were present. At sites where feeder number could not be controlled, the number of feeders in the area was recorded. Hummingbirds were trapped and banded once every two weeks from early March to late October. Trapping and banding began within one half-hour of sunrise and continued for five hours, but was delayed if the temperature was below 38 °F. We used two Hall traps (Russell and Russell 2001) that each covered one feeder. The other feeders were taken down and were not accessible to hummingbirds during the banding period. At the banding table, birds were identified, aged, and sexed in chronological order and were held no longer than 30 minutes. The bander determined how many birds that he/she could safely band within this time limit. When the number of birds waiting to be processed was reached, the bander requested the trappers to stop trapping. While they were not actively catching birds, they recorded the number of birds that entered the trap. They also recorded all birds that escaped while actively trapping.

Statistical Analyses

We used the numbers of hummingbird species captured and observed at a site during a monitoring session and the daily estimated abundance of individuals to identify hummingbird diversity patterns. The abundance estimate includes both the number of individuals captured and one-tenth the number of birds counted at the trap but not captured. We assumed that hummingbirds fed once every 30 minutes and that the feeders were their sole source of nectar. Thus, one hummingbird would visit a feeder 10 times during a monitoring session (2 visits/hour * 5 hours). We used ANOVA to determine which geographic factor—elevation, latitude, and longitude—and if year affected the estimated abundance and species richness values among our sites. We used a standard $P < 0.05$ to indicate statistical significance. Values presented are means ± SD. All analyses were done with AXUM 6.0.

Results

We ran two sets of ANOVA analyses on the monitoring data. In the first set, the data for dependent variables—species richness and estimated abundance—were taken from each monitoring day at each site. This provided large sample sizes, included all the variability in the data, and had high statistical power. For the second set of analyses, we averaged the dependent variables from each site and year. This eliminated much of the variability encountered at a site within a year but likely provided statistical significance values that are more realistic. The mean values for species richness and estimated abundance were essentially equal in both analyses.

In California, where sample sizes are small, geographic factors and year had no significant effect on richness, but elevation significantly affected the estimated abundance (table 2, figures 3 and 4). Richness averaged 3.1 ± 1.3 species for all geographic and year classes. The average estimated abundance varied by elevation and averaged 27.1 ± 19.8 individuals (n = 58) at low elevations and 81.3 ± 53.5 (n = 30) at mid elevations.

In Arizona, elevation and longitude significantly affected richness (table 2, figures 3 and 4). With increased statistical power, year also had an effect. Mid elevation sites in the western Arizona longitudinal class (table 1) had the highest species richness. In 2002, species richness was 6.1 ± 2.1 (n = 28) and in 2003, 5.3 ± 2.1 (n = 62). Low elevation sites had 3.5 ± 1 (n = 12) and 2.8 ± 1 (n = 32) species in 2002 and 2003, respectively. High elevation sites had 3.5 ± 1.7 (n = 10) and 2.8 ± 1.4 (n = 12). At the eastern HMN Arizona sites, richness at mid-elevation sites was 4.2 ± 1.5 (n = 36)

Table 1—Description of HMN monitoring site. The geographic factors—elevation, latitude, and longitude—and vegetation type are given for each site. The years of monitoring, the number of monitoring days, and the number of days defined as migration days are also provided. A migration day is defined if there were more than 100 trap visits within a monitoring session. The number of migration days directly affects the estimated abundance for a site. Each site is also classified into different geographic classes. We defined three elevation, three longitude, and three latitude classes. Low elevation sites occur at less than 1,200 m; mid elevation sites between 1,200 m and 1,800 m; and high elevation site over 1,800 m. Ranges of latitude defined these classes. The most southern sites occur between 31° and 32°, the next between 32° and 33°, and the most northern class between 33°00″ and 34°30″. Longitudinal classes fall within the following ranges: Eastern Arizona sites between 109° and 110°30″, Western Arizona sites between 110°30″ and 111°40″, and California sites between 116° and 117°30″.

Monitoring sites	Monitoring years		Monitoring days 2002	Monitoring days 2003	Migration days 2002	Migration days 2003	Elevation (m)	Elevation	Longitude	Dominant vegetation type
ARIZONA – Eastern Sites										
TNC Aravaipa Canyon	2002	2003	13	13	1	1	1,001	32°52	110°24	Desert Riparian
Private Residence, Klondyke	2002	2003	11	13	3	0	1,065	32°51	110°20	Mesquite/Grasslands
Private Residence, Fort Grant	2002	2003	13	14	6	1	1,496	32°37	109°56	Mesquite/Grasslands Oak/Riparian nearby
Private Residence, Rock Creek	2002		10		1		1,526	31°53	109°28	Oak/Mesquite/ Riparian
NPS Chiricahua Nat'l Mon.		2003		14		1	1,616	32°00	109°21	Oak/Pine
Private Residence, Paradise	2002	2003	12	13	4	2	1,688	31°56	109°13	Riparian/Oak/Pine
USFS Visitor Center, Mt Graham		2003		8		0	2,870	32°42	109°54	Pine/Fir
ARIZONA – Western Sites										
Tohono Chul Park		2003		14		0	765	32°20	110°58	Desert/Garden
Tanque Verde Guest Ranch, Tucson	2002		12		0		840	32°14	110°41	Desert/Mesquite Riparian nearby
NPS Tumacacori Hist. Park		2003		17		7	975	31°34	111°02	Mesquite/Riparian
NPS Coronado Nat'l Mem.		2003		16		0	1,615	31°20	110°15	Oak/Pine
Chuparossa Inn, Madera Canyon	2002	2003	14	16	1	0	1,621	31°42	110°52	Riparian/Oak/Pine
TNC Ramsey Canyon Preserve		2003		16		0	1,686	31°26	110°18	Riparian/Oak/Pine
Private Residence, Miller Canyon	2002	2003	14	15	3	3	1,745	31°25	110°17	Orchard/Oak/Pine/ Riparian
NOAO Kitt Peak Observatory		2003		12		4	2,065	31°57	111°35	Juniper/Oak
Private Residence, Summerhaven	2002		9		5		2,420	32°26	110°45	Pine/Fir
CALIFORNIA										
UC Motte Rimrock Reserve,		2003		16		1	350	33°48	117°15	Desert Scrub
BLM Big Morongo		2003		16		0	805	34°03	116°34	Mesquite
Private Residence, Yucca Valley	2002	2003	11	15	0	0	1,030	34°07	116°28	Desert Scrub
NAS Bear Paw Sanctuary		2003		9		3	1,358	34°06	116°58	Oak/Pine
Private Residence, San Jacintor Mtns.	2002	2003	9	12	3	5	1,405	33°35	116°36	Pine

and 4 ± 1.5 (n = 41) species in 2002 and 2003, at low elevation sites, 3.2 ± 1.3 (n = 23) and 2.7 ± 1.2 (n = 26) and at high elevations 2.4 ± 0.9 (n = 9) in 2003. There were no high elevation sites in 2002.

Year significantly affected abundance estimates at sites in Arizona (table 2, figures 3 and 4). Low elevation sites averaged 31.5 ± 19.6 individuals (n = 35 days) in 2002 and 29.4 ± 32.8 (n = 58) in 2003. Mid elevation sites averaged 75.6 ± 54.4 (n = 64) in 2002 and 34.4 ± 34.9 (n = 103) in 2003. High elevation sites averaged 75.7 ± 54.4 (n = 10) in 2002 and 44.1 ± 60.8 (n = 21) in 2003. At the eastern Arizona high elevation site in 2003, the abundance values likely underestimated the population since feeders ran dry often.

When all sites are combined, the results for species richness is dominated by the Arizona patterns. The results for estimated abundance shows both elevation, which was significant in California, and year, which was significant in Arizona, as significant factors (table 2).

Table 2—Results of the ANOVA analyses. Two sets of analyses were done. In the first set, hummingbird richness and estimated abundances were averaged for each site in each year. In the second set, the richness and estimated abundances were evaluated from data taken from each monitoring day at each site. The factors that showed significant effects are in bold.

			Species richness						**Estimated abundance**					
			Averaged values per site per year			**Values per monitoring day**			**Averaged values per site per year**			**Values per monitoring day**		
Sites	**Factors**	**DF**	**n**	**f stat**	**p**	**n**	**f stat**	**p**	**n**	**f stat**	**p**	**n**	**f stat**	**p**
All sites			29			379			29			379		
	Elevation	2		7.74	**<0.01**		44.2	**<0.001**		4.63	**<0.03**		16.9	**<0.001**
	Longitude	2		5.28	**<0.02**		18.7	**<0.001**		0.97	>0.39		2.52	>0.08
	Latitude	2		0.30	>0.58		1.76	>0.18		1.09	>0.30		2.57	>0.11
	Year	1		2.17	>0.15		8.83	**<0.01**		4.86	**<0.04**		22.5	**<0.001**
California			7			88			7			88		
	Elevation	1		0.01	>0.91		0.00	>0.96		41.2	**<0.01**		47.2	**<0.001**
	Year	1		0.07	>0.80		0.04	>0.83		0.45	>0.54		0.34	>0.55
Arizona			22			291			22			291		
	Elevation	2		8.22	**<0.01**		44.4	**<0.001**		1.90	>0.18		7.33	**<0.001**
	Longitude	1		6.31	**<0.03**		24.1	**<0.001**		0.33	>0.57		0.94	>0.33
	Latitude	1		0.09	>0.77		0.15	>0.70		0.17	>0.68		0.17	>0.68
	Year	1		2.09	>0.16		8.72	**<0.01**		7.01	**<0.02**		30.0	**<0.001**

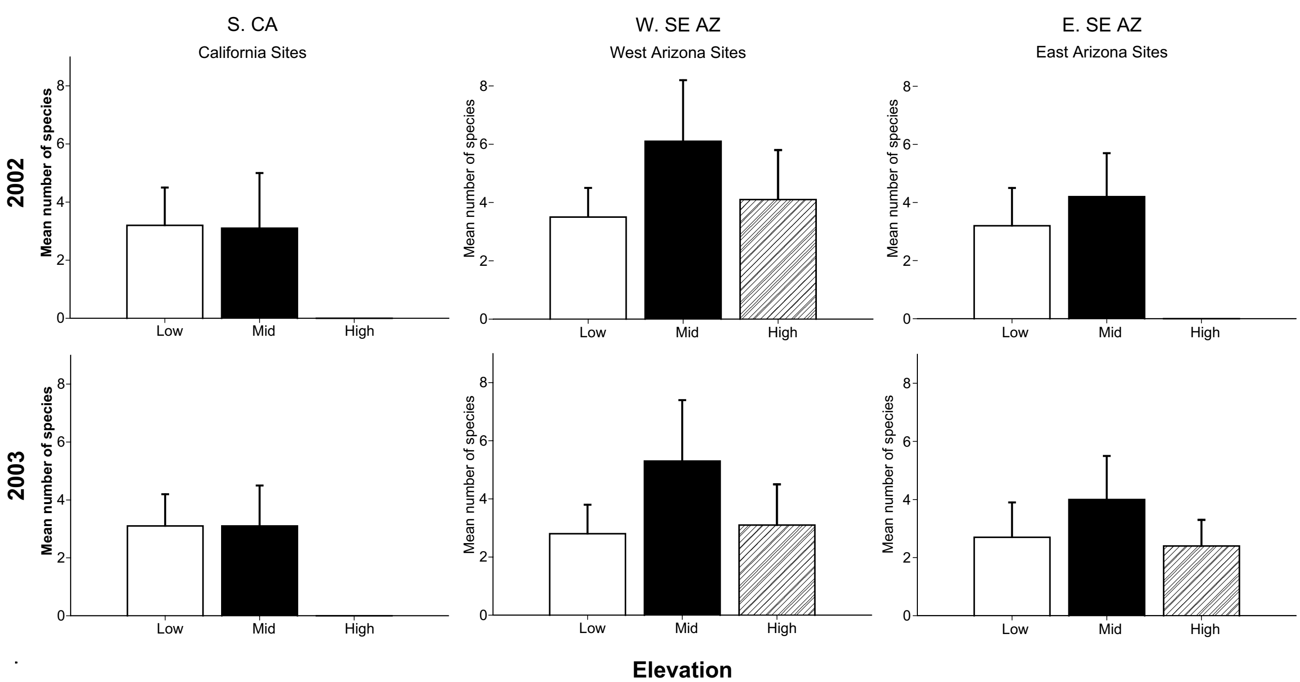

Figure 3—Species richness distributions for hummingbirds at HMN monitoring sites. Each graph shows results of each longitude, elevation, and year class. Mean richness values (± SD) are shown. Geographic factors and year had no significant effect on richness in California. In Arizona elevation and longitude significantly affected richness.

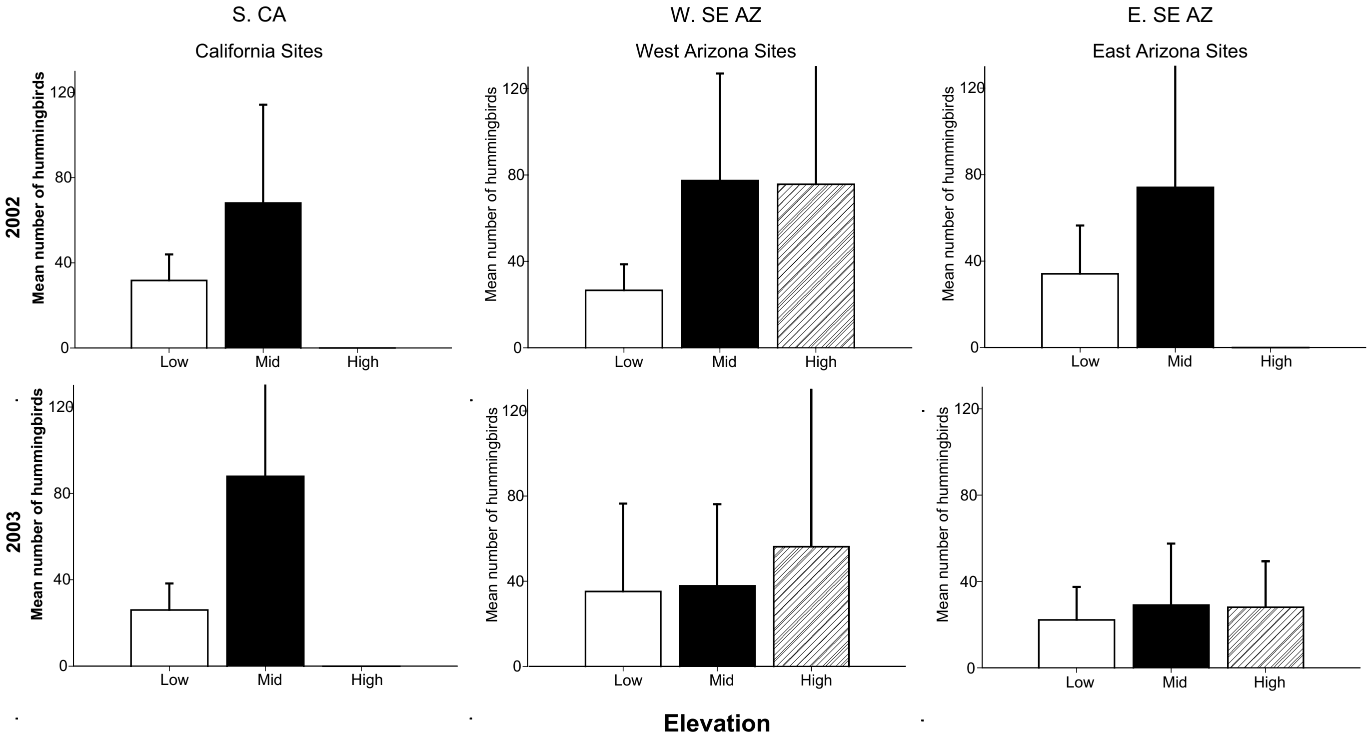

Figure 4—Estimated abundances for hummingbirds at HMN monitoring sites. Each graph shows results of each longitude, elevation, and year class. Mean abundance values (± SD) are shown. Elevation affected abundance in California and year in Arizona.

Discussion

A central goal of conservation is to preserve areas that represent and maintain the diversity of a region (Cabeza and Moilanen 2001; Margules and Pressey 2000). Thus, effective conservation of hummingbirds requires an understanding of factors that promote their diversity and of areas that currently are important for breeding and migration success. The diversity patterns that we identify at the northern end of hummingbird diversity are likely affected by their global patterns emanating from the neotropics. For example, the number of hummingbird species in the neotropics is greatest in the humid forests at elevations between 1,800 and 2,500 m (Schuchmann 1999). Areas lower in elevation but still in moist forest habitats also support high hummingbird richness (Becker and Lopez 1997).

Our results indicate that elevation significantly affects hummingbird richness at their northern center of diversity. The elevations with the highest species richness at HMN sites ranged from 1,500 m to 1,800 m. Both the tropical and temperate elevations where hummingbird richness is greatest occur at middle elevations.

Latitude affects hummingbird diversity throughout the New World, but did not influence species richness or abundance at HMN sites. The latitudes at our sites differ by only three degrees. It is likely that this latitudinal pattern of diversity occurs at larger spatial scales than our study.

Longitude significantly affected hummingbird richness at HMN sites. Yet, this geographic factor has not been identified as a factor in a global diversity pattern for hummingbirds. This unexpected longitudinal effect occurred within Arizona as well as across all our sites. More species occurred in the western Madrean Archipelago region of southeastern Arizona than in the eastern area or in California. HMN western sites in Arizona occurred from the Baboquiviri Mountains in the west to the Huachuca Mountains in the east. The eastern sites occurred east of the Huachuca and Santa Catalina Mountains and included sites in or near the Pinaleno and Chiricahua Mountains. Since hummingbirds occur in humid forests of the tropics, rainfall patterns may be a factor in this geographic affect. Using thirty-year average rainfall amounts reported for areas in southeastern Arizona on the NOAA website (www.wrh.noaa.gov/tucson/climate/seaz_new_rainfall_normals.html), annual rainfall at the weather stations near HMN western sites averaged 23.4 inches whereas rainfall near HMN eastern sites averaged 21.3 inches. Although the difference in rainfall might not be significant, the valley between our eastern and western Arizona also indicates a potential difference in moisture availability. In this valley called Sulfur Springs Valley, vegetation from the Chihuahuan Desert meets the vegetation of the Sonoran Desert (MacMahon 1985). On average, the Chihuahuan Desert is drier than the Sonoran Desert, which has two rainy seasons instead of one. Also, the Mojave Desert, a drier desert than the Sonoran Desert, separates HMN's California sites from the forests of the Sierra Madre (MacMahon 1985).

Although hummingbirds live in virtually all habitats, their diversity appears most dependent on forest habitats throughout the Americas. In 1999, twenty-five hummingbird species were listed as threatened or endangered, but none in the United States and Canada. Of these 25, all but two rely on forests for at least one stage of their life history (Schuchmann 1999). In the Madrean Archipelago region, the mid-elevation range, which supports the greatest number of species, also supports the most diverse forest types. It is likely that maintaining these forest are critical to hummingbird diversity there. A review of the eleven Birds of North America (BNA) accounts for hummingbirds that occur in southeastern Arizona indicate that nine of these species rely on forests for breeding (Baltosser and Russell 2000; Baltosser and Scott 1996; Calder 1993; Calder and Calder 1992, 1994; Powers 1996; Powers and Wethington 1999; Russell 1996; Scott 1994; Wethington 2002; Williamson 2000).

So, why is southeastern Arizona the northern center of hummingbird diversity and not south Texas or Big Bend National Park? South Texas is near sea level and is not forested. The lack of nearby forests likely eliminates a number of species from south Texas. Additionally, forest and elevation maps of Mexico (URL: http://www.unep-wcmc.org/habitats/mountains/cam.htm) show that the area in Mexico bordering south Texas is low elevation and not forested.

These maps suggest that the region south of Big Bend has similar elevations as the region south of HMN's southeastern Arizona sites, but that these mountain ranges are not forested like the area south of southeastern Arizona. An additional difference between the regions south of Big Bend and southeastern Arizona is rainfall patterns. When hummingbird species distribution and rainfall maps of the New World are compared (figures 5 and 6), correlation between hummingbird species richness and average rainfall emerges for Central and South America. It appears that average rainfall and forests are good predictors for hummingbird richness in forested areas.

The factors affecting hummingbird abundance are much less studied than the distribution of hummingbird species (Schuchmann 1999). Often, the abundance of available food, nectar and insects, is suggested as a major factor affecting the abundance of hummingbirds (see BNA references). In HMN's results, the year of monitoring in Arizona significantly affected the abundance of hummingbirds. This temporal variation of their abundance between years suggests that abundance is likely affected by environmental conditions such as food availability. 2002 and 2003 were years of virtually no winter rains and below normal summer rains in southeastern Arizona. It is likely that nectar resources continued to decline during our monitoring seasons and that lowered nectar resources could have affected abundance values.

This exploration of hummingbird diversity suggests that factors affecting hummingbird diversity throughout the New World help explain patterns discovered at their northern center of diversity and are likely important for maintaining hummingbird diversity in the Madrean Archipelago region. These factors are rainfall patterns and the distribution of forests. By studying diversity patterns for the family of hummingbirds, which are a monophyletic group (Sibley and Ahlquist 1990), the patterns associated with these factors could be investigated. We think that monitoring areas of high diversity for a taxonomic family provides important information such as general habitat requirements for that family. Changing diversity patterns at these sites can also help identify species that might be encountering population threats elsewhere and thus help focus attention. We suggest that it is important to focus monitoring efforts at the family level, in addition to the species level. For as the name implies, the family is the evolutionary reproductive unit required for sustainability.

Acknowledgments

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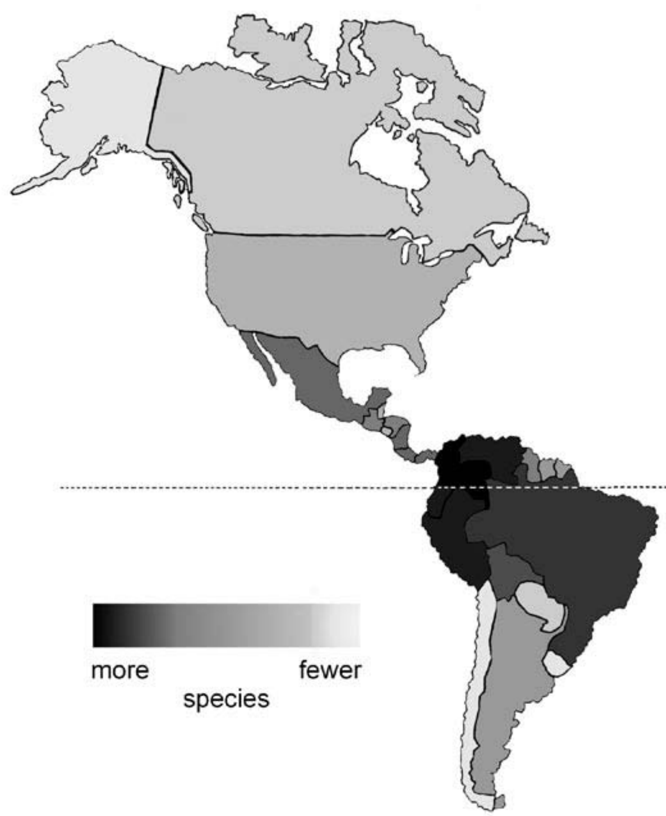

Figure 5—Map of hummingbird richness for North, Central, and South America by country.

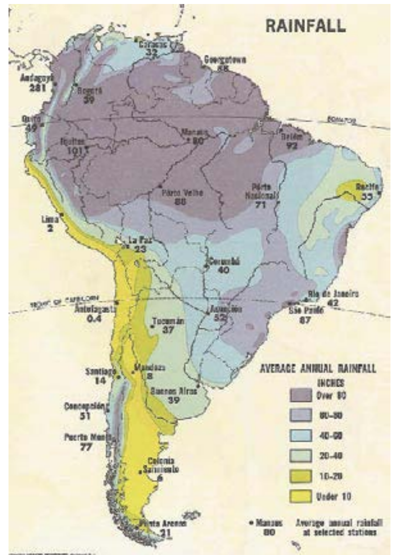

Figure 6—Maps of average annual rainfall for North, Central, and South America (Hamond 1971).

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Ecosystem Monitoring

An Overview of the Floristic Richness and Conservation of the Arid Regions of Northern Mexico

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Abstract—*The arid and semiarid regions of Northern Mexico harbor diverse, highly endemic, and geographically complex ecosystems. These share topographic and biogeographic similarities that can be used as an analytical framework to assess biodiversity patterns. This study presents the current status of vascular plant inventories for Mexican Aridamerica. The spatial distribution of floristic records obtained for different vegetation types was analyzed for a 171-year period of field inventories. Floristic curatorial records (96,302) were obtained from the Mexican National Biodiversity Information System, provided by CONABIO, belonging to 10,772 species. Results show sampling efforts are scarce to characterize the vascular plant diversity of the natural ecosystems of Northern Mexico. The lowest sampling efforts were recorded for the central regions of the states of Sonora, Chihuahua, Coahuila, Sinaloa, Durango, Zacatecas, and western San Luis Potosí. The highest species richness was obtained for currently disturbed areas, since most of the analyzed floristic records are historical. The sites where most specimens were collected are now agricultural lands or urban zones.*

Introduction

Arid regions are characterized by relatively fewer species than those found in more humid environments. In the arid and semiarid regions of Northern Mexico, plants have evolved into a moderately rich and distinctive flora with specialized growth forms that are often unique (Rzedowski 1992). Therefore, biodiversity in these regions must be given high priority, since each species lost from an arid region represents a higher percentage loss of the region's biodiversity than in more speciose regions (McNeely 2003).

Biological inventories have traditionally been considered the most extensive means to document species biodiversity. Herbaria harbor vast information of large geographical areas that are quite useful to describe regional floras and to review phytogeographic patterns. Although inventories are the first step in biodiversity assessment and in many other approaches to biological conservation, taxonomically complete inventories are rarely conducted. In Mexico, botanists have carried out biological inventories for almost two centuries (Davis 1936; Ochoterena 1942; Fulton 1944; McVaugh 1956; Rzedowski 1959, 1981, 1997; Miranda 1961; Sousa 1969; Lozoya 1984; Herrera et al. 1998; Bernabéu et al. 2000, among others). The phanerogamic flora of Mexico is estimated at roughly 220 families, 2,410 genera, and 22,000 species. Approximately 10% of the genera and 52% of the species are endemic to Mexico (Rzedowski 1992). Based on previous data, one could think sampling efforts account for most of the plant species diversity distributed in the country.

In this study, we present an overview of the floristic records and conservation of Mexican Aridamerica by addressing the following queries: Are the current biological inventories enough to describe vascular plant diversity of these regions in Northern Mexico? How does a spatial scale of analysis determine an adequate pattern of sampling efforts in the region? What is the correlation between current land use in these regions and floristic curatorial records?

These queries are addressed by analyzing the specimen records and species richness of vascular plants occurring in Mexican Aridamerica over 171 years, as well as their present spatial distribution according to a current land use and vegetation map.

Methods

The boundaries of Mexican Aridamerica were defined according to physiographic (INEGI-IGUNAM 1990), geomorphologic, and climatic criteria (Cervantes-Zamora et al.

Table 1—Floristic specimen records provided by the Mexican National Biodiversity Information System (SNIB-Conabio 2001) collected by different botanists in the arid and semiarid regions of Northern Mexico during 1827-1998.

Class	Species	Records	Sampling period
Cycadopsida	10	61	1962-1997
Dicotyledonae	8,942	69,234	1827-1998
Gnetopsida	11	64	1946-1994
Monocotyledonae	1,712	23,805	1839-1998
Pinopsida	96	3,111	1848-1998
Taxopsida	1	27	1965-1990
Total	10,772	96,302	

1990), as well as to cultural ones (SEDESOL 2000). The study area comprised all the Northern Mexican states and its limits to the south with the physiographic province "Eje Volcánico Transversal," to the southeast with the ethnic region "Huasteca" and physiographic region "Llanuras y lomeríos," and to the southwest with the ethnic region "Huicot" and physiographic regions "Mesetas y cañadas del Sur" and "Pie de la Sierra." The floristic records included information for 17 Mexican States located in these regions. Baja California, Baja California Sur, Sonora, Chihuahua, Coahuila, Nuevo León, Aguascalientes, and San Luis Potosí were fully covered. Sinaloa, Durango, Zacatecas, and Tamaulipas were covered in the majority of their territory, except for their extreme southern parts. Jalisco, Guanajuato, Querétaro, Hidalgo, and Veracruz were partially covered, specifically their northern areas.

For this area, 68 databases of floristic specimens provided by the Mexican National Biodiversity Information System (SNIB-CONABIO 2001) were analyzed. Data included 10,772 species and 96,302 specimen records collected by botanists from 1827 to 1998 (table 1). Specimen records were analyzed according to sampling dates and were grouped by decades. Specimen records were also digitized and projected onto a grid of cartographic cells (4 × 4 km), using the land use and vegetation map generated by INEGI (2002). Subsequently, the cartographic cells containing at least one specimen record were highlighted on a map. Specimen records were projected onto the digitized land use and vegetation map (INEGI 2002), and species richness was obtained for each land use and vegetation class. Only those classes where species richness was higher than 100 species were included in the analysis.

Results and Discussion

Historical and Spatial Analysis of Field Inventories

An historical analysis of the field inventories carried out by botanists in Mexican Aridamerica is shown in figure 1. These data only include the information compiled in the SNIB, and do not necessarily include the specimen records housed in all the Mexican or foreign herbaria. Three statistical modes in the field inventories, grouped by decades, can be distinguished in this logarithmic graph. The first stage shows that only a very few hundred plant specimens were obtained from 1827 to1866, and they were collected only by foreign botanists. A second stage occurred from 1867 to 1925. During this period, although few field inventories were carried out, important collections were obtained by several herbaria, mostly in the U.S.A. The more relevant botanists who collected vascular plants in these regions of Mexico were E. Palmer, T. S. Brandegee, G. Thurber, J. Gregg, K. Hartweg, C. Wright, J. L. Berlandier, J. G. Schaffner, and A. Schott. The third stage (1927-1998) has been the most exhaustive and productive period, since it accounts for more than one hundred thousand specimens collected by numerous botanists. Some of the more relevant ones are H. S. Gentry, E. Y. Dawson, F. Gander, L. R. Stanford, S. White, F. Miranda, E. Hernández X., I. L. Wiggins, I. M. Johnston, F. Shreve, H. Leseur, R. M. Turner, P. S. Martin, R. M. Stewart, V. H. Chase, R. Moran, A. Carter, J. Rzedowski, R. McVaugh, J. R. Reeder, T. R. Van Devender, R. Spellenberg, F. González-Medrano, R. Bye, and R. Vega-Aviña, to list the most prominent individuals. Likewise, a continuous increase in the number of species and curatorial records obtained during this period is shown in figure 1. This tendency was the result of a growing interest of Mexican authorities to promote scientific policies oriented toward biodiversity monitoring during the last decades of the 20th century, as a consequence of a global interest subsequent to the Convention on Biological Diversity. Unfortunately this pattern changed recently, and a marked decrease in the number of specimens is seen in the last two years of the period analyzed.

The results of the digitization of specimen records and their projection onto a 4- x 4-km grid, using the land use and vegetation map are shown in figure 2. Although the analyzed specimen records are very numerous (96,302), their spatial distribution is heterogeneous and clustered within a few geographical areas. Most of the records come from the northern and southern parts of the Baja California Peninsula, while other areas showing high concentrations of sampled specimens occur in some parts of the States of Nuevo León, Tamaulipas, and eastern San Luis Potosí. Likewise, the northern portions of the States of Guanajuato, Querétaro, and Hidalgo also show areas where plant specimens have been collected more thoroughly. Specimens collected in the central parts of Sonora, Chihuahua, Coahuila, Sinaloa, Durango, Zacatecas, and western San Luis Potosí are completely skewed and incomplete. These were obtained following the highways and road networks and do not represent the flora of broad landscape units. Few interpretations and inferences concerning species richness, distribution, and biodiversity patterns can be derived from these data, since sampling efforts have neither been exhaustive nor intensive in the arid and semiarid regions of Northern Mexico.

Specimen Records, Land Use, and Biodiversity Loss

Changes in land use have been considered one of the greatest threats to biodiversity, globally. This analysis for Northern Mexico illustrated this same issue at a local approach. The highest species richness of vascular plants in this study was recorded in disturbed habitats (figure 3) including areas of seasonal (3,979 species) and irrigated (2,476) agriculture, urban zones (3,100), and induced (1,661) and cultivated grasslands (787). These records account only as historical.

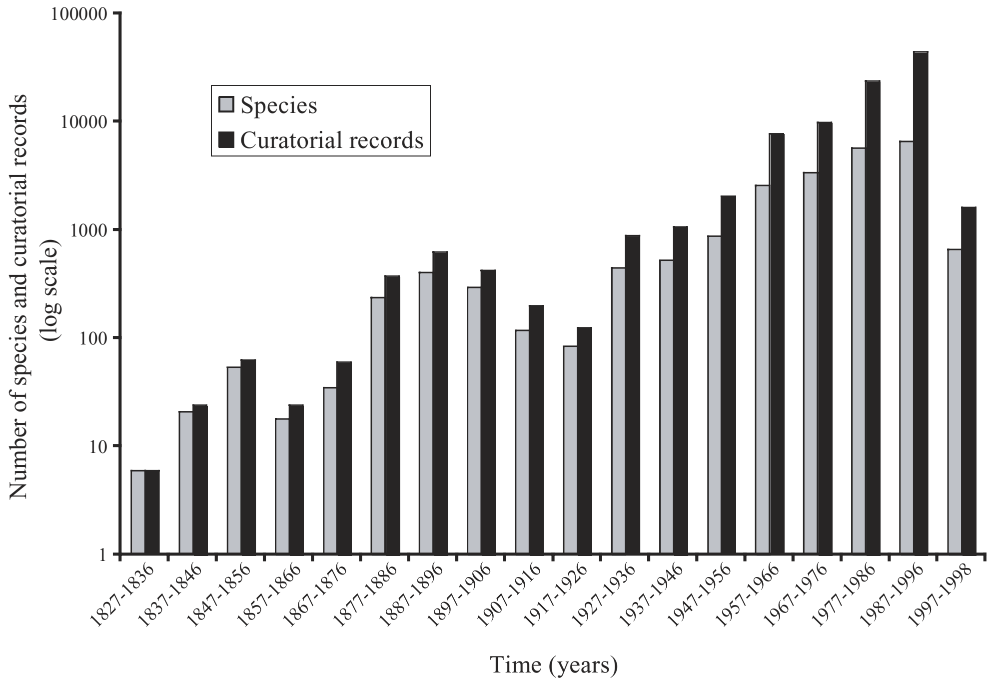

Figure 1—Field inventories of vascular plants for a time interval comprised from 1827 to 1998. Specimen records were provided by the taxonomic databases of the Mexican National Biodiversity Information System (SNIB-Conabio 2001).

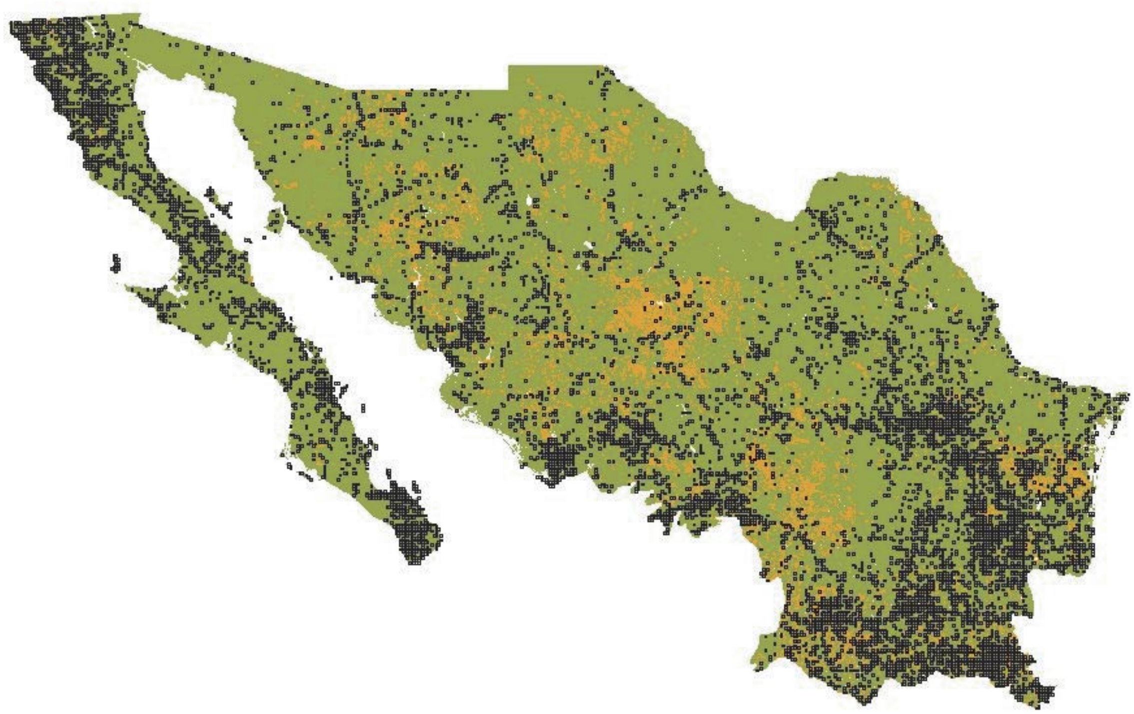

Figure 2—Spatial distribution of the field records of vascular plants in Northern Mexico for a sampling period comprised from 1827 to 1998. Specimen records are projected onto a 4 x 4 km grid. Black color stands for those areas where at least one specimen record was collected. The green color represents all the natural vegetation classes grouped, while the yellow color groups the secondary vegetation according to INEGI (2002).

The natural vegetation classes recording the highest species richness are oak forests (2,522 species), deciduous seasonal forest (2,405), pine (1,988) and pine-oak forests (1,924), submontane scrub (1,824), chaparral (1,562), and microphyllous desertscrub (1,525). Other vegetation types such as sarcocaulescent desertscrub, oak-pine forest, rosetophyllous desertscrub, and natural grasslands also have more than 1,000 species, while the remainder of vegetation classes are less rich (figure 3).

These results show that sampling efforts do not account for most of the plant species diversity distributed in Mexican Aridamerica, and that most of the available specimen records

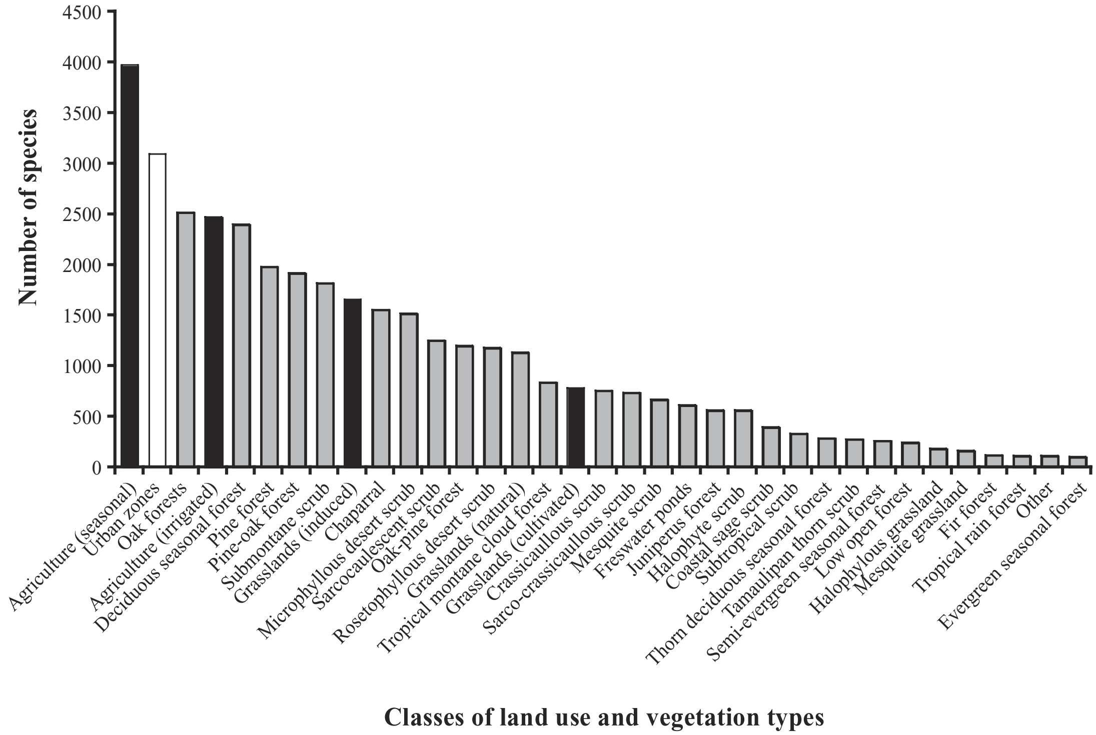

Figure 3—Species richness associated to land use and vegetation classes. Species richness was obtained from plant inventories compiled in the SNIB, and land use and vegetation classes are based in INEGI (2002). Black and white bars stand for disturbed habitats. Only land use and vegetation classes with more than 100 species were considered

in Mexican and foreign herbaria are now historical records that no longer occur in natural habitats, because of changes in land use.

Concluding Remarks

We believe that considerable efforts need to be made to document vascular plants biodiversity in these regions. Taxonomically current species inventories are essential components of regional and global conservation efforts, and although the decade of the 1990s promoted the inventory of biodiversity as never before (figure 1), these efforts do not appear to be enough to describe regional floras or landscape units. It is widely recognized that taxonomic information is a prerequisite to understanding biodiversity. Unfortunately, this discipline is not currently being fully supported in the universities and research institutions. The taxonomic impediment to progress in the study of biodiversity is linked to a worldwide shortage of taxonomists (Simpson and Cracraft 1995). The lack of enough taxonomists and the rapid changes in land use could, in the short term, prevent documentation of the distinctive flora of the unique desert habitats of Northern Mexico. Better collaboration between United States and Mexican botanists need to be promoted to integrate and complete floristic studies in Aridamerica.

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High-Resolution Climate Monitoring on a Mountain Island: The Saguaro National Park Pilot Study

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Abstract—*A pilot project to identify climate monitoring needs within Saguaro National Park began in fall 2003. Nine weather stations were deployed across the complex topography of the park to provide insight into the spatial and temporal patterns of climate within the park management unit. This project will provide a valuable baseline for park management and may highlight unique spatial and temporal patterns that deserve further investigation. Project findings will help dictate long-term climate monitoring strategies for the park and other park units.*

Introduction

Climatic variables are especially important to natural resource management because they are strongly tied to ecosystem function yet are often overlooked in management activities because of inadequate monitoring. Spatial and temporal patterns in precipitation can limit or promote the growth of different plant species, while patterns in temperature can induce mortality in vegetation and wildlife during hard freezes or episodes of excessive heat (Bonan 2002). Current climate monitoring systems within National Parks capture variability at scales too coarse to be relevant to park-level natural resource and ecosystem management decisions. Climate information is integral to many different management activities and needs to be collected at spatial and temporal scales appropriate for a diversity of activities including:

- ***Wildlife studies:*** Predicting amphibian movement patterns based on high-resolution precipitation data.
- ***Hydrological monitoring:*** Addressing water rights issues and maintaining baseflows in critical riparian habitats.
- ***Wildfire management:*** Monitoring spatially explicit fuel moisture conditions and predicting fine fuel accumulations; Analyzing the relationships between post-fire vegetation recovery and climatic variability.
- ***Invasive species management:*** Establishing links between climatically induced disturbances and invasions of non-native species.
- ***Air quality management:*** Monitoring airflow patterns from urban airsheds carrying harmful pollutants; understanding smoke dispersion during prescribed burns for fuel management.
- ***Water quality and channel morphology:*** Characterizing patterns in precipitation with respect to erosion and sedimentation rates in streams.
- ***Education:*** Providing the opportunity for park visitors to learn about the importance of climatic variability on different ecosystem processes and coupled ecosystem-climate monitoring.

Project Background and Design

The Sonoran Desert possesses great habitat diversity due to steep environmental gradients within small geographic areas (Hubbard et al. 2003). The Rincon Mountain District of Saguaro National Park is only 27,000 hectares in size, but contains six biotic communities due to its steep topography. Many programs exist within the park to monitor and inventory wildlife and vegetation, but little has been done to monitor physical environmental parameters in a systematic and long-term manner. This is especially true for climatological variables, which are one of the strongest determinants of the spatial distribution of biological communities within the park.

The present pilot study is an attempt to assess the climatological monitoring needs within a relatively small park with the unique natural resource management challenges posed by the biological diversity found on isolated mountain ranges called sky islands. Since 1994, meteorological data have been collected at two sites within the park boundary. One station is located near the visitor's center at an elevation of 700 meters, while the other is located near the top of the Mica mountain range at 2,500 meters elevation. The lower elevation station is part of the Pima County Department of Environmental Quality (DEQ) air quality monitoring program, and the upper elevation station is part of the National Interagency Fire Center Remote Automated Weather Station (RAWS) program. Each station collects basic meteorological data (wind speed, temperature, relative humidity, precipitation) on an hourly basis, but does so with different sensors and monitoring equipment making long-term comparisons difficult. The two stations' purposes also vary. The Pima DEQ site is focused on air quality monitoring, while the RAWS site is designed for National Fire Danger Rating System (NFDRS) calculations. Each site collects specialized measurements that are not directly comparable. Spatial and temporal patterns of climatological variables relevant to natural resource management activities within the park do exist, but cannot be resolved by the current configuration of meteorological stations within the park.

Nine meteorological stations have been deployed throughout Saguaro National Park-RMD to assess the representativeness of current climate data collection strategies and to explore new ways of integrating climate information into natural resource management decision making. Figure 1 shows the location of meteorological stations within the park deployed for the pilot study as well as the two existing stations (RAWS and Pima County DEQ sites). Each pilot study station collects ten meteorological variables at ten-minute intervals, storing the data in an on-site datalogger. Variables monitored include: air temperature, relative humidity, rainfall, barometric pressure, solar radiation (300-1,100 nm), photosynthetically active radiation (400-700 nm), wind speed, wind direction, soil moisture (10 cm depth), and soil temperature (10 cm depth). Each variable is monitored in compliance with World Meteorological Organization standards (WMO 1983).

The goal for this pilot study was to capture the spatial and temporal variability in climatic patterns potentially relevant to specific natural resource management needs and to identify long-term monitoring strategies that could be applied at other parks. Four stations were located at regular intervals (300-500 m) along a drainage to complement existing hydrological studies and to capture the climatic component of the topographic-environmental gradient. Three stations at the top of Mica Mountain were spaced to assess the importance of aspect and spatial variability over the upper elevation regions of a sky-island. One of these stations was placed adjacent to the existing RAWS to compare data acquisition strategies (variables, sampling interval, sensor placement). The two remaining stations were located near the summit of Rincon Peak and in the saddle between Rincon Peak and Mica Mountain to assess the spatial variability in climatological variables between two adjacent peaks. Site information, including ecological community type, for each station appears in table 1.

These stations are located with respect to existing Saguaro National Park monitoring programs including wildlife monitoring, water quality monitoring, and fuel/post-fire vegetation recovery monitoring. New monitoring programs are also being instituted in conjunction with the weather station network. Vegetation monitoring plots have been established near each station and are being sampled at a high frequency (monthly to seasonally) to compliment the high-temporal resolution climate data. Evaluating links in species composition, phenology, and plant reproductive cycles to high-resolution climate variability will provide insight into ecosystem function and help to better inform resource management decisions.

Preliminary Results

Stations were installed during the period of September 2003 through May 2004, resulting in different periods of record for each station at the writing of this paper. A preliminary examination of data from several stations demonstrates that distinct climatic patterns exist over short distances within the park. Air temperature data from four stations for a 7-day period in late March and early April of 2004 are presented to illustrate climatic variability within the monitoring network (figure 2). The approach of a vigorous low-pressure system and subsequent cold frontal passage transitioned the entire Southwest United States from exceptionally warm and dry conditions to cold and wet. The month of March 2004 was the warmest March on record for many locations in southern Arizona including the city of Tucson (NWS 2004). Early spring growth of annuals and budding on trees were noted during field visits in March to several of the weather station sites, including high elevation sites. The passage of the cold front on April 1, 2004, dropped temperatures over 10 ^{o}C in just a few hours. The upper elevation site (RAWSDN, 2,417 m) recorded below freezing temperatures for over 30 hours after the frontal passage. The lower elevation sites (MADRAN, SHIDAG, and GRASHA) also recorded substantial drops in temperature, but none fell below freezing.

This type of climatic variability is probably not uncommon at each of these sites. Each of these stations is located at sites representing different ecological community types with different long-term climatic regimes. What is unclear is how flora and fauna are responding to climatic variability at short time scales. Subsequent vegetation sampling and wildlife monitoring may show that the period of freezing at higher elevations impacted certain plant and animal species in unexpected ways, while lower elevation species were not impacted. Ecosystem dynamics are driven in part by short duration, high intensity climate variability as well as the slower changes brought on by lower frequency variability (e.g., global warming) (IPCC 2001). Understanding how ecosystems respond to high frequency climate variability (e.g., short duration, extreme events) is necessary to properly manage natural resources in a changing climate. For example, accounting for a late season freeze can provide crucial information on live versus dead fine fuel availability for early summer wildfires.

Examination of wind speed and direction data over the same period further illustrates the spatial variability of climatic variables within the 27,000 hectare park boundary. Wind roses for the same four stations discussed previously are plotted in figure 3. Each wind rose depicts the frequency of occurrence of winds in 16 direction sectors (every 22.5 degrees) and 6 wind speed classes using 1,009 wind observations over the seven day period from March 30 through April 5, 2004.

Each wind rose in figure 3 has one dominant direction with the highest frequency of occurrence and interestingly is a different direction at each site. The MADRAN and SHIDAG sites have a higher frequency of northerly and northwesterly wind observations, while GRASHA and RAWSDN have more northeasterly to southeasterly observations. MADRAN, SHIDAG, and GRASHA are located along a drainage that is most likely influencing dominant wind directions. The dominance of easterly winds at GRASHA and northerly winds at SHIDAG and MADRAN suggests that cold air drainage flows are occurring during the evening hours. Plotting wind roses for evening hours (9 PM LST to 5AM LST) only (not shown) confirms that over 45% of evening wind observations are northerly (MADRAN and SHIDAG) or easterly (GRASHA) consistent with an air flow pattern that follows the drainage along which they are located. The highest elevation station (RAWSDN) is at the top

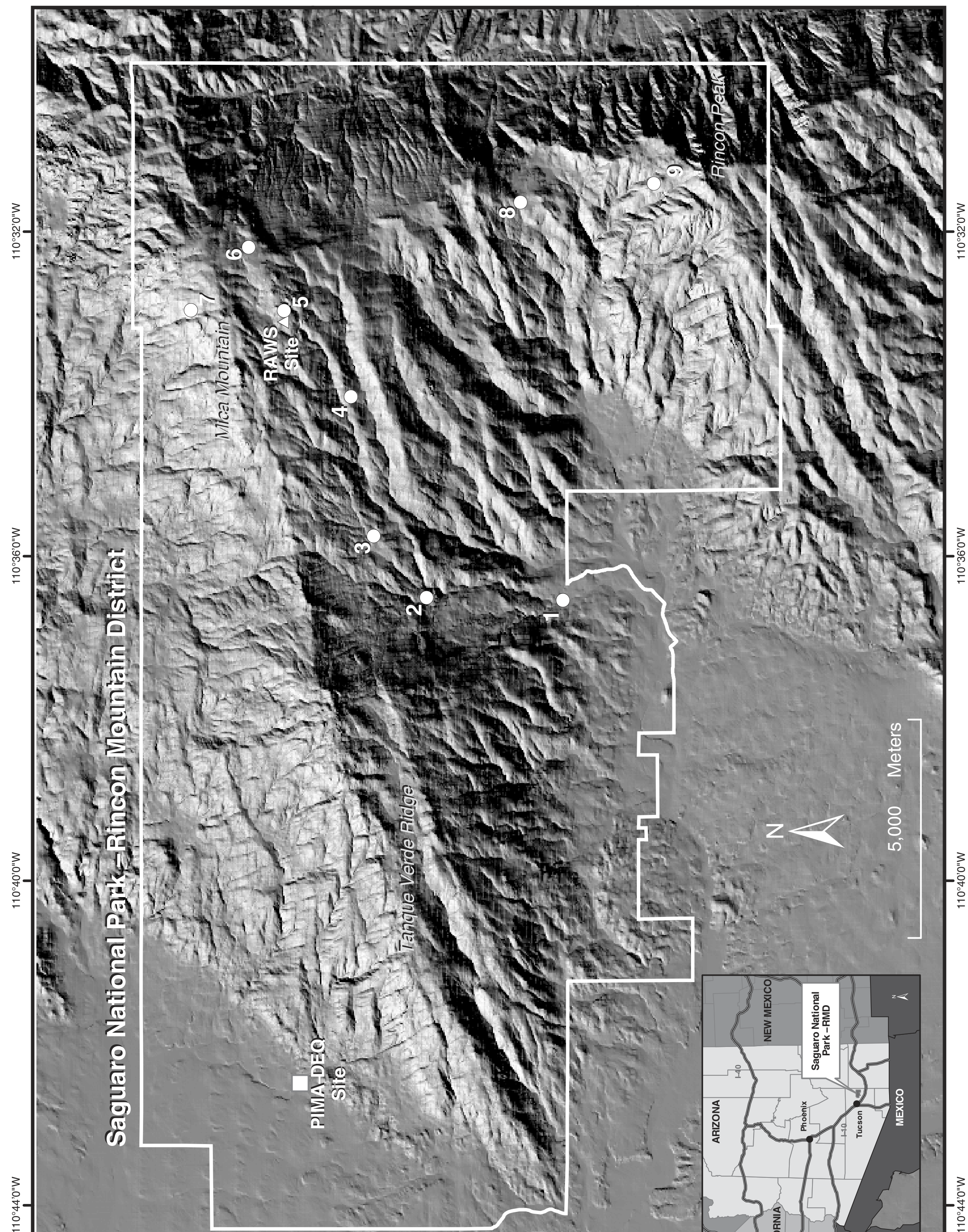

Figure 1—Weather station locations in Saguaro National Park-RMD. Refer to table 1 for station names and site information.

Table 1—Weather station site characteristics.

Station	Name	Elevation	Aspect	Ecotone/community type	Site installation
1	MADRAN	1,052 m (3,450 ft)	S	Upper Sonoran Desert Scrub	September 2003
2	SHIDAG	1,402 m (4,599 ft)	S	Madrean Evergreen Woodland/Chaparral	December 2003
3	GRASHA	1,670 m (5,500 ft)	Level	Madrean Evergreen Woodland	February 2004
4	MANZAN	1,980 m (6,500 ft)	S	Pinyon/Juniper Woodland	May 2004
5	RAWSDN	2,417 m (7,929 ft)	S	Ponderosa Pine Forest	February 2004
6	MICMEA	2,325 m (7,627 ft)	Level	Ponderosa Pine Forest/Open Meadow	March 2004
7	NORSLO	2,430 m (7,972 ft)	N	Mixed Conifer Forest	March 2004
8	HAPVAL	1,923 m (6,309 ft)	W	Pinyon/Juniper Woodland	May 2004
9	RINPEA	2166 m (7,106 ft)	N	Mixed Conifer Forest	May 2004

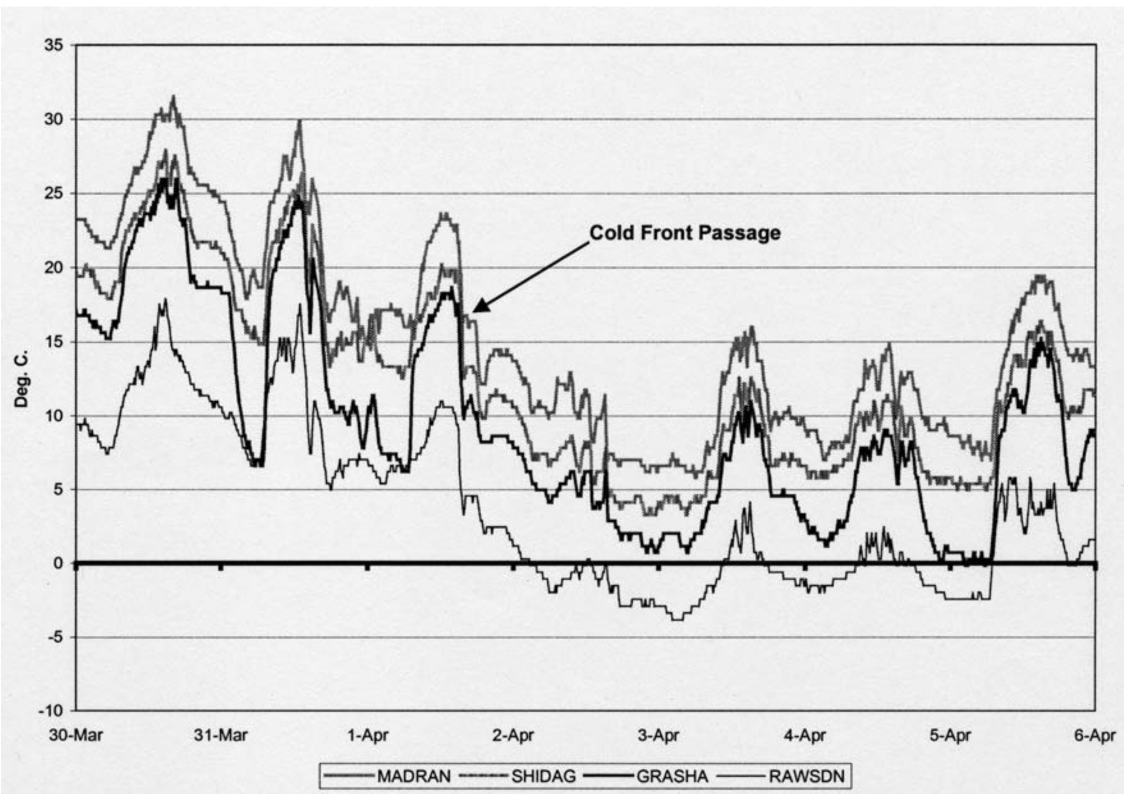

Figure 2—Air temperature data from four stations for the period of March 30 through April 5, 2004.

of this drainage. Wind observations at this ridge-top location are less influenced by local drainage flows, capturing wind variability more dominated by synoptic influences (passing low and high pressure systems).

These differences in wind regimes have direct relevance to park management decisions, specifically wildfire and fuels management. Hypothetically, if a prescribed burn for fuels reduction was scheduled during our seven-day analysis period at upper elevations, the existing RAWS site would indicate that winds were primarily out of the east-southeast. The additional climate monitoring stations show that wind flow patterns are much more complex and variable beyond the RAWS site. Smoke from the prescribed burn could actually be drawn down drainages into low-lying communities outside the park boundary. The management of smoke from prescribed fires could be substantially enhanced with the additional climate

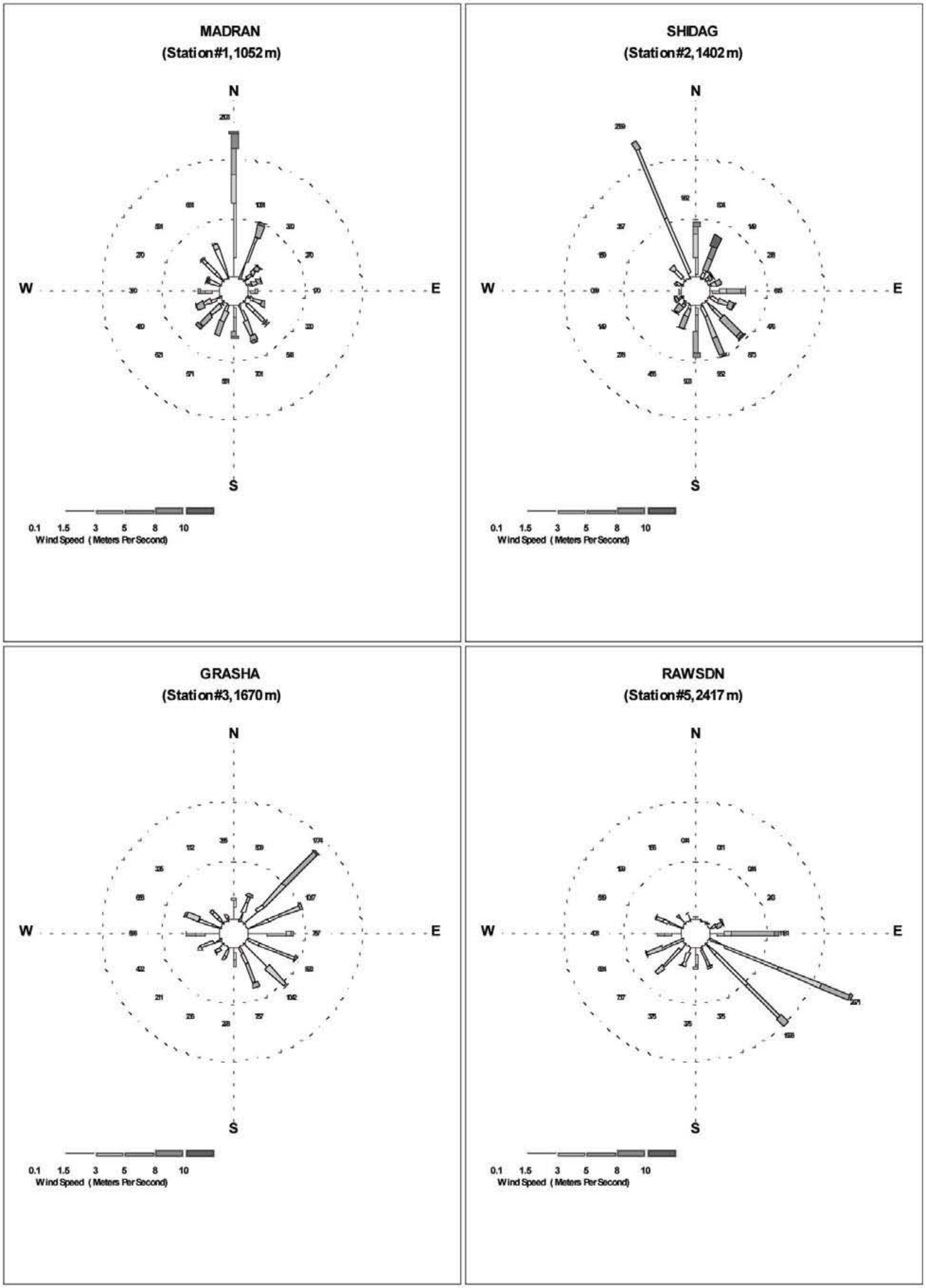

Figure 3—Wind rose diagrams for four stations for the period of March 30 through April 5, 2004. Numbers around petals show relative frequency in percent of total observations. Calm observations were excluded from analysis.

information provided by the monitoring network. As more data are collected, a more complete picture of wind flow pattern variability (daily, monthly, seasonally) will be developed. A high-resolution climatology of all meteorological variables could benefit all aspects of wildfire management including suppression efforts and fuels reduction activities.

Conclusion

Mountain areas are the focus of increasing attention with respect to global change and ecosystem management (Fagre et al. 2003; Diaz 2003). More holistic monitoring systems and approaches that include climate monitoring at appropriate scales (time and space) will be needed to properly manage natural resources and gauge ecosystem changes. Preliminary results from the pilot study at Saguaro National Park demonstrate that the collection of high-resolution climate information can highlight spatial and temporal patterns in climatic variability important for sound management decisions.

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Challenges to Managing Natural Resource Information

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Abstract—*One of the most important issues facing resource managers today is that of information. In order to handle the numerous and diverse requirements for information, landscape-scale information management systems are needed that allow individual land management units to view their resource information in a regional context. The characteristics of such a system are: (1) the storage of basic data sets and GIS layers, (2) the development of Internet software tools and protocols to facilitate data sharing, (3) personnel to operate and maintain the system, and (4) system coordination and training to develop and support cooperators and users.*

Introduction

Numerous efforts are underway by both public and private groups to assess the status of biodiversity on the landscape. The National Park Service, USDA Forest Service, Environmental Protection Agency, and others have national monitoring programs for significant natural resources. The USGS has a program to assess the status and trends of the nation's biological resources (Mac et al. 1998). These are indications that government agencies and society now recognize a close link between natural capital (ecosystem assets) and broader socioeconomic goals. There is also growing understanding that in order to do a better job of managing ecosystem assets there is a need to better understand the interdependence of economies and environment, how to conserve biodiversity, how to protect natural ecosystems, and in some cases how to restore natural systems, in order to add to the quality of life. To facilitate these societal goals, it is necessary to have ever better natural resource information management systems. In the past there have been many efforts to gather data about natural resources. The results of these research efforts have typically ended up in reports or publications with data relegated to obscure locations on shelves, in drawers, or in boxes of information that are now not accessible to anyone. As scientists and managers we now have more information than we've ever had, yet we struggle. Struggle to apply relevant data to pressing issues and struggle to locate information that we know we have, somewhere. In order to do proper assessments and make appropriate management decisions, we have to apply the best scientific understanding possible. Even though there is more information available than any of us can handle, most of the time a new question is asked, the immediate response is, "I need more information!" When we talk about information management, we are in a world where we know where we want to go (having information readily available in a readily accessible form for any question about resource management), but where we want to go is a quantum leap away from where we are.

The ability to provide top quality, relevant information depends on our solving problems associated with scale, format, classification systems, hardware, software, and keeping data up to date. Further, a cultural shift needs to be made in our business of science. That is, to hire people who know electronic data management systems—from a mechanic's perspective and from a data perspective—in order to handle the great volume of data with which we need to deal. We need to develop information management systems that will allow researchers and managers to obtain natural resource information for a region, a State, a county, a local management unit, etc., and be able to readily update that information as appropriate.

Issues Related to Managing Information

System Outputs

When developing an information management system, it is helpful to have in mind what the outputs from that system might be. A very simple system might consist of a database and a report (Swantek et al. 1999). Sometimes data collection systems are developed without a clear purpose or intention of synthesis (Ward and McBridge 1986). These lead to data being collected that fill files and even boxes, but are not very useful over time. A more complete system will provide raw data; synthesized data, data documentation, and maps; in depth state-of-the-art reports and publications; skills training; and personal consultation.

Cost

The primary cost will be in personnel with data managers, information creators, and systems managers being added to the research specialists that are currently conducting individual projects, usually funded through research contracts of one sort or another. These projects typically result in data collection, data synthesis, data analysis, report writing, and infrequently, publications, but do not go beyond that. A secondary cost will be the upkeep on system changes that are becoming increasingly important as hardware and software get increasingly complex through time and with the addition of new raw and synthesized data.

Complexity

The more we know, the more we understand that the world is more complex than we previously thought. Some indications that things are getting more complex: papers written by 10-12 authors, the credit lines for movies, the increased focus on interdisciplinary studies. Other hurdles that need to be overcome: research evaluation systems that still reward scientists for being primary authors on peer-reviewed publications, individuals who will not share data, the use of multiple data collection and classification systems being used, and many different data analysis systems being used (e.g., GAP vegetation coverages that are incompatible across State boundaries).

Quantity, Format, and Scale of Information

Many data sets are still not available digitally, and often unique, "hard copy" information gets thrown out because it is "too old" or there is not enough space to store it any longer. Billions of dollars are being spent every year on collecting information, but there is no plan of what to do with the data and information after the project report is written (other than perhaps "archiving" the data). There is too much. Data are collected in most systems faster than those systems can handle it. Even so, almost always is heard, "I need more information to answer that;" "more research needs to be done on this topic;" and "the more you know, the more you don't know." Now we are hearing statements such as trying to deal with the quantity of information coming past me is like trying "to get a drink from a fire hose."

Data Evaluation

Another need that has arisen is to make sure that data are accurate and meaningful. With the quantity of data coming in, the accuracy assessments, quality assessments, and quality control are getting out of hand. No one can keep up with the volume that most systems are presented with.

Technology

Computer "crashes" lead to lost data and information. Hardware and software upgrades often make data and information exchanges difficult and sometimes impossible. Technology upgrades are a constant battle—how to pay for them and especially how to make them happen in such a way that all the data and information in the system is brought along.

Information Strategy

We all deal every day with a lack of information strategy, from the researcher who plans too little time for handling the data and writing reports after field collecting, to the agencies that still think that information management is accepting the research or management report and putting it on a shelf. Coordination is lacking between monitoring agencies with respect to objectives, protocols, timing of monitoring activities, data analysis, and/or data utilization. This often leads to time and money being wasted (Mogheir and Singh 2002). In a recent study to reestablish and restudy "permanent" study plots that were established in the early 1960s and studied by one person from the early 1960s until the early 1980s, investigators found that the contents of the original researcher's office relating to the study were not well described; there was no overall description of the permanent plots or the nature or purpose of several of the measurements taken; there were photographs of most, but not all of the study plots; and the data were on computer punch cards, 9-track tapes, and computer printouts, all of which needed to be translated onto modern computer media before the project could even begin (Webb et al. 2003). A paradigm shift needs to take place to an understanding that biological data need to be georeferenced and entered into a database that can be related to maps. Not just in an individual lab situation, but into a collaborative, integrated database management system. This needs to start first with the investigator, but the agencies also need to have computer systems and operators to handle the data as it is passed off from the investigator. Fortunately technology has advanced well enough to make this possible.

We also need to be considering that our information management systems need to be set up so that data can be shared through the levels of each agency and across agency boundaries. The level of commitment for this today is analogous to having a fleet of propeller airplanes trying to keep up in a jet engine world. We will not come close to solving this dilemma until the agencies make a commitment to purchase the new equipment, hire and train operators to "fly" the new systems, and hire mechanics to make sure they keep going. It is a commitment that is seemingly still not even in the kitchen, let alone on the back burner.

Where We Are Today

Regional and National Systems

Library systems that collect names and locations of libraries of data—A regional or national system that only tells folks where they can go get data, i.e., a catalog of data sources (National Spatial Data Infrastructure 2004). The biggest problem in this type of system is on the delivery end. If I am a scientist who gets in the system, then some percentage of my time has to be spent on maintaining a computer connected to the Internet that will deliver the data that I have reported that I have. I will also be spending more time answering all the questions that get asked—even if I did put in 30 pages of metadata.

Library systems that collect and archive data—A centralized data collection center or network. This amounts to a digital library that in most cases is managed by one to a few people because upper level managers have a mistaken idea that the computers can do all the work. This type of system can fail rapidly because the funds to maintain it are usually not sufficient and because the site only serves data that are not updated. One of the current sites that goes against this pattern and is well maintained with plenty of up-to-date information is http://www.natureserve.org.

The Future

An effective approach to meeting the information management challenge would employ a combination of expertise in information management systems, geographic information systems, natural resource modelers, population and vegetation biologists, and librarians to develop a Statewide Internet digital interactive library that is a node on a larger international system. This digital library would have the capability to collect, store, and manage information and data from multiple studies at multiple scales (e.g., population, individual species, individual management units, County, State, political or biogeographic region, Nation, or Continent) in a system that is inter-relational. That is, the system would be able to integrate, combine, and synthesize data and information from different sources so that it can be shared with a variety of users (Ram 2000; Ram et al. 1999). Data would be used to produce the usual reports, publications, and presentations, and would be delivered through different filters to those that need it: researchers, managers, NGOs, schools at all levels, and the general public. The system would make it possible for people to use the Internet to obtain complementary information such as a picture of a species or plant community/habitat, a distribution map, and information about species biology, including which collections have specimens of the species. This integrated tool would be extremely valuable for an evaluation focused on a particular location. It would also make it possible for people to obtain information about various management units such as wildlife refuges or units of the National Park Service.

To deal with the problem of serving out dated information, such a digital library of the future, would have the capability to upload new data to the system. That is, a researcher would be able to take from the system information that she needs for her project, collect additional data, conduct analyses and write reports, and then contribute back to the system so that the database is updated. This digital library would also maintain archives of databases so that as databases are updated and changed, an historical record is kept whereby trend analyses could be done.

Any effective electronic library and data delivery system will need systems people to run it. Just as FedEx, UPS, DHL, etc., have truck drivers and mechanics, pilots and airplane mechanics, etc., to run their systems, the information management system of the future will not run with researchers doing it as part of their responsibilities, or by their using research technicians with more computer savvy. The greatest challenge to managing natural resource information in the future will be a shift in culture that allows the equivalent of truck drivers and airplane pilots, truck and airplane mechanics, etc., into the business of science. We have only taken the first few baby steps along this path, but the speed of technology change, the large number of people looking for information, and the large amount of information available and coming in on a daily basis will speed us on our way.

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Wild Cats of the Sky Islands: A Summary of Monitoring Efforts Using Noninvasive Techniques

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Abstract—*A variety of efforts are taking place to detect, inventory, and monitor the wild felids (pumas, bobcats, jaguars, and ocelots) of the Madrean Archipelago. Researchers are using a suite of noninvasive methods, including infrared-triggered photography, DNA analysis of scat and hair (collected from "hair snares"), and old-fashioned tracking and sign searches. These efforts are being conducted by a variety of academic, government, and non-governmental organizations in the United States and Mexico. We briefly outline the various projects including their results to date, discuss threats to native felids in the region, and provide recommendations for further research, monitoring, and conservation.*

Introduction

The region known as the Madrean Archipelago in the Southwestern United States and Northwestern Mexico is, in many ways, unique. It crosses the boundary between two nations and is influenced by two major climatic regimes, tropical and temperate. It is extraordinarily diverse ecologically and is home to 4, possibly 5, species of native wild cats. Two felid species, the bobcat (*Lynx rufus*) and puma (*Puma concolor*) (also known as cougar, mountain lion, and panther) are relatively common throughout the region. The other 3 cat species, endemic to Latin America and known as neotropical cats, i.e., jaguar (*Panthera onca*), ocelot (*Leopardus pardalis*), and jaguarundi (*Herpailurus yaguarondi*), reach their northern limit in the United States-Mexico border region.

Bobcats range from the United States-Canada border to Southern Mexico. Pumas are distributed throughout most of the Americas. However, other than a small, isolated population in Florida known as the Florida panther, they are considered extirpated in the eastern half of the United States. Jaguars historically ranged as far north as the Grand Canyon in Arizona (Brown and Gonzalez 2001; Hatten et al. 2003) but were considered close to extirpation in the United States in the last half of the 20th Century. In 1996, however, photographs taken of 2 live jaguars by houndsmen Warner Glenn (1996) and Jack Childs (1998) in separate areas of southern Arizona led to a resurgence of interest in the species in the United States and northern Sonora, Mexico. The ocelot historically ranged into the Southwestern United States and is extant in southern Texas. The last recorded sighting (photograph) in Arizona was in 1964 in the Huachuca Mountains (Girmendonk 1994). Although the jaguarundi had been reported in Arizona (Little 1938), its existence in Arizona and even Sonora is questionable (Brown and Lopez Gonzalez 1999).

A combination of factors—the 1996 photographs of jaguars, the advent of new, noninvasive research techniques, and increasing concern regarding human-caused threats to wildlife—all contributed to a recent flurry of activity to gather information on the wild cats of the Madrean Archipelago. In this paper we briefly describe the techniques, summarize wild cat-related projects in the region, and discuss management and conservation implications. We emphasize noninvasive techniques, since they are more commonly used in these projects; however, we briefly mention standard capture/radio telemetry efforts, where applicable.

Techniques

Infrared-Triggered Cameras

The development of infrared-triggered or "trip" cameras has greatly increased biologists' ability to obtain information on wildlife in the field (Wolf and Swann 2002). These units emit an infrared beam or series of beams, and when an animal crosses the beam the camera photographs the animal. With trip cameras we can gather such data as presence/absence, activity patterns, habitat use, and, for the spotted cats, even home range and population information, based on unique coat patterns of individuals.

Molecular Genetics

Cutting-edge techniques utilizing DNA extracted from scat (feces) and hair (from "hair snares") have created new tools for gathering information (Ernest et al. 2000; McDaniel et al. 2000) heretofore impossible without invasive and expensive animal capture and radio telemetry. With DNA we can identify species and individuals, estimate populations, delineate home ranges, and determine sex ratios and relatedness. Hair snares are small carpet pads imbedded with protruding tacks. Another type is a spiked "tie" plate (normally used in housing construction) backed by a carpet pad. Both types are baited with commercial trapper's lure and catnip. Cats rub on the snares and leave their hair, which is later analyzed in the genetics lab.

Tracking and Sign Searches

Old-fashioned tracking and sign searches are still being used today but in the modern context of recording trends in tracks found over time in a specific area or documenting wildlife use of critical areas and corridors. Tracking efforts now have specific protocols and procedures to ensure data consistency and to maximize the value of effort expended. Tracking has limitations in terms of distinguishing individuals, determining gender, or estimating populations; however, it is still an effective, low cost method of gathering data in certain well-defined situations (Beier and Cunningham 1996; Smallwood and Fitzhue 1995).

Habitat Mapping

In this summary we also include efforts to map habitats and felid distribution using Geographic Information Systems (GIS) and similar techniques.

Projects

Mexico—Carlos Lopez Gonzalez, Northern Jaguar Project, Naturalia

The 1996 photos of jaguars in Arizona prompted biologists Carlos Lopez Gonzalez and David Brown to travel in northern Sonora to investigate the possible existence of a source population of jaguars. They found an extant population in the region around the confluence of the Yaqui and Aros Rivers (Brown and Lopez Gonzalez 2001), approximately 140 miles south of Douglas, Arizona. Lopez Gonzalez then initiated field projects to gather much needed information on jaguars and the general ecology of jaguar habitat. Using trip cameras, he and his colleagues have obtained numerous photographs of jaguars and in some cases were able to estimate home ranges. They have also documented ocelots, bobcats, and pumas as well as other wildlife. They have conducted prey surveys, analyzed scat, and radio collared several pumas. Also, with the support of Sky Island Alliance and Defenders of Wildlife, a new non-profit organization known as the Northern Jaguar Project has been formed to support conservation and research efforts in this region, including working with local ranchers. Lastly, a Mexican non-profit conservation group, Naturalia, has purchased a ranch to form the nucleus of land-based conservation efforts in this biologically critical region.

Mexico—Octavio Rosas-Rosas, Louis Bender, Raul Valdez, New Mexico State University, Wildlife Conservation Society

Since 2000 Octavio Rosas-Rosas has been studying habitat partitioning and prey relations of sympatric jaguars and pumas in northeastern Sonora, in the northwestern portion of the Sierra Madre Occidental. Multiple photos of jaguars, pumas, ocelots, and other small carnivores have been acquired using double-sided trip camera stations. Researchers are using tracking as well as telemetry to gain more insight into activities of pumas and jaguars in this unique area. Scat is being analyzed to determine overlap in diet of jaguar and puma. Recently the study of smaller carnivores including ocelots has been undertaken. Rosas-Rosas is also working with the local ranchers to create a multiple use area that does not infringe on land use and landowner rights.

United States, Arizona—Jack Childs, Matt Colvin, Borderlands Jaguar Detection Project

After Jack Childs, his partner Matt Colvin, and others treed and photographed a jaguar in 1996 (in the Baboquivari Mountains west of Nogales, Arizona), Childs and Colvin obtained primary funding from the Wildlife Conservation Society to conduct track surveys and place trip cameras and hair snares along the United States-Mexico border. Their study area is a 10-mile strip of land along United States side of the border, from the Baboquivaries in the west to the San Rafael Valley in the east. In 2001 and again in 2003 they obtained photos of a male jaguar, and careful analysis of spot patterns revealed the 2 photos were of the same jaguar. Hair from hair snares and scat samples will be analyzed in the genetics lab run by Melanie Culver, University of Arizona. In addition, Childs and Colvin obtained funding from the Phoenix Zoo to travel to Brazil to document tracks and sign of all the neotropical cats so that they could recognize signs in the United States should the opportunity occur. They published a book describing tracks and signs of borderland cats (Childs 1998).

United States, Arizona—Lisa Haynes, Melanie Culver, Zoe Hackle, National Park Service Border Cats Project

Using noninvasive methods, i.e., trip cameras, track surveys, and DNA analysis of scat and hair (from hair snares), we are gathering baseline data on native felids (as well as feral domestic cats) in four National Park Service sites in southeastern Arizona. The Park Service is mandated to conserve and protect the native species endemic to those sites. The Service is also interested in gathering information on mountain lions, which are increasingly coming into contact with visitors and park neighbors as development increases near park borders. We will summarize occurrence records, especially those of the rarer neotropical cats, and develop management plans for each species. The sites are Coronado National Memorial, at the southern tip of the Huachuca Mountains; Chiricahua National Monument, on the west side of the Chiricahua Mountains; Fort Bowie National Historic Site, in Apache Pass between the Chiricahua and Dos Cabezas Mountains; and Saguaro National Park, in the Rincon and Tucson Mountains. In a related project, we have been noninvasively monitoring the small, isolated population of pumas in the Tucson Mountains (Saguaro National

Park-West). These estimated 2-5 pumas are surrounded by development and may be cut off from other populations (Haynes and Swann 2003).

United States, Arizona and New Mexico—Sky Island Alliance Volunteer Tracking Program and Ft. Huachuca Puma Track Count

Sky Island Alliance (SIA) is conducting two efforts to non-invasively monitor wild cats and other wildlife using volunteer trackers. In recent years, they have organized the annual puma track count on Ft. Huachuca Military Reservation in south-eastern Arizona, now in its 15th year. Under the guidance of experienced trackers and lion biologists, groups of volunteers document tracks on specific routes distributed across the Fort to document trends in tracks observed over time. In addition, SIA is training volunteers to document tracks and signs of pumas, bobcats, jaguars, and 3 other focal carnivore species in four potentially critical wildlife corridors: the Tumacacori-Santa Rita corridor, the Cienega Creek Watershed, the Dragoon-Whetstone corridor, and the north/south spine of the Peloncillo Mountains. The routes are designed to document wildlife use of corridors and valuable habitats, which are threatened by urban development and/or highways. These data are then used in land use planning efforts and to advocate on behalf of open space and conservation. Volunteers undergo a rigorous training program and must commit to monitoring their routes every 6 weeks. Finally, SIA, in conjunction with Arizona Department of Transportation, is using trip cameras to document wildlife use of highway culverts and bridges.

United States, Arizona and New Mexico—Jaguar Conservation Team (JAGCT)

After the 1996 jaguar sightings, a conservation team was organized that is comprised of Arizona and New Mexico State wildlife agency personnel, U.S. Fish and Wildlife Service biologists, and other agency representatives. In addition, private individuals and stakeholder groups (environmentalists, ranchers, hunters, etc.) who have an interest in jaguar conservation issues, are members of and participate in JAGCT meetings and activities. Meetings are held twice a year near the Arizona-New Mexico border. Both Arizona and New Mexico State Game and Fish Departments, in collaboration with other members of JAGCT, have mapped potential jaguar habitat in each State using Geographic Information Systems (GIS). Classifications were based on historic sightings, areas now identified as unsuitable due to human development, and habitat characteristics such as ruggedness, vegetation, perennial water sources, etc. Each State now has a map delineating areas with the highest potential for jaguars (Hatten et al. 2003; Menke and Hayes 2003). In addition, the JAGCT conducts other valuable activities, such as environmental education in relation to jaguars, evaluating current sightings, and conducting field checks of potential jaguar/livestock depredation incidents.

United States and Mexico—Defenders of Wildlife Bordercats Working Group

This group is in the process of publishing the results of a GIS-based habitat conservation map for ocelots, jaguars, and jaguarundis in the border region. Several years ago they started to compile sightings for all three species and also initiated a pilot field study in southeastern Arizona, which included track surveys, trip cameras, and interviews. They combined this sightings database with results from the field studies and then held an expert mapping workshop in order to develop a "blueprint" of high priority areas and corridors for each species across the entire border region. The results will be published in 2004. The defined areas will then provide a focus for conservation efforts, which includes working with private landowners in Mexico.

Discussion

The above-described efforts are important for two primary reasons. One is to assess the current status of the native felids of the Madrean Archipelago. In Mexico, we now know there are extant populations of the native assemblage of cats in the region, although occurrences and distribution of the rarer, neo-tropical cats are probably much reduced from historic levels. In the United States, there is considerable interest in assessing the possibility of the current existence of the rarer cats and of potentially reestablishing their presence as members of the historic fauna of the Southwest.

The second reason such data are critically needed now is the threat from development and human activity in the region. Urban development, highway construction, and habitat loss are the most significant risks to wild cats. The possibility of genetic isolation due to loss of connectivity across the landscape is especially threatening to the wide-ranging larger cats, i.e., puma and jaguar, as well as the smaller species. Also of tremendous concern are impacts related to border immigration. Migrant traffic degrades habitat in many of the same areas used by wild cats and their prey and may also disturb nocturnal hunting activities of the cats. Of even greater concern is U.S. Border Patrol's plan to significantly expand its current efforts to stop illegal immigration by building impenetrable fencing along some of the Arizona/Mexico border, constructing towers for stadium lighting, grading roads along the border, and driving those roads with OHVs and other vehicles. If these impacts continue, all efforts to maintain or manage for carnivore connectivity between the United States and Mexico will be for naught. In addition, biologists are still concerned about poaching and illegal killing of wild cats. In Mexico, despite legal protections, ocelots are still poached for their fur and jaguars are killed as predators of livestock. In the United States in 1986, a rancher/lion hunter killed a jaguar near Willcox, Arizona, and eventually was prosecuted. It is unknown how many incidents such as this may occur, unknown to authorities. Finally, prices for bobcat pelts are dramatically increasing again, after a twenty-year decrease, possibly adding to other pressures on that species.

There should be a dramatically increased effort to assess the status of the neotropical cats on both sides of the border and in potential corridors between known populations in Mexico and the United States. Noninvasive techniques are ideal for this purpose. We also need to know basic information about these species such as home range size, activity patterns, social organization, and resource/habitat partitioning in the unique biomes of Northern Mexico. Previous research of the neotropical cats has been conducted in tropical areas, and most research on pumas and bobcats has been conducted in temperate habitats. Data are needed to understand the unique situation of the Madrean Archipelago, and both noninvasive and standard radio telemetry methods will be needed.

In addition, we need to continue to gather baseline genetic information on wild cats in the region to address impacts of development, border immigration, and highway construction. Loss of connectivity and gene flow is probably the single greatest threat in the long run, followed closely by loss of habitat. The example of the highly inbred Florida panther, complete with deformities and other abnormalities, is a likely scenario for wild cat populations in this region. The information gathered then needs to be translated by agencies, government, and landowners in both countries into meaningful management prescriptions on the ground. Continued efforts should be made to work with landowners and ranchers to conserve valuable habitat and to eliminate illegal killing of wild cats.

This is a critical time if we want to ensure the existence of the wild cats of the Madrean Archipelago into the future. What transpires in the next 5 to 20 years could make the difference between continued existence versus extirpation of these species in the region. We hope this summary and our recommendations result in increased interest in, funding for, and conservation of these fascinating and ecologically important species.

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How Do Humans Restructure the Biodiversity of the Sonoran Desert?

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Abstract—*We studied patterns of biodiversity across the entire urban, suburban, agricultural, and surrounding Sonoran Desert landscape of central Arizona-Phoenix. A probability-based extensive integrated field inventory was used to survey perennial plants, pollen, birds, and sample soil chemistry, supplemented by monthly or quarterly monitoring of arthropod and bird communities at some sites. For taxa and ecosystem properties directly manipulated by people (e.g., perennial plant diversity, pollen) dominantly geomorphic controls in undeveloped desert were replaced by factors such as land use, agricultural legacy effects, income, and population density across the urban core. In contrast, native taxa indirectly affected by human activities (e.g., invertebrates and birds) showed modified diversity rather than widespread replacement, with reductions in ground arthropod, spider, and bee diversity, but increased bird diversity in some seasons.*

Introduction

Although much ecological research has been carried out on the Sonoran Desert, the ways in which humans restructure ecosystem biodiversity in developed parts of the region has not been a focus of research. However, in 1997 the Central Arizona-Phoenix Long Term Ecological Research (CAP LTER) project was added to the network of sites funded by the National Science Foundation with the goal of understanding ecological patterns and processes of this rapidly expanding urban-desert region. In this paper, we outline the aims, methodology, and some of the main findings from our research on biodiversity to date, specifically on plants, pollen, arthropods, birds, and soil resources.

Aims and Methodology

The overall goal of CAP LTER is to understand how patterns and processes of urbanization alter ecological conditions in central Arizona-Phoenix and how the ecological consequences of that change feed back to generate additional future changes. One of our specific aims is to analyze broad-scale patterns of biodiversity across the region and to document how various processes, particularly human drivers, rearrange and reshape those patterns. In this paper, we focus on the results from an extensive survey, supplemented by selected findings from more detailed studies.

Study Area and Sampling Design

Our study area covers 6,400 km^2, contains over 3 million people, and includes the rapidly expanding metropolitan Phoenix area as well as surrounding agricultural land and undeveloped Sonoran Desert. To obtain a spatially dispersed, unbiased sample of the ecological resources of this entire region, we used a dual-density, randomized, tessellation-stratified design (Stevens 1997; Peterson et al. 1999). This design consisted of a 4 km x 4 km grid from which one random sample was taken in every square within the main Phoenix metro area and one sample in every third (random) square outside that area (figure 1). This resulted in approximately 100 samples inside and 100 samples outside the developed urban core, to take account of the greater landscape heterogeneity of the urban core (Luck and Wu 2002). From a total sample size of 206, access was denied for only 2 samples, giving a total of 204 sites surveyed.

Integrated Field Inventory and Statistical Analyses

A synoptic integrated field survey was carried out between late February and early May 2000 within a 30 m x 30 m plot at each sampling site. We mapped the main surface cover types (e.g., asphalt, soil, turf) and permanent built structures, collected soil cores (2.54 cm diameter, at 0 – 10 and 11 – 30 cm depth intervals) to determine major soil physical and chemical properties (Zhu et al., submitted; Hope et al., in preparation), and collected surface soil for pollen identification. At a randomly chosen sub-set of sites, we have conducted bird surveys quarterly since 2000 (N = 40, 15 minute, unlimited radius point counts, using both sight and sound, within 3 hours of sunrise). Land use was classified into one of five main categories: urban (n = 91), desert (n = 73), agriculture (n = 23), transportation (n = 6), and a "mixed" class (n = 11). We also obtained the following key geographic and socioeconomic variables: latitude, longitude, elevation, distance of each site from the urban center and from the nearest major freeway, the number of years each site had been in agricultural use, whether the site had ever been in agriculture, median family income, median age of housing stock, and human population density. These were then used as independent variables to model spatial variations in plant diversity and soil nutrient concentrations, using both generalized linear modeling and Bayesian statistical techniques, after accounting for any spatial autocorrelation in the residuals, as described by Hope et al. (2003) and Oleson et al. (in preparation).

Other Studies

The above survey was supplemented by less extensive, more targeted work, which included ground arthropod pitfall trapping (McIntyre et al. 2001), a pollinator study (McIntyre and Hostetler 2001), and a study of birds and vegetation in municipal parks (Kinzig et al., submitted; Warren et al., submitted; Martin et al., in press).

Results

Plant Diversity

Overall, native plant diversity was only slightly lower across the developed urban core compared to the surrounding desert (table 1) and greatest at desert foothills sites around the urban fringe and edges of desert remnants within the city (figure 2). Plant community analyses of the data show three main native plant communities in the region—an *Enceli-*Foothills *Palo Verde* community, along with *Ambrosia0-* and also *Larrea*-dominated communities (Gries et al., in preparation). However, while desert plots were dominated by native genera, urban plots had around half as many native compared to exotic genera (table 1), and at many developed sites native plant diversity is low or absent, replaced by numerous (total

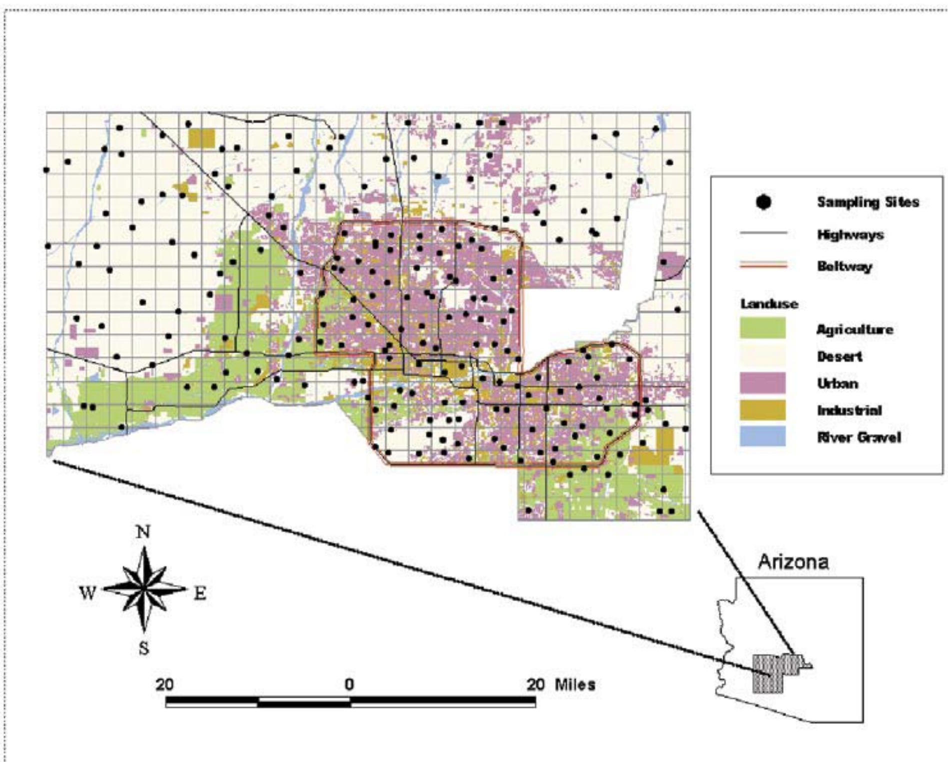

Figure 1—Map of the Central Arizona-Phoenix Long Term Ecological Research (CAP LTER) study site and extensive sampling scheme.

Table 1—Plant diversity (number of perennial genera per site) across CAP.

	Urban (n = 91)			Desert (n = 73)		
	All genera	Native	Exotic	All genera	Native	Exotic
Total (γ diversity)	156	50	117	63	55	6
Mean (α diversity)	8.0	4.2	8.0	8.4	9.0	1.5

of 117 non-natives) imported exotic genera comprising the human-created plant communities established by irrigation. This increased total plant richness (gamma diversity) across the region as a whole, with a total of 188 perennial plant genera recorded. Moreover, while the urban landscapes had a similar local diversity to the native desert vegetation they replaced (alpha = 8 genera per site), they had considerably higher compositional turnover, with a beta diversity of 7.5 in the desert, 19.5 in the city, and 26.7 for the region overall (Hope et al. 2003).

Perennial plant diversity was spatially autocorrelated among desert sites, reflecting the close correspondence of plant communities to topography, landform, water, and nutrient supply in the region (McAuliffe 1994; Whittaker and Niering 1975). There was no such relationship among urban sites, where perennial plant diversity reflected the influence of a combination of natural (e.g., elevation) and human factors such as income and agricultural legacy effects. Diversity at sites with per capita incomes over $50,750 per year was on average twice that found in less wealthy areas, and sites that were formerly farmed had 43% fewer woody plant genera than locations that had never been cultivated (Hope et al. 2003). Urban vegetation can be grouped into four broad communities—those with lawns, xeric landscapes containing *Prosopis*, "oasis" landscapes characterized by Queen Palms (*Syagrus*), and a fourth extremely diverse "catch-all" category that had no indicator species (Gries et al., in preparation).

Soil Nutrients

Comparison of the urban and undeveloped desert parts of the region suggest that soil resources are significantly affected by urbanization. Across the CAP region, soils at urban and agricultural versus undeveloped desert sites had higher moisture contents, more organic matter, and lower bulk density (Zhu et al., submitted). Soil nitrate (NO_3-N) concentrations were also higher at sites in the developed part of the ecosystem compared to desert sites, varying by up to

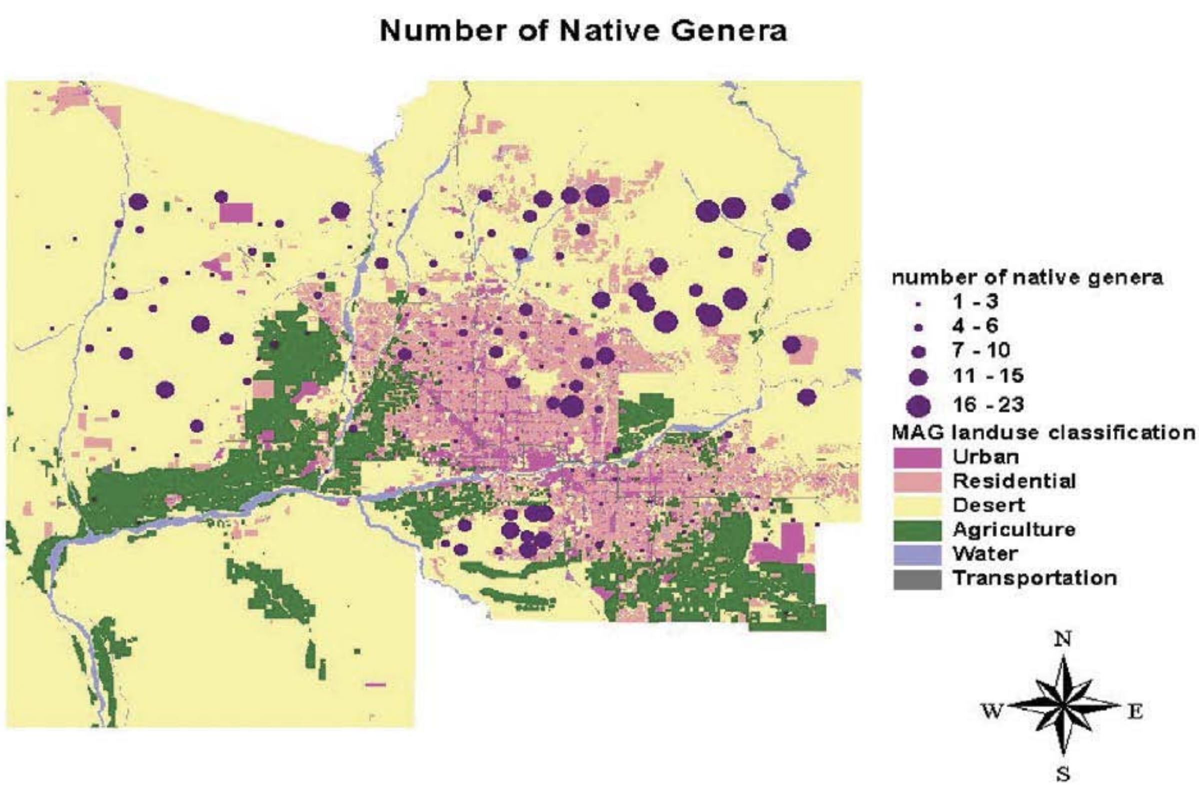

Figure 2—Map of native perennial woody plant diversity at each extensive survey site at CAP LTER. Plants were identified, to species where possible or to genus where the appearance of horticultural cultivars made accurate identification to the level of species difficult. Identification was standardized at the level of genus for subsequent statistical analysis, although in most study plots plant diversity on the genus level corresponds closely to diversity at the species level (Hope et al. 2003).

three orders of magnitude (Hope et al., submitted). These differences between developed versus desert sites persist even at sites located on same soil type and series, suggesting that pre-existing regional patterns of variation in soil properties cannot account for the observed patterns (Zhu et al., submitted). Statistical models show that dominantly geomorphic controls on spatial variation in soil nutrient concentrations in undeveloped Sonoran Desert are replaced by variables such as current and former land use, family income, population density, and housing age across urbanized parts of the region, as well as showing a clear legacy effect of higher soil nitrate concentrations at sites with current or former agricultural land use (Hope et al., submitted). These findings are similar to those for plant diversity (Hope et al. 2003). There tended not to be simple linear relationships between soil nutrient concentrations and independent variables for the urban sites. Rather, the *variation* in soil nutrient concentrations increases with changes in human population density, per capita income, elevation, and the like. This tendency toward higher variance in soil variables would seem to be a characteristic property of urban soils.

Pollen

We found widespread deposition of imported exotic pollen taxa across the region in addition to that from native desert species (Stuart et al., in revision). Relative abundances of native pollen inside the urban core have been reduced by increased abundance of pollen from exotic genera such as *Olea*, *Morus*, *Fraxinus*—the latter often creating local pollen deposition "hot spots" in areas where those plants are present in urban landscaping. Several desert taxa (e.g., *Ambrosia*, *Parkinsonia*, and xerophytes) feature strongly in the pollen record across the entire CAP region and show a strong correlation with extant vegetation cover on a site-by-site basis, clearly delineated by the major undeveloped Sonoran Desert areas (figure 3). Even *Pinus*, an imported genus with highly mobile pollen, shows a clear zonation across the central and southeastern part of the region, corresponding closely with the location of the oldest and most mature urban landscapes.

Arthropods

Ground dwelling arthropod species are abundant in urban settings and have been systematically monitored for the last five years at sites representing the four most common land use types across the metro area (residential, industrial, agricultural, and desert). While taxonomic richness was comparable among different land uses, community composition differed, certain taxa being associated with each land use type (McIntyre et al. 2001). Taxon-specific differences in community composition were related to habitat structure, the most important effects being due to presence of native vegetation, agricultural crops, or "exotic" habitats such as formal landscaping and buildings at residential and other developed plots (McIntyre et al. 2001). More detailed work on spider diversity has shown that agricultural fields and mesic yards are characterized by higher spider abundance (particularly of wolf spiders *Lycosidae* and sheet-web weaver *Linyphiidae*) but lower diversity (Shochat et al. 2004). Meanwhile richness and abundance of bee species was generally lower in residential areas compared to desert, although residential yards that contained xeric landscaping have bee communities with higher diversity than mesic yards, suggesting that human choices in how they undertake urban development can be designed to maximize retention of native diversity (McIntyre and Hostetler 2001).

Bird Communities

Through systematic monitoring of birds over four seasons per year, we have recorded 166 species of birds in three of the four main land-use types: urban (77 spp.), desert (81 spp.), and agriculture (89 spp.). After controlling for sample sizes, bird diversity was highest in the desert, followed by urban and then agricultural land uses. Multivariate analysis found that bird species richness increased with median family income, plant volume, plant species diversity, and number of new houses (figure 4), although the relative importance of these factors varied seasonally (Katti et al., in preparation). These relationships are corroborated by results from a study of small urban parks, stratified by neighborhood socioeconomic status (Kinzig et al., submitted; Warren et al., submitted). While the urban avifauna is numerically dominated by a few exotic species (House sparrow *Passer domesticus*, Starlings *Sturnis vulgaris*, Rock Pigeon *Columbia livia*), it also supports significant populations of many native Sonoran species, including House Finch *Carpodacus mexicanus*, Abert's Towhee *Pipilo aberti*, Cactus Wren *Campylorhynchus brunneicapillus*, and Curve-billed Thrasher *Toxostoma curvirostre*.

Discussion and Conclusions

We conclude that urbanization has resulted in a landscape in which biodiversity reflects social, economic and cultural influences in addition to those recognized by traditional ecological theory. There are two broad themes that emerge from our findings so far. First, the extent to which native diversity is affected by urbanization depends on the taxon in question. Native plant communities are still almost entirely replaced with exotics in urban landscapes across metro Phoenix, despite the increasing fashion for xeric residential landscaping over the last couple of decades. These urban plant communities have similar alpha diversity but much higher beta diversity than the native vegetation they replace. Taxa less directly affected by people (e.g., arthropods, birds) show less dramatic effects. Second, the broad gradients in a relatively small number of key drivers that govern biodiversity patterns in native Sonoran Desert (e.g., geomorphology, water and nutrient availability) are replaced by a much larger suite of interacting partially co-dependent variables in the city, including socioeconomic variables and land use legacies, which are often very site specific and result in a dramatic increase in spatial heterogeneity.

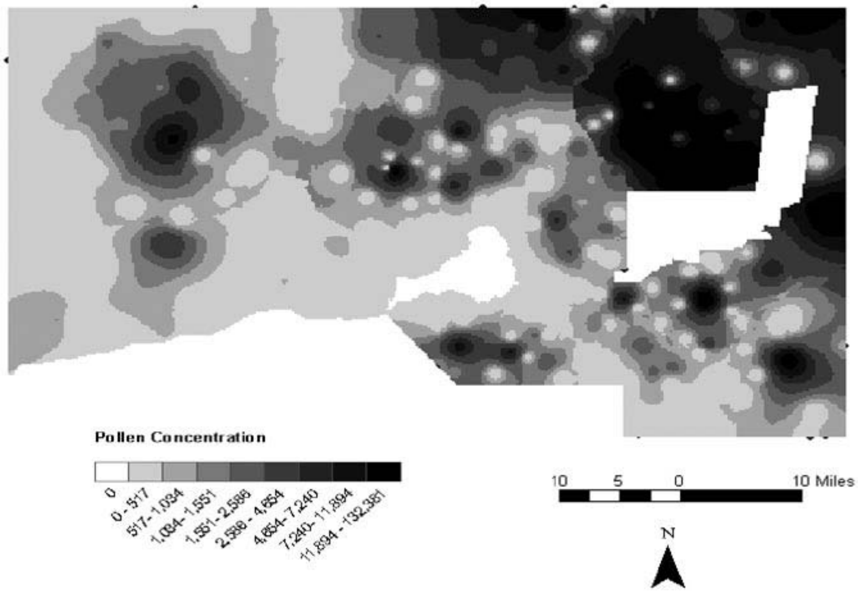

Figure 3—Contoured map of total xerophyte (all *Cactacea* and succulents) pollen concentrations across the CAP region.

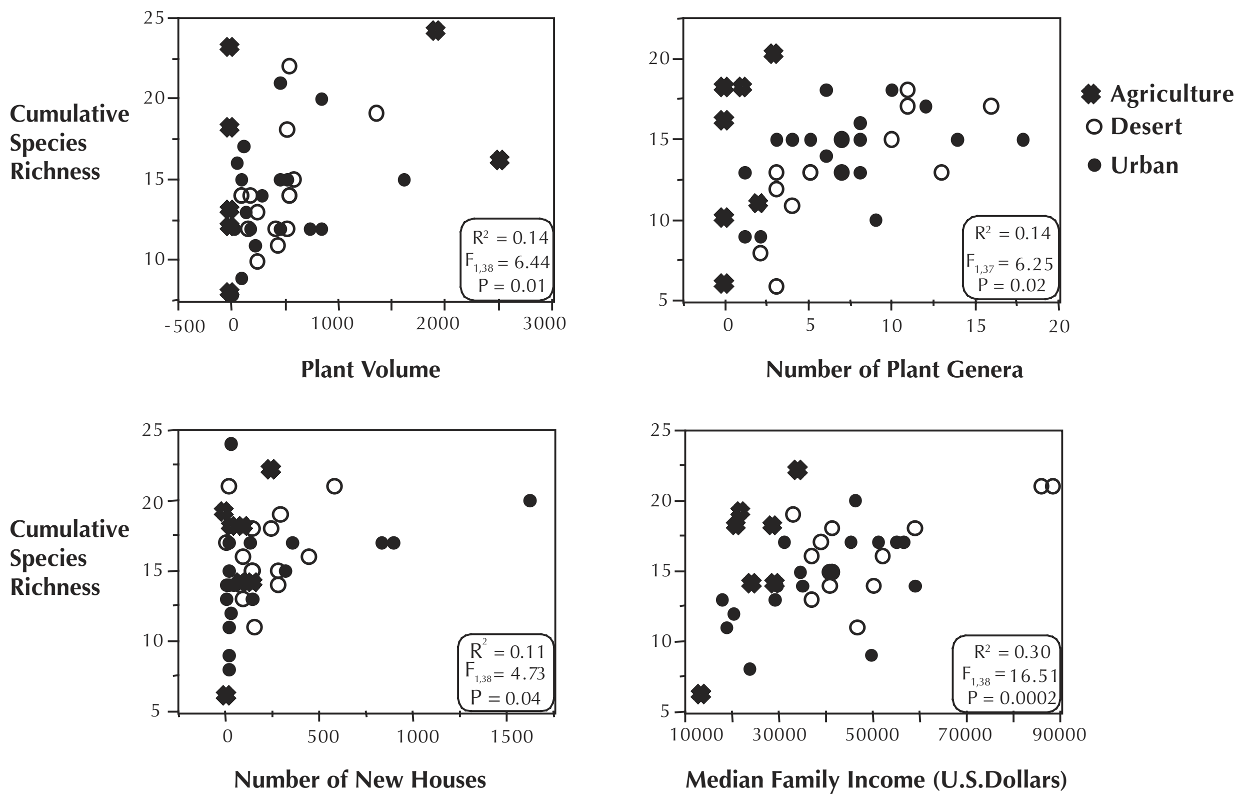

Figure 4—Determinants of bird species diversity in the CAP region. Graphs show significant bivariate relationships (with respective R^2, F, and P values indicated in each case) between bird species richness and plant volume (upper left, spring), plant diversity (upper right, summer), number of new houses (lower left, summer), and median family income (lower right, summer). The strengths of these effects vary seasonally and from year to year, but these graphs represent the general patterns.

Acknowledgments

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Using Cluster Analysis and a Classification and Regression Tree Model to Developed Cover Types in the Sky Islands of Southeastern Arizona

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Abstract—*The objective of this study was to develop a rule based cover type classification system for the forest and woodland vegetation in the Sky Islands of southeastern Arizona. In order to develop such a system we qualitatively and quantitatively compared a hierarchical (Ward's) and a non-hierarchical (k-means) clustering method. Ecologically, unique groups represented by only a few plots were appropriately distinguished using k-means, while Ward's combined these unique plots into the large mixed conifer groups. Similarly, plots dominated by more than one species were more appropriately grouped with other mixed-species plots using k-means. The two clustering methods were numerically compared using a classification and regression tree (CART) model. Groups based on the two clustering methods had similar recovery rates, but k-means groups required fewer nodes or decision rules. Based on these results we developed a detailed cover type classification system for the existing vegetation of the Sky Islands in southeastern Arizona. The final cover types were based on the original k-means clusters, with some minor modifications made using CART analysis to compensate for overlapping values. This allowed us to transform the CART output into a dichotomous identification key for 20 detailed cover types. Finally, these detailed cover types were linked to a flexible three-level hierarchical framework that allows users to aggregate or segregate forest lands as needed. The hierarchical organization of this framework is similar to the natural organization of ecosystems, which will aid our understanding of natural processes in these forest and woodlands.*

Introduction

Classification schemes are an important tool used to separate large areas into manageable units (Layser 1974). Classification systems provide a framework to organize information that differs between vegetation types, such as fire history, fire behavior, productivity, aesthetics, and wildlife habitat. Such information then can be used to evaluate and assess problems or opportunities to improve resource management (Layser 1974; Pfister 1975; McRae 1996). Classification systems also standardize the identification and definition of vegetation groups (Layser 1974), enhancing communication among managers and researchers (Volland 1975).

In North America, classification of forest and woodland vegetation typically is based on either potential (Moir and Ludwig 1983) or existing conditions (Eyre 1980). Potential or "climax" conditions define "habitat types" (Layser and Shubert 1979). In contrast, "cover types" classify forested lands based on the existing composition of dominant tree species (Eyre 1980).

In the Sky Islands of the Southwestern United States and Northern Mexico, both habitat types and cover types have been described (USDA 1997a,b; Shreve 1919; Wallmo 1955; Lowe 1961; Brady and Bonham 1976; Brown 1982; Niering and Lowe 1984). Earlier studies focused on describing plant communities along elevational/moisture gradients (Whittaker and Niering 1968), and provided valuable knowledge about the relationship among vegetation groups and their ordering in ecological space. However, there is still a need for deterministic models that can distinguish between vegetation groups, similar to the mechanism already in place for identifying habitat types (Muldavin et al. 1996).

Currently, numerous forest classification schemes describe cover types at different levels. Several authors (O'Hara et al. 1996; Pregitzer et al. 2001) have called for a hierarchical classification framework that would unite both existing and newly developed classification schemes at various spatial scales and levels of detail. Such a framework would standardize and relation classes facilitating crosswalking from a landscape to a stand level as necessary. Forests in the Western United States have been classified into broad cover types (Eyre 1980); these cover types do not fully illustrate the interactions between individual species or the modal distribution of species along environmental gradients. These broad cover types could be used in conjunction with more detailed classification systems to build a hierarchical classification framework.

In this study, we subdivided broad forest cover types to develop a detailed classification of mid-elevation forest cover types in the Sky Islands of southeastern Arizona. Our objectives were to: (1) group plots into vegetation groups based on similarity in species composition, (2) identify quantitative differences that distinguished each group, and (3) quantitatively describe each of the unique cover types resulting. These detailed cover types allow for finer scale ecological assessments than the broader types, and can be integrated with coarser types to facilitate assessments at multiple scales.

Study Area and Methods

The Sky Island mountains of southeastern Arizona, which are separated by a low elevation desert matrix, are a northern extension of the Sierra Madre Occidental of Northwestern Mexico. Geographically, the Sky Islands are located at the intersection of four major biomes (the Sonoran and Chihuahuan Deserts plus the Sierra Madre and Rocky Mountains [McLaughlin 1995]). Southeastern Arizona has a bimodal moisture pattern receiving winter precipitations that falls as snow (rains) at high (low) elevations in additions to the summer monsoonal rains (Sellers and Sanderson-Rae 1985). Total precipitation varies between approximately 45 cm at 1,500-meter elevation to 70 cm at 2,500 meters (Shreve 1919). The vertical relief and unique geographic position of these mountains combine to create a diverse mosaic of vegetation assemblages stratified along elevation/moisture gradients (Whittaker and Niering 1968; Lowe 1961; Niering and Lowe 1984). Plant communities at higher elevations (above 2,000 meters) are closely related to the Cordilleran/Rocky Mountain floristic province, and lower elevation communities (below 1,500 meters) are more closely related to the Madrean floristic province (McLaughlin 1995).

Our study sites were located in the Santa Rita, Santa Catalina, Huachuca, Chiricahua, and Pinaleño Mountains in the Coronado National Forest. We established four to eight line transects in each range, depending on their relative sizes. Transects were stratified by general cover types, although vegetation at low and high-elevation extremes (oak savannas and spruce-fir forest) were not included in this analysis. Transect origins and orientations were randomly selected with the constraint that they fell within 1.6 km of an accessible road or trail. Each transect consisted of 12 central points, with four vegetation plots established in and around each point. One plot was centered on the point itself, and three satellite plots were systematically distributed at least 80 meters apart. We used 954 plots from 27 partial and complete transects in the analysis.

Within each plot, we recorded genus, species, and diameter at breast height (DBH) for all standing trees >10 cm DBH within a 0.1 ha circular area. A total of 52 tree species were identified in the field and narrowed to 23 variables for the analysis. Species in the genera *Acer*, *Fraxinus*, and *Juniperus* were recorded at the genus level; hybrid and less common species of *Quercus* were also recorded. Unidentified tree species were recorded as a separate category. To standardize for the different physiognomy of oaks and conifers (Barton 1999), variables were represented according to the percent of the total basal area (%BA) they contributed. In addition to its simple interpretation, this attribute incorporates the strong relationship between BA, canopy cover (Mitchell and Popovich 1997), and overstory dominance (Neldner and Howitt 1991).

We initially separated the 954-plot dataset, represented by 23 variables, into 20 groups using the k-means clustering method (Romesburg 1984). This non-hierarchical method minimizes the variance within each group by independently organizing plots according to the desired number of groups (del Moral 1975; Belbin and McDonald 1993). This process avoids the sequential merging of entire groups typical of hierarchical clustering thereby improving homogeneity within clusters. We arbitrarily chose 20 clusters based on our desire to (1) include groups of both pure and mixed species composition, and (2) strike a balance between creating a classification scheme that was sufficiently detailed yet did not include an unmanageable number of cover types. Each group was named after the dominant species, with mixed species groups named after co-dominant species or species groups such as "Madrean oaks."

After the grouping of plots by cluster analysis a classification and regression tree (CART) model was used to identify critical distinctions between each of the 20 clusters. CART analysis has the advantage of being non-parametric, robust to outliers, and provides results that are easy to interpret in the form of dichotomous keys (Verbyla 1987). The CART models discriminate by sequentially selecting specific values, within the range of dependent variables that best partition the plots into purest group membership. The dependent variables we used were the 23 species plus 2 additional variables that aggregated conifer and woodlands species, respectively. Using %BA, the CART model initially separates all plots into their original groups. However, CART then selects the optimal solution (or number of splits) for the overfitted model by "pruning" the classification tree using a cross-validation technique.

Results and Discussion

Dichotomous Identification Key

Using the classification tree of the k-means clusters we were able to develop an identification key for 20 detailed cover types (table 1). This key is based on a series of sequential criteria taken from the discriminant values identified in the CART analysis. Using this key a cover type is identified when all criteria are met. Therefore, the sequence itself provides important information for understanding differences between groups. Also, the parameters clearly define and facilitate the identification of these cover types. This process is simple to implement and could allow researchers in other areas to apply the clustering method and CART analysis to an existing

Table 1—Dichotomous key to identify 20 cover types in the Sky Islands of Southeastern Arizona. The 20 groups were originally separated using the k-means clustering method then modified using classification and regression tree (CART) analysis. Each criteria or node was based on percent basal area by species. The four letter codes represent the first two letters of the genus and species scientific names.

1. POTR ≥ 43%	Pure Aspen
2. QUSP ≥ 63%	Oak Scrub
3. CUAR ≥ 31%	Pure Arizona Cypress
4. QUAR ≥ 63%	Pure Arizona White Oak
5. PIDI ≥ 42%	Pure Pinyon
6. JUSP ≥ 49%	Pure Juniper
7. QUEM ≥ 23%	7a
7a. PIEN ≥ 25%	Apache Pine/Oak
7b. PIEN < 25%	Emory/Arizona White Oak
8. PILE ≥ 26%	Chihuahua Pine/Oak
9. PIPO ≥ 55%	Pure Ponderosa Pine
10. PSME ≥ 53%	10a
10a. PIPO ≥ 25%	Douglas-fir/Ponderosa Pine
10a. PIPO < 25%	Pure Douglas-fir
11. ABCO ≥ 26%	11a
11a. $UPLN ≥ 56%	11b
11a. $UPLN < 56%	11c
11b. ABCO ≥ 36%	Pure White fir
11b. ABCO < 36%	Douglas-fir/Ponderosa Pine
11c. QUGA ≥ 44%	Gambels Oak
11c. QUGA < 44%	White Fir/Maple
12. PIST ≥ 24%	White Pine/Mixed Conifer
13. QUGA ≥ 25%	Gambels Oak
14. PIEN ≥ 22 %	Apache Pine/Silverleaf Oak
15. QUHY ≥ 45%	15a
15a. PIPO ≥ 22%	Silverleaf Oak/Ponderosa Pine
15a. PIPO < 22%	Pure Silverleaf Oak
16. JUSP ≥ 21%	Juniper/Oak
17. QUAR ≥ 31%	Arizona White/Silverleaf Oak
18. QUHY ≥ 23%	Silverleaf oak/Ponderosa Pine
19. PSME ≥ 29%	Douglas-fir/Ponderosa Pine
20. $UPLN ≥ 86%	White Pine/Mixed Conifer
21. #WDLN ≥ 30%	Silverleaf Oak/Ponderosa Pine
22. #WDLN < 30%	Douglas-fir/Ponderosa Pine

Woodland (WDLN) species include: POTR, ABCO, QUGA, PIST, PSME, RONE, PIPO, PILE, PIEN, *Acer* spp, and *Fraxinus* spp.
$ Upland (UPLN) species include: QUHY, QUAR, PIDI, QUEM, ARAR, JUMA, PLWR, CUAR, *Juniperus* spp., and hybrid oak species.

data set and develop their own classification key to classify existing or future plots.

Cover Type Description

The 20 cover types developed can be aggregated into seven broader forest cover types (tables 2 and 3). For example, the broader deciduous forest type was separated into the Pure Aspen and Gambel oak cover types (table 2). Both detailed cover types (CT) are limited in spatial extent within the Sky Islands, but provide important contributions to diversity in Sky Island forests. Both quaking aspen (*Populus tremuloides*) and Gambel oak (*Quercus gambelii*) are seral species in mixed conifer forest, which tend to dominate certain sites following severe disturbances such as wildfire. The Aspen CT was limited to mesic sites at high elevations, and dominated by quaking aspen forming mostly pure stands. In contrast, the Gambel oak CT had greater species diversity and a strong component of conifers, especially ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*).

The broad mixed conifer forest type was subdivided into six cover types (table 2). Of these six, the White fir/maple cover type (CT) occurred in the most mesic sites, such as shady ravines. This cover type was dominated by white fir (*Abies concolor*), but also had a large component of deciduous species (table 2). In contrast, within the Pure white fir CT, white fir accounted for more than 36% of the BA and lacked a pronounced deciduous component. The White pine/mixed conifer CT was an unusual type that occurred at higher elevations (2,540 m), and was dominated by a combination of Douglas-fir, southwestern white pine, (*P. strobiformis*), and ponderosa pine.

Douglas-fir had a wide elevational distribution, forming a Pure Douglas-fir CT at around 2,550 m, with Douglas-fir accounting for at least 50% of the BA, and ponderosa pine contributing <25% (table 1). In slightly less mesic sites, Douglas-fir intermixed with ponderosa pine to create the Douglas-fir/ponderosa pine CT. This mixed species type was a transition between the Pure Douglas-fir and Pure ponderosa pine CT. The latter type was dominated by ponderosa pine, which contributed at least 55% of stand BA (table 1).

The transitional or pine/oak forest typically occurred between 2,300 and 1,975 m. This broad cover type was partitioned into three more detailed cover types. The Silverleaf oak/ponderosa pine CT occurred at higher elevations and was dominated by silverleaf oak (*Quercus hpoleucoides*) and ponderosa pine, which co-occurred with a wide variety of other species (table 2). The Apache pine/oak and Chihuahua pine/oak CTs occurred at similar elevations and were comparable to each other in terms of species composition, differing mainly in relative proportions of Apache (*P. engelmannii*) and Chihuahua (*P. leiophylla*) pine, respectively (table 2). The Apache pine/oak CT also had a stronger component of silverleaf oak, and was more limited in geographic distribution (personal observation).

The overlap in the ecological distribution of silverleaf and Arizona white oak (*Q. arizonica*) created four detailed cover types within the broadleaf evergreen woodlands type (table 3). The Pure silverleaf oak CT was dominated by silverleaf oak, which accounted for at least 45% of the BA. The Arizona white oak/silverleaf oak CT had a strong component of both dominant oak species, whereas the Arizona white oak CT lacked a strong silverleaf oak component (table 3). The Emory/Arizona white oak had strong components of both Arizona white oak and Emory oak (*Q. emoryi*). This cover types usually was found at lower elevations where it blendes into pure Emory oak woodland and eventually into desert grasslands. These latter cover types were not included in this analysis.

In addition to broadleaf evergreen woodlands, our analysis also identified three cover types within the broader conifer woodlands type (table 3). The Juniper/oak CT was dominated by various species of juniper (*Juniperus* spp.) and Arizona white oak, in addition to a considerable component of silverleaf oak and border pinyon (*P. discolor*). Pinyon and juniper often co-occurred, but in the Sky Islands each of

Table 2—Mean and standard deviation (in parentheses) of basal area (m^2/ha) by species for 11 detailed cover types found at higher elevations in the Sky Islands of southeastern Arizona. Bolded numbers indicate dominant species used in distinguishing cover types. These 11 cover types aggregate to three broader forest types, as shown.

Broad	Deciduous Forest		Mixed Conifer Forest						Transitional Forest		
Detailed Cover Types	Pure Aspen	Gambel Oak	White Fir/Maple	Pure White Fir	White Pine/ Mixed Conifer	Pure Douglas-fir	Douglas-fir/ Ponderosa Pine	Pure Ponderosa Pine	Silverleaf Oak/ Ponderosa Pine	Apache Pine/ Madrean Oak	Chihuahua Pine/ Madrean Oak
POTR	**21.4** (12.3)		2.3 (5.6)	.4 (1.1)	.0 (.5)	.6 (2.6)	1.0 (4.1)				
QUGA		**11.8** (4.9)	3.2 (4.4)	2.0 (3.4)	1.0 (2.2)	1.1 (2.5)	1.6 (2.7)	.4 (1.4)	.3 (1.1)	.1 (.3)	
ACSP	.6 (.7)	.6 (2.3)	**5.2** (5.5)	.8 (1.6)			.1 (.6)				
ABCO	1.7 (1.2)	1.7 (2.7)	**9.4** (5.3)	**21.6** (10.1)	.8 (1.6)	2.8 (4.1)	3.1 (4.5)	.1 (.3)	.2 (.8)	.0 (.1)	
PIST		1.3 (2.0)	.1 (.2)	2.4 (3.0)	**10.2** (4.3)	2.1 (3.2)	1.7 (2.4)	1.1 (.4)	.6 (.9)	.3 (.7)	.1 (.3)
PSME	.7 (.9)	3.8 (5.5)	1.5 (2.4)	6.0 (5.7)	**6.4** (5.0)	**26.2** (13.9)	**13.0** (6.3)	2.6 (1.8)	3.5 (3.8)	.7 (1.7)	.6 (1.0)
PIPO		5.0 (6.1)	1.0 (2.9)	2.2 (3.8)	**7.0** (4.4)	1.7 (2.5)	**7.5** (6.1)	**21.3** (11)	**6.5** (6.2)	.5 (1.5)	2.0 (7.0)
PIEN				.3 (1.6)	.2 (1.0)	.0 (.3)	.2 (.7)		.4 (1.1)	**10.9** (6)	1.5 (2.8)
PILE				.0 (.2)		.0 (.2)	.3 (1.0)	.3 (1.2)	.6 (1.4)	.7 (1.2)	**10.2** (5.4)
QUHY		.7 (1.3)	.3 (.8)	.2 (.9)	1.0 (3.6)	.3 (1.0)	2.0 (2.6)	2.1 (2.8)	**8.8** (4.8)	6.0 (4.6)	3.3 (2.9)
QUAR		.3 (.6)		.1 (.3)	.1 (.2)	.2 (.5)	1.0 (2.1)	.3 (.9)	2.8 (2.6)	2.9 (2.4)	3.4 (2.9)
Other	.4 (.4)	1.2 (2.1)	4.6 (3.9)	.4 (.7)	.5 (1.5)	.7 (1.5)	1.5 (3)	.4 (.9)	2.4 (2.8)	3.1 (4.5)	1.4 (1.3)
# Samples	4	27	8	40	37	80	80	161	88	50	26
Elevation	2837	2348	2368	2531	2540	2550	2366	2313	2169	2029	2015
	(90)	(194)	(295)	(275)	(279)	(275)	(258)	(178)	(135)	(140)	(131)

these species also dominated distinct sites. Juniper typically dominated sites at around 2,115 m., whereas border pinyon was less common and tended to dominate at slightly lower elevations (table 3).

Cover Type Framework

The broad and detailed cover types described in this paper are related to each other and to other classification systems. For example, the seven broad types can be related to an even broader classification such as the Anderson system (Anderson et al. 1976), which is used to classify remotely sensed images into land cover classes. Similarly, the 20 more detailed cover types can be further subdivided into structurally distinct classes (Iniguez 2000) to assess successional status. These classification schemes all are based on existing or current conditions, but each describes vegetation communities with different levels of detail. Consequently, these schemes can be used jointly to aggregate or segregate forest lands as needed for specific analyses, while maintaining a standardized conceptual framework across scales.

The detailed cover types described in this paper have a wide range of management implications. For example, although Mexican spotted owls (*Strix occidentalis lucida*) are typically found in the broad mixed conifer forest type, more specifically they favor Pure white fir and Pure Douglas-fir over Pure ponderosa pine cover types (e.g., Ganey and Dick 1995). Similarly, insect and disease outbreaks are typically species-specific requiring detailed cover type information to evaluate susceptibility and speculate damages (e.g., Dahms and Geils 1997).

Conclusion

In this paper, we present a detailed classification scheme for mid-elevation forests in the Sky Islands of southeastern Arizona, as well as a dichotomous key allowing for identification of the cover types recognized. This key allows users to classify new plots and to quantitatively differentiate between cover types. We recognize that some areas will be transitional between the distinct cover types recognized; therefore, our quantitative breakpoints should be viewed as approximations. The key should allow users to determine approximately where they are within the classification scheme, but will not clearly define all stands. Despite this "fuzziness" at some boundaries, we believe that the classification scheme presented will improve our understanding of the ecological relationships among forest types in the Sky Islands.

We also provide a general quantitative description of the 20 cover types recognized based on the distribution of basal area among species within each cover type, in hopes that this information will be useful to researchers and managers in the Sky Islands region. The cover types identified and described here fit within a larger hierarchical framework, and thus facilitate our ability to classify forested lands at varying levels of detail.

Table 3—Mean and standard deviation (in parentheses) of basal area (m^2/ha) by species for detailed cover types found at lower elevations in the Sky Islands of southeastern Arizona. Bolded numbers indicate dominant species used in distinguishing cover types. These nine cover types aggregate to four broader forest types, as shown.

Broad	Broadleaf Evergreen Woodlands				Conifer Woodland			Conifer Riparian	Other
Detailed Cover Types	Pure Silverleaf Oak	AZ White/ Silverleaf Oak	Pure AZ White Oak	Emory/AZ White Oak	Juniper/ Oak	Pure Juniper	Pure Pinyon	AZ Cypress	Shrub Oak
PSME	1.0 (1.7)	.9 (1.7)	.2 (.6)	.1 (.2)	1.7 (4.3)	.3 (.7)	.2 (.7)	.3 (.6)	
PIPO	.5 (1.0)	.6 (1.6)	.0 (.2)	.1 (.2)	.7 (1.9)	.1 (.3)		.2 (.6)	
PIEN	.9 (1.4)	.4 (.9)	.2 (.5)	1.2 (1.6)	.2 (.7)	.2 (.8)			
PILE	.4 (1.2)	.6 (1.1)	.1 (.3)	.2 (.5)	.8 (1.8)	.1 (.4)	.0 (.1)	.3 (.8)	
QUHY	**12.8** (5.1)	**3.5** (3.1)	1.2 (1.6)	2.8 (3.4)	2.0 (2.9)	1.1 (2.8)	0.4 (.8)	0.1 (.2)	0.1 (.2)
QUAR	3.1(2.4)	**8.5** (3.7)	**12.2** (6.6)	**5.6** (3.7)	**5.0** (3.0)	2.9 (3.3)	1.8 (2.0)	1.5 (1.6)	
JUSP	.6 (1.5)	1.4 (1.4)	.7 (1.1)	.3 (.5)	**6.9** (4.2)	**10.2** (7.1)	1.3 (2.2)		
PIDI	.2 (.9)	.8 (1.5)	.3 (.5)	.2 (.4)	1.8 (2.2)	1.4 (2.9)	**7.6** (3.8)	.9 (1.2)	
CYAR	.0 (.1)	.0 (.2)			.1 (.5)		.2 (.5)	**10.2** (7.5)	
QUEM	.1 (.6)	.2 (.5)	.2 (.5)	**5.8** (2.1)	.2 (.7)	.2 (.7)	.1 (1.2)	.1 (.2)	
QUSP	.3 (.6)	.2 (.5)	.1 (.3)	.1 (.1)	.2 (.5)	.3 (.9)	.3 (1.2)	.4 (.4)	**1.5** (1.9)
Other	1.2 (1.6)	.8 (1.3)	.6 (1.0)	1.8 (3.1)	.7 (2.0)	.4 (1.1)	.4 (.4)		
# Samples	76	68	47	67	27	44	13	9	2
Elevation	2039	2050	2124	2062	2166	2115	1989	1928	2430
	(162)	(180)	(149)	(206)	(303)	(129)	(55)	(55)	(242)

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Long-Term Ecosystem Monitoring and Change Detection: The Sonoran Initiative

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Abstract—*Ecoregional Systems Heritage and Encroachment Monitoring (ESHEM) examines issues of land management at an ecosystem level using remote sensing. Engineer Research and Development Center (ERDC), in partnership with Western Illinois University, has developed an ecoregional database and monitoring capability covering the Sonoran region. The monitoring time horizon will extend from the 1970s to at least 2020. The driving issues behind the design of ESHEM are military installation sustainability and encroachment. This paper describes the data in ESHEM as well as "beyond the fence-line" issues that public land managers must now face. It is realized that Federal lands management in the 21st century must occur in cooperation with neighbors. Past experience has shown us that ignoring realities "beyond the fence-line" is an invitation to land use conflicts*

Background

The Ecoregional Systems Heritage and Encroachment Monitoring (ESHEM) initiative examines issues of land use change and land management at an ecosystem level. The longstanding relationship between the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) and military installations, and recent technological advances have made this feasible only within the last few years. The Sonoran Initiative is the second prototype out of ERDC. The first focused on the Sandhills region in the Southeastern United States. This paper will discuss the Sonoran components and examples of applications in the region (figure 1).

Grounded in requirements for managing or tracking entire ecoregions (or a sensible focus on ecosystem sub elements), ESHEM incorporates ecoregional databases and monitoring capabilities from multiple data sources. Potential applications will include regional characterization, change detection, habitat fragmentation for biological species of concern, development encroachment, eco-monitoring, or Base Realignment and Closure (BRAC) support. ESHEM integrates multi agency (USGS, NASA, EPA) data and state-of-the-art scientific capabilities and is intended to cover many land monitoring concerns over a temporal horizon from the 1960s to at least 2020. It is expected that cooperation with other land managers will become part of the process as this research matures.

The military has good reason to be involved in regional ecosystem monitoring. Mission sustainability and encroachment are important issues in the military. In the last decade questions of habitat and urbanizing development have emerged that have the potential to affect an installation's military training and readiness mission. However, neither of these issues can be adequately managed solely within the installation boundaries. They are by their character issues "beyond the fence line." For example, should a species, such as *Gopherus polyphemus* (gopher tortoise) be listed as a threatened or endangered species (TES) in the Eastern United States because of increased urbanization and/or changes in forestry management practices, then off road training at several military bases will be severely curtailed. The military, however, is trying to cooperate with other land managers. Particularly in the Sonoran region, Federal and other non-private lands dominate the face of the country. Within this region the military has one of its best opportunities to cross-manage. In general, Federal lands management agencies must cooperate with their neighbors, and political and local interest groups.

The current support by the military for addressing habitat and urban encroachment concerns emanates from the need to develop and deploy the "Objective Force," that is the new Army configuration, intended to be in place by about the year 2010. It is increasingly clear that questions of habitat and urban encroachment have the potential to limit the effectiveness of the "Objective Force" vision. Another important driver for looking at regional issues is found in DoD Directive 4715: Range Infrastructure. This Directive deals with concerns about sustainable ranges, land management processes, and range "health" or status. If the military has to set aside lands for species protection, particularly Threatened and Endangered Species (TES), that land is not fully available for support of the installation's training and readiness mission. Similarly, if land that was once adequate for heavy weapons ranges is now adjacent to civilian residential housing, it becomes more difficult for the military to carry on its training and readiness

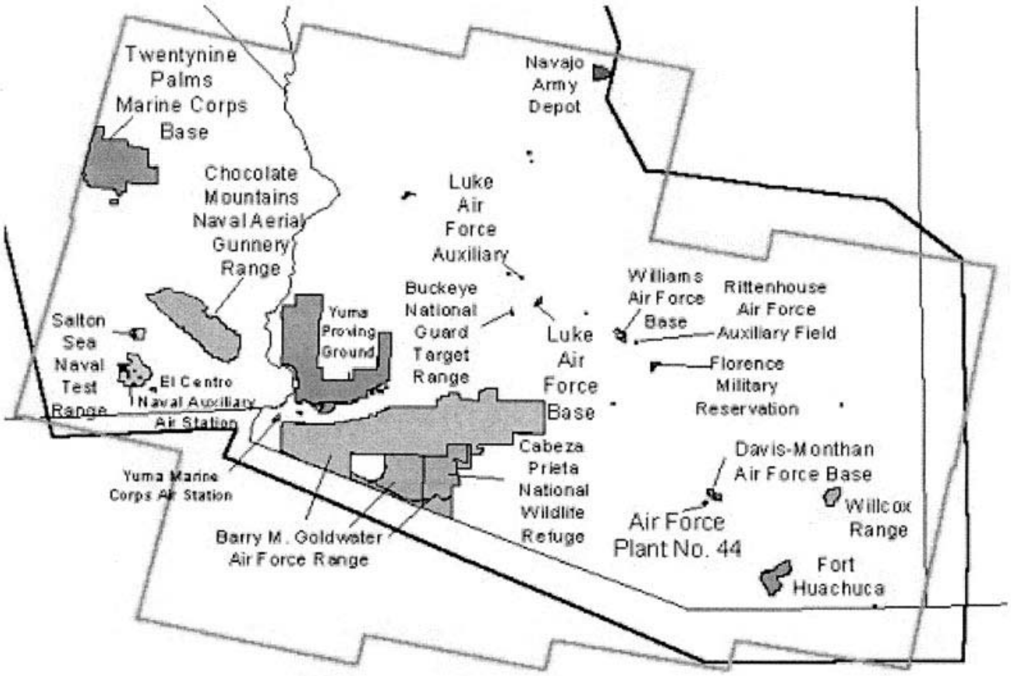

Figure 1—Military ownership within Sonoran Imagery coverage. From Federal Lands distribution in the National Atlas. The military has a high presence in the Region.

purpose without alienating those individuals that live along the installation boundary. The result of this is that the range becomes less useful over time. In most cases, installations will not gain additional lands; they are now rarely available. At the same time, the vision of the "Objective Force" is to establish weapons systems and training techniques that will require more land than is available at most current installations. Thus the double edged sword of more restrictions on current lands and the requirement for even more land means the military needs to manage its current resources even more intensely (including for conservation purposes) and no longer has the option of worrying only about it's own land. Ignoring realities beyond the "fence-line" is an invitation to land use conflicts.

ERDC is now focusing on issues of habitat and TES management. The purpose of this portion of the research is to support the ability to identify ecosystem wide critical habitats and habitat fragmentation. It also is intended to provide the basis to efficiently and cooperatively partition the TES habitat management responsibilities among agencies within a region. Within the Army conservation pillar research program, Environmental Requirement A (4.6c) is concerned with Threatened and Endangered Species Inventory, Survey, and Monitoring Areas of Concern in terms of habitats and populations. It specifically states, "... recognizing that military actions may result in or contribute to more subtle longer-term land and ecosystem changes, research and investigation is needed on TES in a larger ecosystem context."

Purpose of Sonoran ESHEM Initiative

The purpose of Sonoran ESHEM Initiative is to provide the framework for land management and monitoring at the ecosystem level for Southwest ecosystems in the United States (in a manner similar to the research already accomplished in the Southeast Sand Hills area). The focus is the dry desert and scrub domain in the United States Southwest that includes a high concentration of military installations and Federal lands. The product is in three parts:

1. A historic land cover data set at high-resolution (60 meters) covering a large portion of the Sonoran Ecosystem.
2. A cost effective monitoring ability to give near real time information about potential significant changes
3. Applications of the system to show usage and payback.

Development of the Historic Land Cover Data

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL), Champaign, IL, has engaged in several research projects investigating tools for encroachment risk assessment. The concept of following the trend of urbanization within a region and the prediction of how that might continue into the future has been developing for several decades (Steinitz 1967). ERDC/CERL has engaged in several research projects that investigated risk assessments from increased development near installations. The conceptual framework for the approach has been investigated (Rose et al. 2000). Some regions that include military installations have been studied for the alternatives that are available to policy managers (Steinitz et al. 1996). Some studies have focused on the restrictions resulting from resource depletion (Steinitz et al. 2002) more than from the development issues. These studies have helped formulate the establishment of a military-specific predictive tool (Deal 2001) for evaluating future alternatives.

Several advances have occurred that now make possible a more defensible illustration of developmental growth. The integration of remote sensing techniques into a single coordinated Geographic Information Systems (GIS) framework is primary. Our long term land change data base takes advantage of the opportunities remote sensing present. Two standardized sources of data form the backbone:

- The National Land Cover Data is the result of a project to generate land cover data derived from images acquired in the early 1990s by the Landsat satellite's Thematic Mapper sensor.
- The North American Landscape Characterization is a project to provide complete Landsat Multispectral scanner (MSS) coverage of the conterminous United States and Mexico in the years 1973, 1986, and 1991 for the purposes of mapping land cover and land cover change.

In a series of CERL development contracts, one of the authors, Dr. Ehlschlaeger, formerly at the Department of Geography, Hunter College (CUNY), has developed a unique procedure called "CellPicker" that uses the NLCD to derive historical land cover maps from the images in the NALC data (Lozar et al. 2003). It consists of a series of steps using a suite of image-processing tools GIS manipulations, and Java applications to generate land cover maps for the 1970s, 1980s, and 1990s. A version was used to generate map coverage for the entire Sonoran Ecoregion in the Southwestern United States. The "ground-truth" data are considered to be the 1990s NLCD, which are classified raster grids based on 30-m Landsat TM data. The 1980s and 1970s Land Use Data are grids derived from the NALC images. The CellPicker process attempts to find grid cells in the NALC images that have the same appearance over all three decades. Grid cells with the same appearance over three decades are considered "ground truth" and are given the NLCD category at the same location. The classified grids are developed via a supervised classification technique using ground-truth cells from the CellPicker process (Cox 2003).

Near Real Time Monitoring Ability

Once you have a long-term land use base in place, the next issue is, "What is the most cost effective means of monitoring the region covered?" NASA has had a long history of developing satellite instruments that provide remote sensing imagery for civilian purposes beginning in 1972. The Landsat series provided high-resolution multi-spectral images of the Earth's surface. The Multispectral Scanner (MSS) instrument provided detail at roughly 60- x 80-meter pixel size in four broad spectral bands. Beginning in 1982, the Thematic Mapper (TM) instruments were launched. The TM images continue to provide detail at about 30-meters resolution in seven spectral bands. Though highly useful, the Landsat series of instruments have some shortcomings:

- They are too detailed and slow to cover the entire Earth in a short period.
- They are surface sensing instruments without collateral atmospheric instruments to provide corrections for atmosphere and sensing angle effects.

In response to the scientific investigation of global climatic change, NASA developed a program to use remote sensing capabilities to study the Earth from space. As part of the EOS, the Terra mission (also called EOS AM-1) is part of NASA's ESE. The Terra satellite was successfully launched from Vandenberg Air Force Base, CA, on December 18, 1999. The second in the series, Aqua, is now also providing products. Several of the instruments aboard Terra provide data and products of interest to military land managers.

The Terra platform and its products represent cutting edge science as applied to remote sensing (Eos Data Web site). Specifically, products derived from the EOS are physical process based, meaning that they are:

- Based on "first principle" physical processes.
- Objectively derived.
- Calculated and repeatable.

Though these objectives may seem obvious to most scientific disciplines, Terra products come closest to obtaining this goal in the remote sensing discipline. Most remote sensing products require subjective analysis and expert knowledge to be useful in scientific analysis.

Land managers have a need for the products from Terra. Most of the instruments generate a suite of products, some for atmospheric or oceanographic studies and some for land monitoring. Of particular interest to land managers are those products of greater detail (high resolution) that dependably cover their installations. Though the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instrument (Aster Web site) has high resolution (15 meters), coverage is spotty. MODIS and Multi-angle Imaging Spectraradiometer (MISR) instruments sense the entire globe every 2 days; some of the spectral bands are at roughly 250 meters resolution. Though this scale is gross for most management purposes, it still provides some unique advantages over other sources of imagery. Further, products derived from the images are:

- Available at no cost.
- Available on a dependable schedule (daily, monthly, yearly; planned for at least the next 15 years).
- Built through a series of steps using data from other instruments on the Terra satellite that correct for atmospheric, directional, and seasonal effects. This unique benefit of Terra is not available with other existing satellites.
- Based on the most advanced scientific understanding (still in development).
- Based on objective "first principle" physical science of the objects being derived (e.g., vegetation characteristics are based on the physical response of chlorophyll to radiation).
- Developed for environmental monitoring purposes (for land managers, land/habitat/monitoring and change detection).
- Standardized and comparable through time.
- Spatially stable. On a Terra product, the location and size of a single pixel will be the same in March 2001 as in December 2018 to within 10 meters for a 250-meter pixel.

- Coordinated with legacy products in some cases. The Normalized Difference Vegetation Index (NDVI) product is coordinated with a 20-year-older National Oceanic and Atmospheric Administration (NOAA) product1. Together, these characteristics provide an excellent potential base for land and ecological monitoring over a nearly five-decade horizon.

The MODIS instrument2 is of particular interest to land managers. The MODIS hyperspectral sensor is the key instrument aboard both the Terra and Aqua satellites. MODIS views the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands. These data will improve the understanding of dynamics and processes occurring on the land (as well as in the oceans and the lower atmosphere). The series of MODIS instruments will play a vital role in the development of validated, interactive Earth system models able to predict change accurately enough to assist policymakers in making sound decisions concerning the protection of our environment. To do this, not only are the raw spectral band data made available, but also many calculated (level 2 and 3) products, some of which are of interest and use for regional ecosystem monitoring and management.

We translated useful and existing MODIS Land Products from the NASA Unique HDF format to a standard GIS (ESRI GRID) format. CERL now has more than 280 Gigabits of MODIS data—all the indicated MODIS LAND data that was available in CY2003 in an easy to use format. To provide some idea of the significance of this data:

The western region's coverage:

- Is over one million square miles.
- Covers 16 States and Mexico.
- Includes 112 ecosystems.
- Covers 300 military installations.

The idea behind ESHM is that the MODIS products can be easily integrated with Historic Trend Data of the Sonoran land cover data sets within the MODIS monitoring region. The dozen imagery areas that make up the Sonoran land cover data can be directly compared with the grosser MODIS Vegetation Indices and Land Use Types. Thus a set of temporally consistent trends can be derived for both the natural and man-made environment. By this method we have the ability to use NASA instruments within the Sonoran to help monitor and manage lands, particularly in this case military lands.

Applications to Show Potential Paybacks

Although the spatial detail is low in the MODIS images and products, the temporal coverage is very high. As an example for the area around the Imperial Valley of California (where several military installations exist in the region), from the Landsat images the NLCD are generated once a decade (maybe). From the NALC Triplicates, we were able to generate three decades of land cover for the region at 60 meters resolution. But that was a long and costly process. Looking at a region only once a decade really isn't monitoring and you likely shouldn't try to use such infrequent snapshots to proactively manage the landscape. However, the MODIS Land Cover product is generated once a year for the entire globe and preliminary products are produced quarterly. Most land managers will ignore the MODIS Land Cover product because it is at a kilometer resolution. Yet, if you ask these same land managers two critical questions, the usefulness of the MODIS Land Cover is immediately put into perspective. The questions are:

- How long ago was your current land use map generated?
- How much did it cost?

Most answers indicate the land cover maps are about a decade old and they cost tens of thousands of dollars. Compare that to the MODIS Land Cover every 90 days and no cost for acquisition (there may be some minor cost for analysis and formatting for use respectively. MODIS products offer the potential to manage lands and land use changes in near real time.

The current work is being done as one thrust of a TES habitat fragmentation project. Fire is a significant and continuous factor in the ecology of savannas, boreal forests, and tundra. It plays a central role in deforestation and habitat change and fragmentation. Important habitat impacts of fires include changes of physical state of vegetation, release of soot and other particulate matter during fires, and changes in plant community development and soil nutrient, temperature, and moisture. One of the MODIS Products is the Fire Occurrence Product that is generated daily (or more often) because a MODIS instrument senses each location on earth four times a day. (The Terra platform senses at 10:30 a.m. and 10:30 p.m., while the Aqua platform senses at 2:30 p.m. and 2:30 a.m. Near real time fire products can be acquired from the MODIS Rapid Response Team at NASA GSFC or through a product that is summarized as an 8 day composite. For example, in the MOD14a2 Summarized 8 Day Composite Fire Product for the period ending May 8, 2001, we found a fire that covered more than 13 square kilometers at the west edge of the Goldwater Range and less than 5 kilometers south of Yuma MCAS. Such data can temporally monitor potential large and small changes in the habitat of Endangered Species as they relate to management of lands on or near military installations. This concept has lead to ERDS's most recent thrust.

ERDC and Western Illinois University are currently working on relating MODIS products to Threatened and Endangered Species (TES) monitoring. The objective of this work is to investigate and develop examples of Space-Time modeling of Threatened and Endangered Species Habitat from the MODIS data. MODIS data provide scientifically measured products available on a regular time scale. Traditional habitat modeling, for example, landscape pattern metrics, has assumed static land cover maps defined at a nominal scale. However, species live a dynamic life requiring different resources at different portions of their life cycle. Species' life cycles often correspond to the seasons of the year. MODIS' temporally specific and ratio scale data combined with detailed land cover data using the latest spatial statistic techniques that can organize three dimensional data (latitude, longitude, and time) can potentially provide a superior model for species, especially TES habitat modeling.

To do this, specific TES lifecycles will be associated with MODIS data. The project will identify space-time data products (geographic and temporal dimensions) necessary to model the seven TES of greatest concern to military installation land managers. Then a sample of space-time products will be conflated from multiple sources for a target date in the year 2002. For example, the MODIS Land Cover data can be combined with vegetation information to create biomass values at specific space-time locations. This space-time data would be useful for space-time habitat fragmentation analysis. For example, NDVI values from MODIS data at specific vegetation type locations can provide a good measure of biomass for a particular TES during its mating season.

Results and Conclusions

The Ecoregional Systems Heritage and Encroachment Monitoring (ESHEM) initiative has begun to put together the ability to examine issue of land use change and land management at an ecosystem level. Recent technological advances have made this feasible only within the last few years. The Sonoran Initiative is the second prototype out of ERDC. This paper discusses the development of historic land cover data, remote sensing components to the ESHEM initiative, cost effectiveness, and applications.

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Phenology and Trend Indicators Derived From Spatially Dynamic Bi-Weekly Satellite Imagery to Support Ecosystem Monitoring

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Abstract—*Ground-based ecosystem monitoring presents some practical challenges to natural resource managers and ecologists tasked with assessing vegetation dynamics across large areas through time. RangeView (http://rangeview.arizona.edu) provides online access to spatially and temporally explicit biweekly vegetation indices derived from satellite data. It also permits side-by-side comparisons of different periods and relative greenness products (e.g., difference from average). Qualitative visualization of vegetation dynamics could be enhanced with quantitative assessment of phenology for specific locations and time periods. Case studies of the Santa Catalina Mountains and the Mogollon Rim suggest phenological indicators of greenness onset, peak greenness, and length of growing season show promise for quantitative assessment of vegetation trends.*

Introduction

Of the 2.26 billion acres that comprise the land area of the United States, 590 million were considered pasture/rangeland and 740 million were considered forest land in 1992 (Daugherty 1995; NRCS 2000). Vegetation change on these lands has been significant over the past century, with 62 million acres undergoing afforestation and another 70 million undergoing deforestation (Birdsey and Lewis 2003). The periodic ground-based measurement of the status of vegetation resources or associated indicators is essential to assess the health of rangelands and forests (National Research Council 1994). Nevertheless, the monitoring of vegetation dynamics over large areas is a major challenge identified by natural resource managers. Ground-based methods could be enhanced if regularly captured satellite images are made operationally available in a spatially and temporally explicit manner. Natural resource managers have been making requests for value-added, easy-to-use, and spatially explicit products derived from remote sensing data since the launch of the first civilian satellite in 1972. Government officials (ARSC 2001) and natural resource managers (Marsh and others 2001) in the agriculture sector (Moran and others 1997) have echoed the constraints to adoption of such products. From the end user's standpoint, the adoption of geospatial technology is predicated on the regular availability of timely, quantitative, validated, operational, and site-specific information products.

Though a variety of satellite sensor options are now available, practical considerations (i.e., data and processing costs, the inherent tradeoff between spatial and temporal resolution, and the influence of cloud cover) favor platforms that provide frequent images that are systematically processed into products useful for the assessment of vegetation. Two sensors among those that currently meet these criteria are the NOAA Advanced Very High Resolution Radiometer (AVHRR) and NASA's Moderate Resolution Imaging Spectroradiometer (MODIS). Both capture spectral information in the requisite wavelengths which, when ratioed or otherwise transformed, enhance the vegetation signal. Among the products that can be derived from these images are vegetation indices (VI) that allow us to reliably monitor seasonal and inter-annual variations in photosynthetic activity (often termed vegetation "greenness") associated with biophysical, structural, and phenologic vegetation canopy parameters (Huete and others 2002). The most widely used VI is the normalized difference vegetation index (NDVI), which is a normalized ratio of reflectance (ρ) in the near infrared (NIR) and red bands (equation 1). NDVI has served as an intermediary for the assessment of other biophysical parameters such as green canopy cover, biomass, and leaf area index. The USGS creates biweekly NDVI composites derived from AVHRR (14 days) and MODIS (16 days) imagery that may be ordered through the EROS Data Center (USGS 2004). To produce composite images for AVHRR, daily NDVI data are compiled such that the highest NDVI value over the composite period is selected for each pixel in the resultant

$$NDVI = \frac{\rho NIR - \rho Red}{\rho NIR + \rho Red}$$

Equation 1. Normalized Difference Vegetation Index.

image. MODIS composites balance the highest NDVI value method with the optimal view angle for each pixel. For both sensors this technique minimizes cloud contamination.

These derived products are of great value, but are delivered in a form that requires expertise and software, limiting their operational potential. To address this need, the University of Arizona (UA) partnered with natural resource managers to make these data operationally accessible online via the RangeView (http://rangeview.arizona.edu) Web site (University of Arizona 2004). This web-based information system allows users to assimilate disparate spatial datasets and visualize time-varying spatial relationships. RangeView is used primarily by vegetation scientists and natural resource managers who are now requesting the tools necessary to analyze spatially and temporal explicit vegetation trends. Through case studies in the Santa Catalina Mountains and the Mogollon Rim, we are evaluating methods to assess greenness onset, peak greenness and length of growing season in a spatially and temporally explicit manner (e.g. Reed and others 1994; Zhang et al 2003). This paper describes the dynamic visualization tool, associated analytical products, and the development of phenological indicators which, when automated, should help natural resource managers quantitatively assess vegetation dynamics.

Visualization

RangeView is a NASA/Raytheon-sponsored initiative that seeks to make NASA Earth Observation System (EOS) data accessible and useful to natural resource managers. The system serves to enhance users' understanding of and ability to manage natural resources as they vary across the landscape and change through time. The underlying application has flexibility to handle raster, vector, and tabular data at varying spatial and temporal resolutions. It provides the user with the spatial dynamic of an Internet map server, the temporal dynamic of time-series animation, and the analytical capability of graphing software. RangeView currently provides near-real time (~3-7 days lag time) access to time-series data, including:

- NOAA's Advanced Very High Resolution Radiometer (AVHRR) (1989 to present)
  - NDVI (1 km spatial and 14 day temporal resolution)
  - Coverage over the conterminous United States, Southern Canada and Northern Mexico
- NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) (2000 to present)
  - NDVI and the Enhanced Vegetation Index (EVI) (250 m and 1 km spatial and 16 day temporal resolution)
  - Leaf Area Index (1 km and 8-day)
  - Coverage of Western United States, Southern Canada, and most of Mexico at 1 km spatial resolution
  - Coverage of Southwestern United States at 250 m spatial resolution

Spatially and temporally explicit visualization is made possible through a series of automated data conversion steps that transform AVHRR and MODIS data from their native format into bitmapped graphic images compressed for Web-based viewing. The data are displayed interactively through the use of an internet map server (ESRI ArcIMS 4.01 with the Java Connector to serve maps and ESRI ArcSDE 8.3 for MS SQL Server 2000 to store spatial data). RangeView permits the overlay of ancillary data layers (such as roads or boundaries to facilitate geo-location), zooming and panning capabilities as well as capacity to run time-series animations. Figure 1 provides the example of the Aspen Fire, which, in the summer of 2003, burned 84,750 acres and destroyed 333 structures on Mount Lemmon in the Santa Catalina Mountains sky island just north of Tucson, Arizona.

Interpretation

Visualizing vegetation greenness on a biweekly basis provides insight into vegetation dynamics through time. However, in order to answer questions like, "Is it greener than it usually is for this time period in this location?" it was necessary to develop a suite of interpretive tools. The RangeView application allows users to view several map windows at once to compare vegetation greenness between different years. Using the longer-term AVHRR data set (1989 to date), users can also assess departures in vegetation greenness from a 14-year average. Figure 2 depicts the period ending May 4, 2004, during which much of the Madrean sky islands and desert seas exhibited vegetation greenness levels less than the average greenness recorded for early May (averages are calculated pixel-by-pixel on NDVI data from 1989 through 2003). Notice the pronounced impact of the 2003 Aspen Fire (north of Tucson) and the 2002 Rodeo-Chediski Fire (top of image). Options to visualize differences in vegetation greenness from the previous year or the previous bi-weekly period are also available.

Indicators of Phenology

Spatially and temporally dynamic access to visualizations of VIs greatly enhances the capacity of non-specialists to use MODIS and AVHRR imagery for understanding vegetation dynamics. However, further assessment of trends and temporal transitions in vegetation greenness require quantitative analysis of the underlying VI data. Discussions with RangeView lead users (Orr and others 2003) suggest that identification of trends in the start, peak, end, and duration of the growing season would greatly assist in management decision making. Ultimately users would like to visualize these indicators graphically for selected areas on the images such as for specific vegetation types or pastures (user-defined) in conjunction with the time-series animations.

In order to begin addressing this challenge, we set up a methodological case study on an elevation gradient across Mt. Lemmon to capture eight of the Arizona gap analysis vegetation types (Halvorson and others 2001) represented by Madrean sky islands and their environs in the Sonoran Desert (figure 3). This also permitted the assessment of phenological changes associated with the recent Bullock (2002) and Aspen (2003) fires.

We began by automating a method to extract NDVI data for pixels residing within individual polygons. Using scripting language associated with a geographic information system (GIS) software (ESRI ArcINFO's Arc Macro Language [AML]), we calculated the mean NDVI for pixels within each polygon for each time period and stored these in a spreadsheet. A number of different methods have been developed to determine the timing of green-up and senescence (Zhang and others 2003), the simplest being a characterization of phenology through multitemporal profiles (NDVI plotted against time). The multitemporal profiles depicted in figure 4 are based on the mean NDVI values extracted from the gap analysis (Halvorson et al. 2001) vegetation type polygons (figure 3). The profile shows the high variability within phenologic trends, particularly at higher elevations where snow and cloud cover can impact the vegetation signal.

This variability must be addressed in any system that automates the identification of the start, peak, and end of the growing season. An operationally simple, yet intuitive method for curve characterization involves calculating moving averages (Reed and others 1994). In the Mt. Lemmon case study we applied a three-period (a) forward-looking, (b) backward-looking, and (c) centered moving average. The convergence of these curves can be used to identify the timing of the beginning, peak, and end of the growing season in the NDVI temporal profile (figure 5). Changes in phenological patterns exhibited in satellite data have been linked to short-term impacts like wildfire as well as to the longer term impacts of drought (e.g., Kogan 1995). Analysis of the sum of NDVI values over the length of the growing season for the Mt. Lemmon vegetation cover types highlights the impact of drought, particularly in lower elevation vegetation (figure 6).

The greater relative difference between maximum and minimum cumulative NDVI for upper elevation woodland vegetation types indicates that these types are not as immediately responsive to changes in precipitation as are lower elevation vegetation types. At higher elevations these values may be impacted by the presences of snow or clouds; however, this contamination is generally limited to a couple of periods, so the impact should be slight. The cumulative NDVI of upper elevation woodland also shows the impacts of the Bullock Fire of 2002. Ultimately, providing natural resource managers direct access to these information products should significantly enhance their ability to monitor and understand changes in vegetation associated with climatic or anthropogenic impacts.

Conclusions and Future Directions

RangeView currently provides interactive access to current and historical vegetation products derived from AVHRR and MODIS satellite data. The ability to zoom in on any area of interest and run a time-series animation of absolute greenness

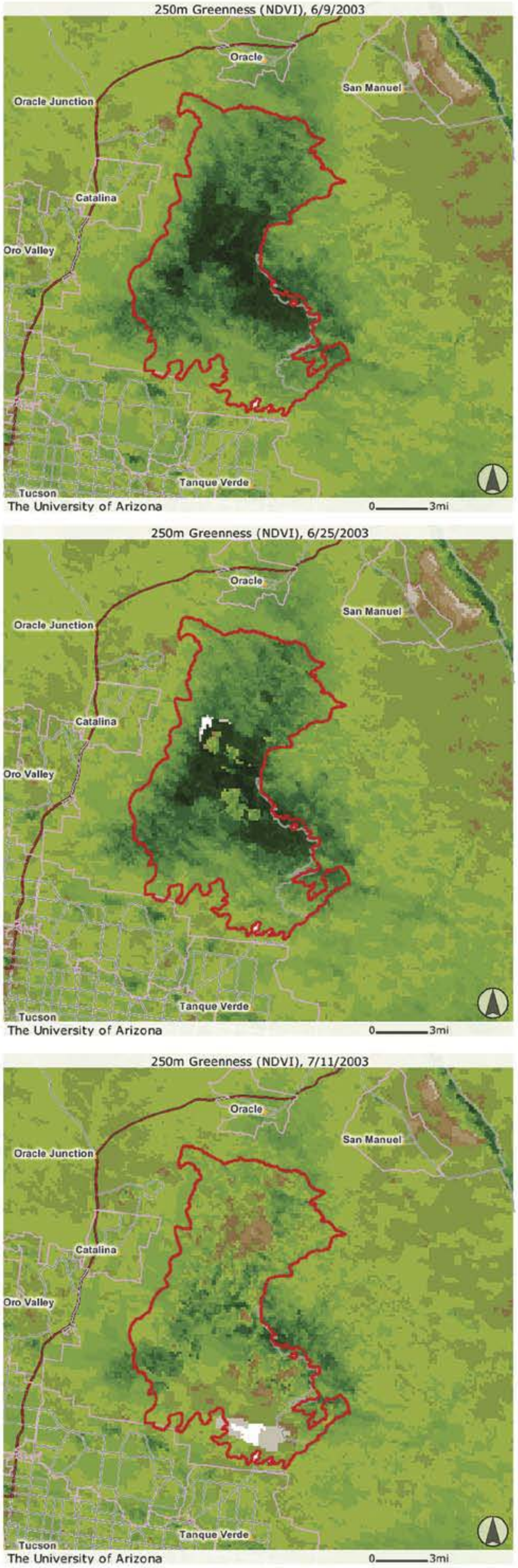

Figure 1—From left, MODIS 250m NDVI composites before (period ending June 9) and during (periods ending June 25 and July 11) the Aspen Fire of 2003 (outlined in red) north of Tucson, Arizona.

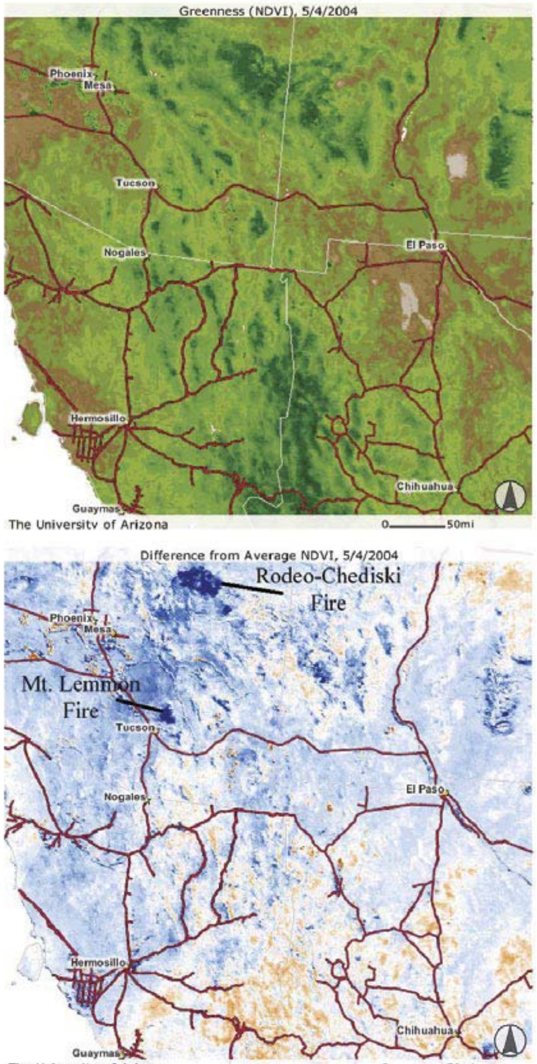

Figure 2—Example of viewing vegetation greenness (AVHRR NDVI) on the left and difference from average on the right (white = average greeness, blue = below average greenness, orange = greener than average).

as well as create departure-from-average maps can aid in ecosystem monitoring efforts and associated decision making. The RangeView team has begun to explore methods that will take the application beyond data visualization into the realm of data analysis. This paper documents our first steps in this transition as we develop methods to automate the site-specific identification of phenological indicators and their temporal trends. This case study of the evaluation of multitemporal greenness profiles across a range of vegetation types utilizing moving averages has demonstrated the potential of quantitative monitoring techniques and the automation of trend indicators. We will continue to explore additional techniques such as the Vegetation Condition Index (VCI), which is a ratio of the NDVI collected in a given period compared to its historical range (Kogan 1995), piecewise logistic regressions fit to NDVI data (Zhang and others 2004), and waveform polynomial curve fitting. Ultimately, we will implement the most effective methods that will both map and analyze trend indicators to help natural resource managers meet the considerable challenge of ecological monitoring.

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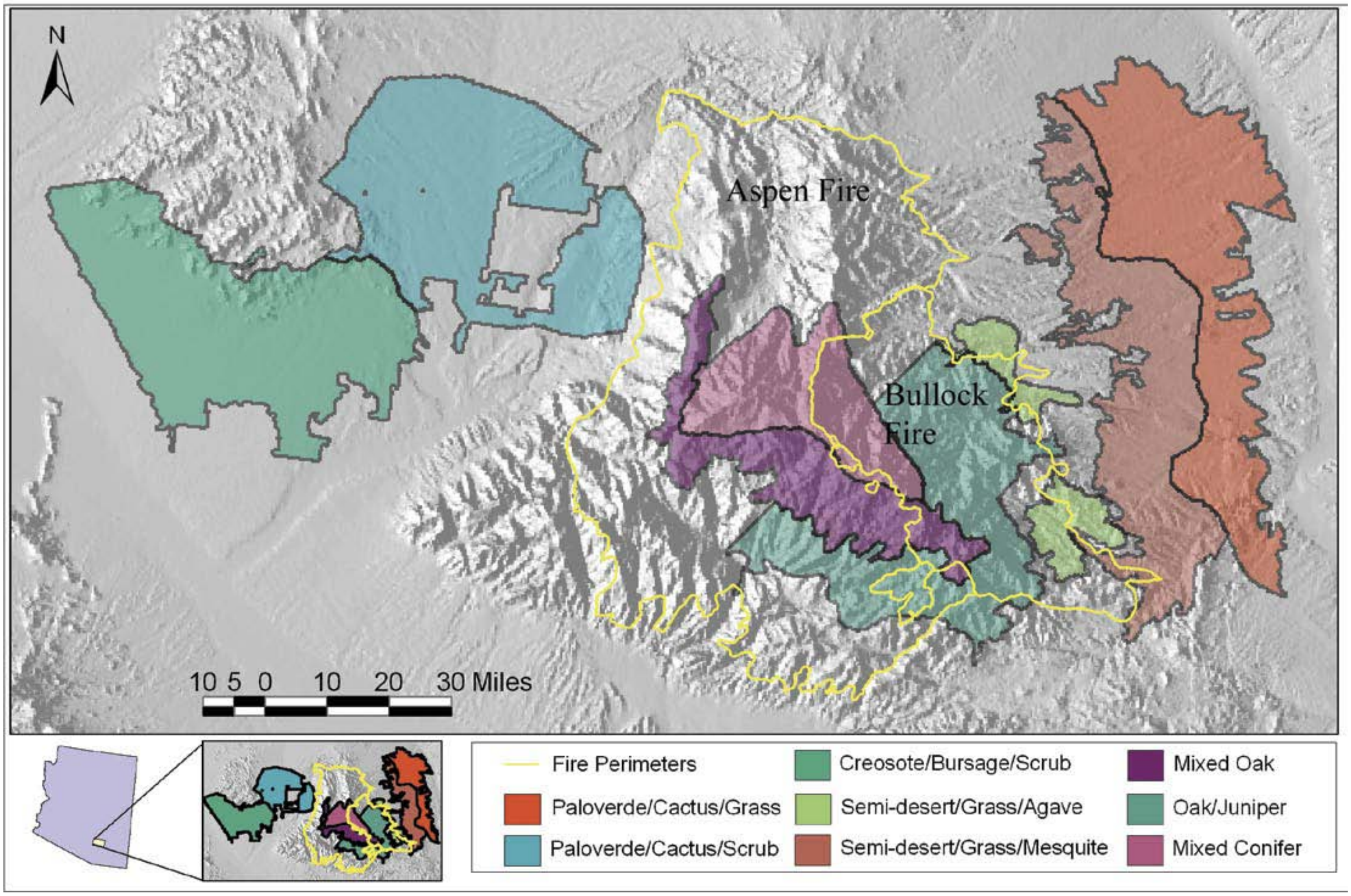

Figure 3—Arizona gap analysis vegetation polygons used to extract NDVI data.

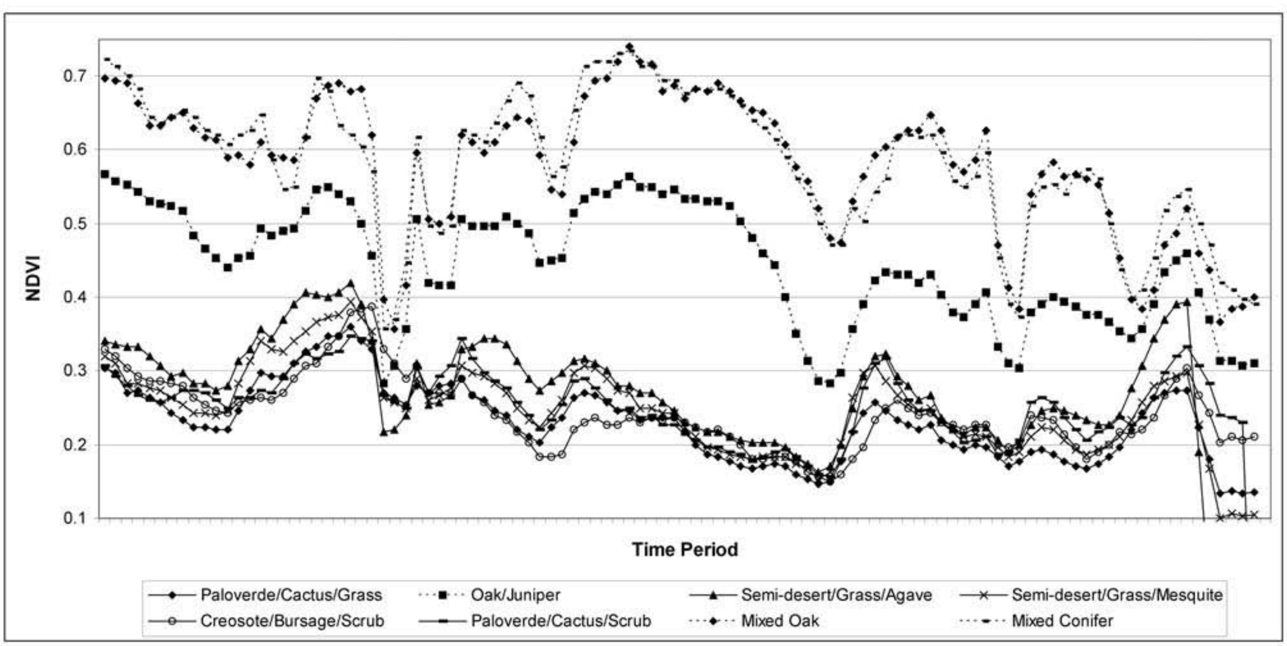

Figure 4—Multi-temporal NDVI profiles of 8 sky island gap analysis vegetation types.

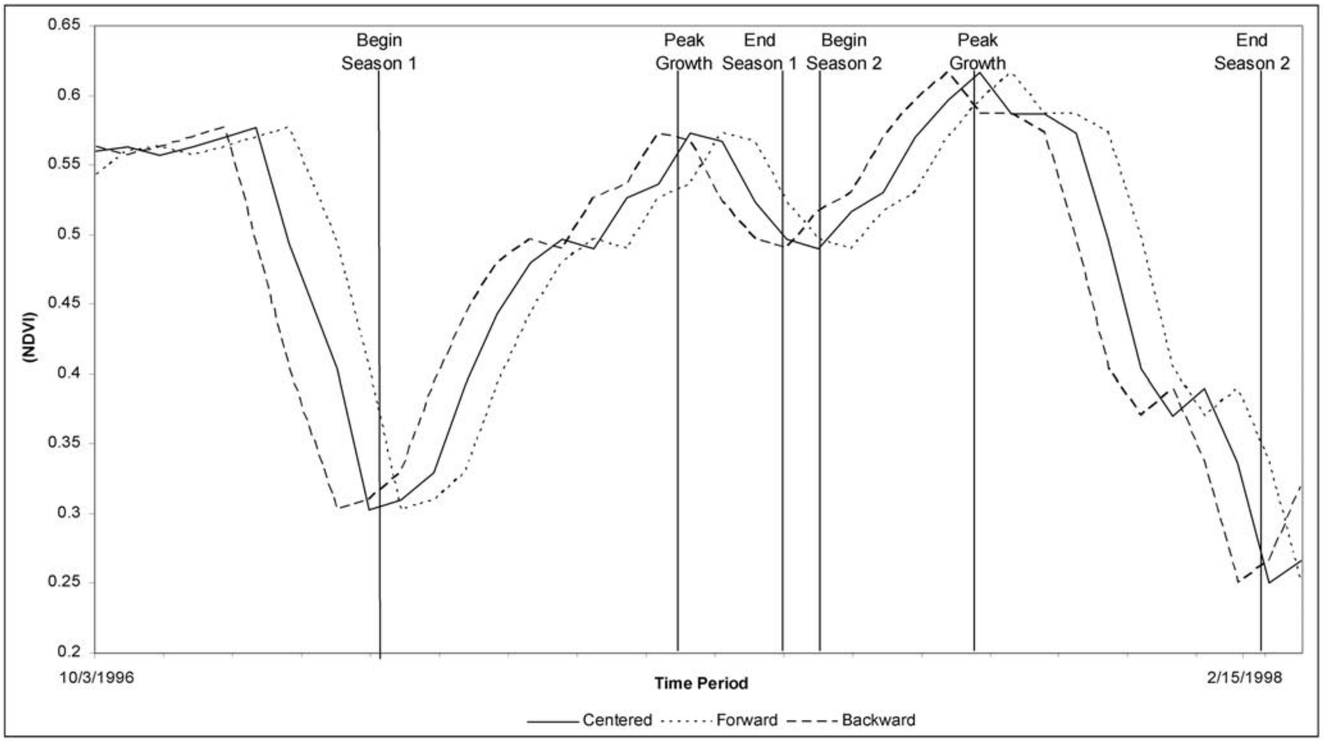

Figure 5—The convergence of forward, backward, and centered moving averages can be used to identify phenological indicators in the NDVI temporal profile.

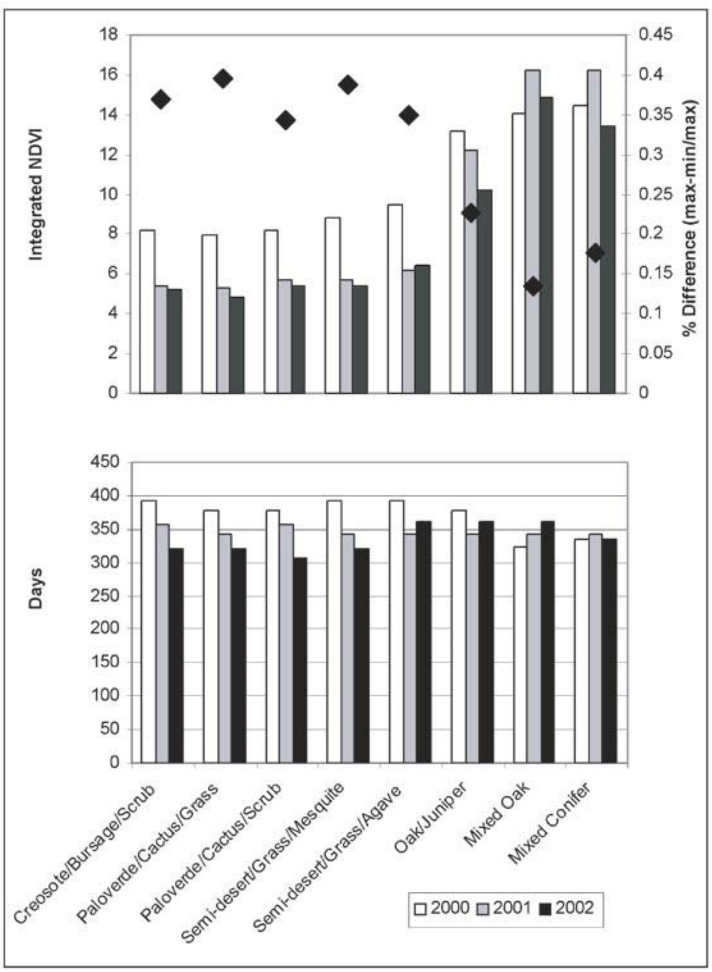

Figure 6—Cumulative NDVI and length of growing season for Mt. Lemmon vegetation types between 2000 and 2002. Average elevation for vegetation types increases from left to right.

Community Based Monitoring: Engaging and Empowering Alberta Ranchers

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Abstract—*Community based monitoring (CBM), a form of citizen science, is presented as a potential contributor to ecosystem management and sustainable development. A conceptual model for CBM and lessons learned from a Canadian national pilot program, the Canadian Community Monitoring Network, are summarized along with a description of the European university-based "science shop" approach. Local knowledge can be legitimized and validated through CBM programs, and participants are empowered to engage in the adaptive policy, planning, and management processes that affect their communities. Ranchers in southwestern Alberta are working collaboratively with the academic community to develop their own CBM program.*

Introduction

> Successful approaches to ecosystem management are increasingly community-based – initiated by local people, and motivated by a "love of place." In such cases, ecosystem management is in the local interest, and is a means to achieve the beneficial use of its "natural capital" (Sexton et al. 1999, p .4).

Ecosystem based management (EBM) is a dominant emerging philosophy for natural resource management. For our purposes here, EBM is defined as "an approach to guiding human activity using collaborative, interdisciplinary, and adaptive methods with the long-term goal of sustaining desired future conditions of ecologically bounded areas that, in turn, support healthy sustainable communities" (Quinn 2002, p. 371). Whereas conventional natural resource management has relied more on (natural) scientific and economic information to drive decision making, it is a central tenet of EBM that socio-cultural, value-based input and community engagement are at least as important to effective understanding and management. Hence, one of the most significant challenges of EBM is to create interdisciplinary methods and approaches for framing and addressing problems that embrace traditionally disparate knowledge systems.

The purpose of this paper is to discuss one way, *community based monitoring* (CBM), in which local knowledge and expertise might be collected and integrated into understanding complex environments with the aim of achieving better policy, planning and management. CBM employs indicators so as to provide early warning signals for adaptive adjustments to management programs. We summarize the key lessons learned from Canadian experience with CBM and present a conceptual framework developed by the Ecological Monitoring and Assessment Network (EMAN) coordinated by Environment Canada. We then offer a brief description and approach for applying these lessons and the framework to a CBM project for ranchers in southwestern Alberta. Our emphasis is on the processes and benefits of social learning and community capacity-building with the assumption that better informed citizens, planners, and managers will contribute to more informed and effective decision-making.

Community Based Environmental Monitoring

> Monitoring and evaluation get a rhetorical nod from practically everyone in natural resource management. In practice, monitoring and evaluation have been frequently shunned, ignored, and underfunded by resource managers and policy makers alike…. Complex systems, incomplete data, and uncertainties about the effects of management actions mean that *monitoring and evaluation are not luxuries but essential components for any ecological approach to managing natural resources* [emphasis added] (Szaro, 1999, p. 223).

Monitoring is an essential, but often under-achieved, component of ecosystem based management (Vaughan et al. 2001). Community based monitoring (CBM) is an act of civil society whereby concerned citizens, government agencies, industry, academia, community groups, and local institutions collaborate to monitor, track, and respond to issues of common community concern (EMAN 2002). CBM is confluent with the pursuit of sustainable development and ecosystem based management. CBM derives from a holistic perspective, encourages an interdisciplinary approach, focuses on collaboration and cooperation, and is driven from the bottom up. Furthermore, CBM operates within ecological boundaries, incorporates flexibility and adaptability, recognizes the importance of socio-political and values frameworks, and contributes to achieving sustainable communities (Bliss et al. 2001; Fleming and Henkel 2001; Whitelaw et al. 2003). Effective CBM should be collaboratively designed and implemented to address locally determined information needs and provide contextual data for more informed decision-making.

CBM is part of the much longer tradition of citizen science, which is in turn a product of amateur natural history pursuits (Noss 2002). Citizen science describes any process where various sectors of society engage in the development and practice of public-interest research in order to bridge gaps between science and the community and between scientific research and policy, and decision-making and planning (Fisher 2000; Heiman 1997; Irwin 1995). The process involves social learning through environmental research, public participation, adaptive management practices, and effective integration of knowledge into the decision-making process. Citizen science recognizes the divide between those who control specialized knowledge required for complex public decisions and those who want to influence policy decisions that affect their lives. In essence, citizen science is a process that democratizes expertise (Farkas 2002) and extends the notion of peer review (Functowicz and Ravetz 1994).

A particularly rich form of citizen science transcends the engagement of local non-specialists in conventional scientific protocols by facilitating the incorporation of local knowledge, wisdom, and other ways of knowing. In other words, the full potential of citizen science is approached when it encompasses more than just having non-scientists participate in science (i.e., conventional science by non-scientists), and expands the realm of what *kind* of information is included in policy, planning, and management (i.e., conventional science and local knowledge in a mutual process of social learning). This expansion of participation, process, and epistemology is well established in the theories and practice of communicative and collaborative planning (Cheng and Daniels 2003; Healy 2003), post-normal science (Functowicz and Ravetz 1994), and integrated adaptive management (Kusel et al. 1996). The significance of the challenges associated with integrating knowledge types cannot be underestimated, for as Irwin (1995, p. 161) points out: "science citizen relations founder not simply because of the lack of appropriate mediating structures but because of a deeper incongruity (or structural incompatibility) between the needs of citizens and the cognitive and institutional structure of contemporary science." CBM can provide a gateway for the advancement of our understanding and technique in the field of developing new social and knowledge relations as well as demonstrating the relevance of monitoring.

The European model of university-based "science shops" (*wetenschapswinkels*), founded in Holland in the 1970s, embraces the value of local knowledge and expertise and considers these inputs across the whole spectrum of research, from problem identification to application of the results. Today, a network of science shops across Europe cooperatively engages citizens with scientists to combine contextual and technical information for more comprehensive knowledge creation (Farcas 2002; Heiman 1997; Sclove 1995; Sclove and Scammell 1999). At the core of the science shop approach is the desire to advance university research that is socially relevant and in the public interest.

Although the science shop model has some presence in North America, citizen science is more often associated with organized volunteer monitoring, especially by amateur naturalists. The National Weather Service was one of the first such programs and in 1890 began training volunteers to report daily measurements of air temperature and rainfall. Early in the 20th century the Audubon Society launched its annual Christmas Bird Count, another program that, along with breeding bird surveys, butterfly and wildflower watches, and fossil collecting, contributes valuable data that are commonly relied on by professionals (Noss 2002; Heiman 1997). Today there are a growing number of volunteer monitoring programs engaging local citizens in everything from monitoring water quality to community health. The Internet has been a notable boon to citizen engagement in a wide variety of projects (see for example: www.naturewatch.ca and http://birds.cornell.edu/LabPrograms/CitSci/).

The benefits of CBM as citizen science are many and include, but are not limited to: (1) enhancement of community capacity and social capital; (2) development and improvement of social networks; (3) more proactive public participation in policy, planning, and management initiatives; (4) developing community based definitions of sustainability and desired future conditions; (5) increased understanding of local contexts by external "experts"; (6) more inclusive decision-making processes that lead to better decisions; (7) proactive identification of environmental change for continuous improvement and active adaptive management; (8) more and better data for long-term research and monitoring; (9) development of better working relationships between the public and land managers; (10) the development of a sense of empowerment and ownership over local conditions; and (11) the advancement of theory and practice of sustainable development (EMAN 2002; Merrifield 1989; Pollock et al. 2003). CBM should be seen as a valuable addition to be developed along side of more technical and expert-driven environmental monitoring programs. The promulgation of CBM initiatives must not be used as an abrogation of government/agency responsibility (Sharpe et al. 2000).

Lessons Learned From Canadian Community Based Monitoring

In 2001, the Ecological Monitoring and Assessment Network (EMAN), in partnership with the Canadian Nature Federation, initiated a nation-wide pilot program to test approaches and identify critical factors in community engagement and environmental monitoring. Based on a review of past experiences, it initiated community-based environmental monitoring initiatives in 31 communities. Twelve regional coordinators were hired by EMAN to facilitate and learn from the individual community efforts (for more information see: http://www.ccmn.ca). A comprehensive review of the results was conducted to articulate key lessons learned and to development a conceptual model for CBM (Pollock et al. 2003; Whitelaw et al. 2003). In addition, a community of practice, the

Canadian Community Monitoring Network (CCMN), emerged from the 31 "experiments" to assist in broader application of the results. A central aim of the program was to "provide a valuable resource to other communities interested in starting a CBM program" (EMAN 2002, p. 22), and it is in this spirit that we adopt the lessons and model for our own research and practice reported in this paper. The key lessons learned through the EMAN study are summarized here under the following broad themes: community context, community engagement, organizational structure, and creating change.

Community Context

Complexity, both ecological and social, dictates that CBM be adaptable and specific to a particular local context. Allowing for considerable flexibility in how coordinators engage the community, and employing monitoring protocols that are appropriate for the given community capacity, are critical in creating a CBM program that is socially acceptable and scientifically meaningful. However, concerns for such things as clean air and water as well as healthy wetlands and forests are common and offer the opportunity to implement standardized monitoring protocols across the country. The CCMN experience validated that CBM is a powerful tool for building social capital. CBM can activate individuals who do not normally engage in volunteer activities and build reserves of social capital that will be valuable to not only future CBM, but also to other local governance issues (Pollock et al. 2003).

Community Engagement

Engaging the community in meaningful public participation is a cornerstone of CBM. It is critical the participants understand the benefits and values of long-term ecological monitoring and the importance of their contribution (Bens 1994; Fleming and Henkel 2001; Wilson 2002). In particular, participants should see the value in informing local decision-making through the collection and communication of timely information. Monitoring activities should be appropriate to the available time and energy of volunteers, with accessible protocols that employ equipment and data analysis accessible to the existing community capacity (Cuthill 2000; Fleming and Henkel 2001). Public participation should use transparent, inclusive, constructive, efficient, and meaningful processes. These include forums such as roundtables, workshops, and visioning sessions that bring together multi-stakeholders and favor consensus-based decision-making focusing on the development of creative solutions to complex problems. The participatory processes should be facilitated and guided with the philosophy that scientific expertise in CBM is more to inform the process than it is to dictate the results. Finally, public participation is most effective when the results and uses of monitoring activities are presented to the broader community (Pollock et al. 2003).

Organizational Structure

The goals of the group or network, their vision, and available capacity and resources will determine at what scale and organizational structure CBM will occur. The scale of monitoring may vary from the neighborhood to the landscape level, defined by ecosystem boundaries such as watersheds. When starting CBM, groups should consider their objectives and community capacity, possibly starting at a smaller scale and expanding as capacity develops (Pollock et al. 2003). CBM at the landscape scale can be appealing for a number of reasons. It may provide access to greater resources, the larger area may include more historical monitoring data, and there will likely be an increased number of government agencies, NGOs, and private sector actors with which to network and partner. CBM at the landscape scale also facilitates the integration of monitoring efforts, avoids duplication, and has the potential to influence decisions on a broader scale (Pollock et al. 2003). However, it is at the local scale that CBM is most effective and can most directly influence decision-making. Larger scale issues might be best approached through the aggregation of local efforts.

Two key lessons relating to organizational structures emerged from the CBM initiative. First, top-down support, including financial resources for hiring coordinators at both the national and regional level, is essential. A community coordinator significantly advances CBM through such activities as networking, partnership development, fundraising, and skills training. A second lesson relates to the institutional affiliation of the coordinator. Those who had such an affiliation made considerable progress on CBM through their ability to tap into existing organizational structures (Pollock et al. 2003). Again, the most important function here is to create an enabling environment rather than an attempt at heavy-handed control or management. The long-term sustainability of CBM initiates will also be influenced by how well they are institutionalized and supported within the host communities.

Creating Change

CBM can help create change by increasing local governance and achieving influence with decision-makers. Local governance refers to a broader involvement of civil society and the private sector in the formulation of policy and influence on decision-making through networks and partnerships. CBM can contribute to the development of this governance through the creation of new networks and partnerships in pursuit of sustainability. CBM is appealing to government, NGOs, and the private sector, as it is neutral, allows for discussion of issues in a generally non-confrontational arena, and results in mutually beneficial partnerships and activities. The development of long-term networks may enhance governance structures and provide valuable input into difficult issues ranging from resource and land use to community development (Pollock et al. 2003).

Achieving influence should be a priority for CBM groups and networks. A series of methods can be used to achieve influence within the community at large and with those who can affect change. Actively pursuing partnerships with government staff at all levels from municipal to Federal, and engaging politicians and planners to influence policy development is a key step towards achieving influence. Increasing awareness and transforming public values by engaging people in monitoring and stewardship activities is an equally critical pursuit particularly when the results of their efforts can be seen to make a difference. Business should also be brought into the fold, by building partnerships to collaborate and influence. Finally, enhancing the capacity of decision-makers and governance institutions will go a long way towards achieving influence and moving the community towards a sustainable path (Pollock et al. 2003).

A Conceptual Framework For Community-Based Monitoring

EMAN's conceptual framework recognizes three core principles for how to approach CBM. First the approach must meet the challenge of diversity with flexibility. In other words, it should be suitable to the community context, considerate of local cultures, and represent an attempt to find "best practices." Second, the approach must be iterative in nature. The approach should not be constrained to a linear process, but rather should encourage the dynamic interaction between phases, goals, and outcomes in an ongoing cycle, enabling synergistic activities that build capacity at all stages of CBM. Finally, the approach must be flexible, opportunistic, and adaptive to change. In a continuous feedback loop, the approach should incorporate new information, assess capacity needs, and fulfill them to build social capital (Pollock et al. 2003). Based on these three principles the conceptual framework encompasses four dynamic phases: community mapping, participation assessment, capacity building, and information delivery.

The phases are iterative, synergistic, and ongoing in a cyclical fashion and can be undertaken in sequence or concurrently. Each phase consists of a series of steps and desired outcomes. Presented in a linear fashion, the steps build from one to the next; however, they do not necessarily represent a rigid format. Depending on the existing capacity of the community, not all components will be necessary, and in some cases certain tasks can be skipped (Pollock et al. 2003). Communication is a critical component that runs throughout each phase of the framework. We have modified the original EMAN model in minor ways to fit our context (figure 1), but we have retained all of the essential components as described below.

Community Mapping

Community mapping is composed of four steps: reconnaissance, governance analysis, consultation and outreach, and visioning. This phase focuses on gathering information about the community to inform the design of a CBM program that is unique to the community and its values, vision, and interests. It also provides the opportunity for decision makers to articulate their information needs and the chance to develop meaningful partnerships. Goals in this phase include: assess community readiness and concerns, identify existing groups and activities, establish trust, build contact network, conduct consultation and outreach, and inventory existing monitoring programs (Pollock et al. 2003). This phase establishes the context and relationships for the on-going development of the CBM from knowledge assessment through to community vision.

Participant Assessment

Participant assessment, the second phase of the conceptual framework, is composed of two steps: membership assessment and champion identification. This phase shifts its attention to understanding the groups and people involved in CBM, and thereby generating knowledge about how to engage them, enlist their skills, and satisfy their needs. Participation assessment is designed to identify the best approaches for building capacity. Goals include: assess public understanding of CBM, identify participants' motivations and expectations, understand membership skills, assess capacity and training needs, identify champions and leadership roles, and engage decision-makers (Pollock et al. 2003). Once participants have been identified, key groups and organizations engaged, and initial relationships formed in the community mapping phase, a membership skills assessment is undertaken. Another important component of participant assessment is identification of champion(s). Experience suggests that a champion(s) within the community is essential to drive the creation of community-based initiatives (Pollock et al. 2003; Curtin 2002). A cautionary note with respect to champions is that they likely have competing demands on their time and should be protected from "burn out" as much as possible.

Capacity Building

The four components of the capacity building phase are: partnership development, organizational structure, capacity building, and fundraising. CBM requires resources and skills, both social and technical. Capacity building enhances the community's ability to carry out monitoring through good coordination, training, technological access, and knowledge and skill development. Goals of this phase include: create or expand partnerships and networks (including the formation of agency partners and funding mechanisms), develop organizational structures, use good communication mechanisms, select appropriate monitoring protocols and make data management operational (Pollock et al. 2003).

Information Delivery

The final phase of the conceptual framework, information delivery, is composed of three steps: ecological monitoring, project management, and achieving influence. This is the phase where CBM becomes operational. Communication plays a major role throughout all aspects of CBM, and at this phase is critical to identifying local priorities and reporting the results of monitoring activity. CBM should be demand-driven, where information needs are identified and monitoring then informs the development of more effective tools and solutions for local environmental issues. Decision makers should weigh this knowledge and skill to make appropriate local choices that are adaptive. Given the preliminary nature of the information, adaptive choices might include verification, investigation of cause, research into mechanisms, or development of

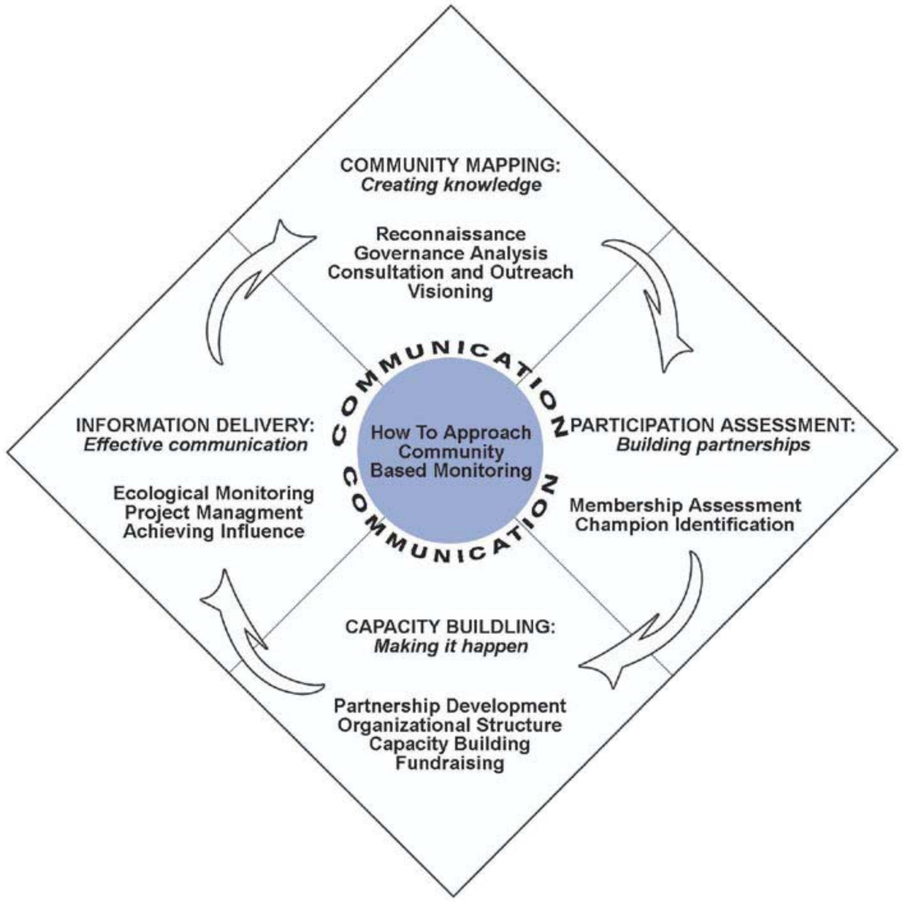

Figure 1—A conceptual model for community-based monitoring (adapted from Pollock et al. 2003; Whitelaw 2002).

options. Goals include: articulate information needs, translate data into meaningful information, provide and integrate new information into decisions, and institutionalize ecological monitoring (Pollock et al. 2003).

Monitoring indicators and protocols are developed at this stage with particular attention to existing monitoring in the community. Indicators should be based on the vision and issues identified, informing a picture of present conditions and future trends. It is also important to use existing and tested ecological monitoring protocols to ensure the quality and usability of the data. The nature of information collected in CBM should be: useable in form and for a specific context; targeted, accessible, and understandable to its audience; integrated, and suggest a course of action; timely; allow decision-makers to weigh choices, trade-offs and consequences; and ensure those involved continue to be in control of the problem. Project management follows as CBM becomes operational. This allows for monitoring to be carried out in an efficient and effective manner and ensures that all participants have full knowledge of the particular project underway and the overall direction the group is moving (Pollock et al. 2003).

Finally, achieving influence is one of the ultimate goals of CBM. Strategies should be developed to influence decision-making through setting agendas, negotiating outcomes, conferring legitimacy, and implementing solutions. Strategies should be incorporated into all aspects of the CBM framework and play a major role in the communication plan, data reporting methods, outreach, and organizational structure (Pollock et al. 2003).

Ranchers and Local Knowledge

> Over the last two decades it has been demonstrated that local knowledge, while different from Western scientific knowledge, is nevertheless systematic, based on observation and analysis, very extensive, imminently practical, and relevant to the management of resources (Feit 1998, p. 126).

The ranching community of southwestern Alberta makes its home along the interface between the eastern slopes of the Rocky Mountains and the western edge of the Great Plains. Many of the families trace their roots to the first European settlers on this part of the continent and have managed the health of their rangelands for generations. Native grasslands and parklands characterized by foothills rough fescue (*Festuca campetris*) and a diverse ecotonal faunal assemblage contribute to the international significance of the area. Of particular importance is the fact that much of the region remains relatively intact compared to the fragmented landscape in which it is embedded. This area of high environmental significance is the focus of increasing oil and gas exploration and development, as well as rural residential and urban expansion (the city of Calgary, with a regional population exceeding one million is less than an hour drive away). In response to mounting land-use change pressures, a group of ranchers and other local interests recently coalesced around their opposition to a proposed series of gas wells. The "Pekisko Group," comprised of over 50 ranch families, is dedicated to maintaining the ecological integrity of the native rangelands as well as their regional agrarian culture and livelihood. The group came to the realization that understanding baseline conditions and creating protocols for assessing change are critical to achieving their objectives.

At the invitation of the Pekisko Group, the Miistakis Institute for the Rockies (an affiliated research institute of the University of Calgary dedicated to facilitating ecosystem based management, see: www.rockies.ca) and the Faculty of Environmental Design at the University of Calgary have agreed to work with the ranchers and other local interests to develop and implement a long-term environmental monitoring program. The program is being developed to be consistent with the EMAN framework presented above and will examine the approaches and lessons derived from the European experience with science shops. The program will develop from the strong local knowledge foundation that exists in the community and will also consider the lessons learned from similar initiatives—such as those in the Malpai Borderlands (Curtin 2002). Many of the ranchers already participate in some form of formalized monitoring for rangeland condition and/or riparian area health. Wherever possible, the existing protocols will be adopted by the new monitoring program (see for example, www.cowsandfish.org). The aim of the CBM program is to validate existing forms of knowledge and to standardize data collection, storage, and analysis so as to improve the present and future utility of the information for land-use planning and management.

Through a collaborative, participatory approach, we will first identify the values of the community and their vision for the future of the landscape. We will then work with the community and ecological monitoring specialists to identify a suite of appropriate indicators to map and monitor ecological condition over time. It is expected that the implementation of monitoring will employ a three-tiered approach: (1) indicators that derive from local capacity and knowledge of the landscape (e.g., rangeland condition, weeds, riparian condition, water quantity, location, etc.) will be monitored by ranchers using standardized protocols developed by the project; (2) indicators and measures requiring specialized skills available in the voluntary sector will be monitored in collaboration with selected interest groups (e.g., regional natural history groups could participate in breeding bird surveys, amphibian counts, etc.), and (3) indicators requiring specialized skills, equipment, or analysis will be monitored by specialized sources through funding partnerships with government and industry interests (e.g., water and air quality monitoring that require laboratory analysis).

The CBM program is in the formative stages and is being developed with the ranching community of southwestern Alberta. The program will provide a valuable test of the conceptual framework developed through EMAN and the Canadian Community Monitoring Network. After two years, we intend to provide a thorough critical reflective analysis of our work to both contribute to the adaptive management approach advocated and to advance the theory and practice of CBM and collaborative ecosystem management in general.

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Water Quality Monitoring for High-Priority Water Bodies in the Sonoran Desert Network

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Abstract—*This paper describes a network monitoring program for "high priority" water bodies in the Sonoran Desert Network of the National Park Service. Protocols were developed for monitoring selected waters for ten of the eleven parks in the Network.*

Park and network staff assisted in identifying potential locations of testing sites, local priorities, and how water quality sampling might be integrated into overall vital signs monitoring and park operations. Several criteria were used to determine the priority of these water bodies. These include ecological and perceptual threats to public and wildlife health, as well as adequacy of monitoring efforts.

In conjunction with selecting water bodies and sample sites, water quality monitoring parameters are also identified. These include five "core" parameters that will be sampled as part of the NPS Vital Signs monitoring program: temperature, dissolved oxygen (DO), conductivity, pH, and flow or water levels. Additional parameters were selected based on park-specific stressors or threats gathered from discussions with park and network staff, literature research, and ADEQ 303 (d) mandated reports on water quality.

Introduction

The National Park Service (NPS) is committed to significantly reducing the amount of pollution in park water bodies, and preserving the pristine water quality. Basic water quality and quantity data are a needed, yet lacking, component of management for many parks. The study described in this paper supports the above-stated NPS long-term water quality goal by developing a water quality and quantity monitoring program for the Sonoran Desert Network (SODEN) Parks of the National Parks Service.

This monitoring plan was developed as part of the Sonoran Desert Network's Vital Signs Inventory and Monitoring Program. Managers need reliable data to maintain resources unimpaired for future generations, especially as conditions outside of parks rapidly change. For the area of water, the goal of the Inventory and Monitoring Program is to identify trends in water quality and quantity, which could be utilized to guide management actions, or to trigger further inquiries. This report represents the second phase of a study that examined water quality issues. The Phase I report, completed in May 2002, presented an overview of existing water quality and groundwater data. That report listed data that had previously been collected for each park and it identified where gaps in data existed. The Phase II report, utilizes data from the Phase I study to establish monitoring plans for each park. Results from these reports can be integrated into park management decisions. Cooperation with similar agencies can allow for management of water resources on a larger scale.

The main objective of this study is the formulation of a network monitoring program for "high priority" water bodies, or those considered to be the most important for water monitoring purposes, in the Sonoran Desert Network. One high priority water body was selected for each park (table 1), in addition to other important water bodies. The monitoring design is grounded in historical and current water quality efforts.

Receive Park Input

A dialogue was established with park staff via email, telephone and park visits to identify park-specific water quality issues that may not have been addressed by the Phase I effort. Park and network staff have assisted in identifying potential locations of testing sites, local priorities, and how water quality sampling might be integrated into overall vital signs monitoring and park operations.

In the fall of 2002 the study team made trips to "high priority" water bodies. The team was accompanied on the site visits by consultants Dr. Sam Kunkle and Dr. Richard Hawkins. Follow-up trips to the parks were made through September 2003.

Table 1—High priority surface water bodies by park.

Casa Grande	N/A	
Chiricahua	Unnamed Spring below King of Lead Mine Pond	CHIR*
Coronado	State of Texas Mine #11	CORO
Gila Cliff	West Fork of Gila River	GICH
Ft. Bowie	Apache Spring	FOBO
Mont. Castle	Montezuma's Well	MOCA
Organ Pipe	Quitobaquito Springs and Pond	ORPI
Saguaro East	The "Grotto" on Rincon Creek	SAGU
Saguaro West	King Canyon Mine Seep	SAGU
Tonto	Cave Canyon Creek	TONT
Tumacocori	Santa Cruz River	TUMA
Tuzigoot	Tavasci Marsh	TUZI

* Name code

Several criteria were used to determine the priority of water bodies. These included ecological and perceived threats to public and wildlife health, adequacy of current monitoring efforts and ecological uniqueness. The ecological value of a site is determined by not only the presence of threatened and endangered species, but also the value of the riparian area to both the park unit and to the surrounding area. Secondly, the perceived value of the water resource carried a strong weight in selecting high priority water bodies and was determined by interviews with NPS staff in combination with survey results. High priority water bodies were also selected based on the degree of threat to public and wildlife health, and the short-term immediacy of the threat. Lastly, a third criterion for determining priority was based on whether or not particular water bodies and parameters were being adequately monitored by others at the time of the study.

"High Priority" List

One "high priority" water body was selected from each park unit to monitor. In many cases, it was fairly easy to identify that water body. For example, in park such as Tonto National Monument, Fort Bowie National Historic Site, Tuzigoot National Monument and Tumacocori National Historic Park, there was only one major water body located in the unit. In other cases, where there are a variety of sites to choose from, such as Saguaro National Park, Coronado National Memorial and Gila Cliff Dwellings National Monument, the location of the water body, utilization by wildlife and humans, and presence of habitat for threatened and endangered species were factors considered.

Review Database

A review of the existing water quality database was conducted to confirm that all relevant water quality issues were identified in the Phase I analysis. Hydrologists from the U. S. Geological Survey (USGS) and Arizona Department of Environmental Quality (ADEQ) reviewed the Phase I document. Both agencies stated that the Phase I document was thorough in its documentation of existing data. Hydrologists from Colorado State University (CSU) and the University of Arizona (UA) also provided an external review of the database, and made suggestions as to other potential sources of water quality data. Recent provisional surface water quality data were received from USGS for some of the parks. The new data were analyzed and compared with the existing data which were previously assembled, to assure that the monitoring program was based on the most recent data available. USGS data for all of the parks was not available prior to publication of the Phase II report.

Synthesis of Existing Protocols

To utilize existing protocols, a detailed review was done of existing water-quality testing procedures and equipment used by the USGS, ADEQ, and the NPS-Water Resource Division guidance documents on Long-Term Aquatic Monitoring Projects. We have incorporated these procedures into the Sonoran Desert Network protocols.

QA/QC testing protocols incorporated into the monitoring plan includes:

- Field note worksheets
- Equipment calibration guidelines
- Field blanks for quality control
- Proper sampling methodology
- Equipment troubleshooting
- Equipment maintenance
- Decontamination and cleaning of equipment
- Safety practices
- Proper disposal of calibration solutions
- Sample
  - preservation
  - holding time
  - tracking and labeling

Sampling Design

The results generated from the review of the data base, park input and the synthesis of existing protocols were used to produce a water quality monitoring plan for the SODEN network. Specific protocols were developed for key water quality parameters at appropriate sampling locations (table 2). The protocols include an overview defining measurable objectives, sampling design, field techniques, data reporting, personnel requirements, training procedures, and operational requirements. We recommended that sufficient metadata be collected to fulfill the requirements of the EPA-STORET National Water Quality Database, where the data will be ultimately archived. Core parameters that will be collected are: temperature, specific conductivity, pH, dissolved oxygen and flow.

Other recommended parameters include: turbidity, nutrients, biological conditions, major ion balance, carcinogens, toxins and metals. Parameters were chosen on the basis of the Clean Water Act and other regulatory standards, as well as on the basis of network needs, and suggested criteria.

When sampling, NPS staff members need to be aware of specific conditions in each water body and park unit. One

Table 2—Parameters by Park (see table 1 for Park name codes).

Core Parameters	CHIR	CORO	FOBO	GICH	MOCA	ORPI	SAGU	TONT	TUZI	TUMA
pH	XX	XX	XX	XX	XX	X	XX	XX	XX	X
Conductivity	XX	XX	XX	XX	XX	X	XX	XX	XX	X
Dissolved Oxygen	XX	XX	XX	XX	XX	X	XX	XX	XX	X
Temperature	XX	XX	XX	XX	XX	X	XX	XX	XX	X
Streamflow or Water Level	XX	XX	XX	XX	X	X	XX	XX	XX	X
Biological/Physical Conditions										
E. coli	XX	XX	XX	XX	XX	XX	XX	XX	XX	X
Biochemical Oxygen Demand										X
Narrative Water Quality Description	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Turbidity				XX	XX				XX	X
Acid-Base Equilibrium										
Alkalinity	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Major Ion Balance (K, Ca Mg, C. SO4, HCO3-CO3)	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Bicarbonate					XX					
Nutrients										
Total Phosphorus				XX	XX				XX	XX
Nitrites + Nitrates				XX	XX				XX	XX
Ammonia										XX
EPA Priority Pollutant Metals										
Metals Suite (Be, Se, Pb, Hg, Ni, Cu, Fe, Tl, Zn, As, Ag, Cr, Cd)	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Carcinogens										
Trihalomethane										XX
Residual Cl-										X
Toxins										
Cyanide										X
Organic Chemicals										
PCBs								XX		XX
VOCs								XX		XX

XX = Proposed; X = Previously monitored.

example is the incidence of amphibian epithelial chytridiomycosis in Saguaro National Park. Chytridiomycosis is a water-borne fungal disease that causes mortality in lowland leopard frogs as well as other amphibian species. In order to prevent spread of the disease from an infected water body to a non-infected one, NPS staff must disinfect sampling equipment between samples.

Sampling frequency and timing ideally depend upon the overall objectives of the water quality monitoring program. There are three basic objectives that can be satisfied by the combination of field and laboratory sampling that the NPS will conduct which will help managers to identify trends and guide future research. These objectives include:

- To understand a particular aquatic system, including the relationships between the geological, hydrological, and biological elements.
- To monitor current water quality status (trends, seasonal variation and flow).
- To anticipate future problems before they manifest themselves in a water body.

The sampling strategies address the aspects of these objectives, to include important water quality factors such as environmental or seasonal variations that NPS wants to understand. We therefore recommend utilizing the strategies in table 3 in order to capture the most relevant data for each parameter. While more frequently monitoring, such as each month, would be better than quarterly monitoring, the former was selected reflecting the limited resources, both financial and in personnel, that exist in the parks. More frequent monitoring can be done, and is recommended as additional resources become available.

Research and Test Field Instrumentation

To simplify the water quality sampling process for the NPS personnel a multi-probe unit was selected which can monitor multiple parameters at one time rather than using a separate piece of equipment for each individual parameter. The multiprobe can monitor temperature, conductivity, dissolved

Table 3—Sampling strategy by category of parameters.

Category	Parameters	Method	Frequency
Hydrology	Flow and/or Water Level	Current Meter, Staff Gage, Field Inspection	Quarterly
General Water Conditions	Temperature, Dissolved Oxygen, pH, Conductivity, Barometric Pressure	YSI 6820 Instrument	Quarterly
Acid-base Equilibrium	Alkalinity, Major Ion Balance, Bicarbonate	Laboratory Sampling	Quarterly
Biological Conditions	Biochemical Oxygen Demand (BOD), E. coli, Narrative Water Quality	Laboratory Sampling, Field Inspection	Quarterly
Nutrients	Ammonia, Nitrogen (Nitrate+Nitrite),		
	Total Phosphorus	Laboratory Sampling	Quarterly
Carcinogens	Free chlorine, Trihalomethane	Laboratory Sampling	Annually
Metals	Antimony, Arsenic, Beryllium, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Silver, Selenium, Thallium, Zinc	Laboratory Sampling	Annually / 5-year period
Toxins	Cyanide	Laboratory Sampling	Annually

oxygen, pH/ORP, barometric pressure, turbidity, chlorine, ammonia, and nitrate. After extensive research and field testing we concluded that a Yellow Springs Incorporated (YSI) 6820 Sonde Multiprobe best fit the water quality monitoring needs of the National Park Service. Other probes evaluated and tested were the Hydrolab Quanta Multiprobe, and the In-Situ 9000 Troll.

The Price Pygmy Meter was selected to measure water current. Most of the streams to be measured in SODEN are shallow with relatively low flows. Velocities in these streams are usually less than 2 feet per second for most of the year, and rarely reach velocities greater than 5 feet per second. Because of these low flows and shallow depths the Price Pygmy meter was selected. The Pygmy can be used for depths up to 1.5 feet, such as those in the Santa Cruz River at Tumacácori. For water depths between 1.5 ft. and 2.5 ft., the Price type AA meter would be more appropriate. In cases of very low flow, other techniques will have to be employed to determine water quantity, such as capturing flow in a receptacle during established time periods.

Summary

This water quality monitoring plan was developed as part of the Sonoran Desert Network's (SODEN) Vital Signs Inventory and Monitoring Program. It was designed with the assumption that managers need reliable data to maintain resources unimpaired for future generations, especially as conditions outside of parks rapidly change. For the area of water, the goal of the Inventory and Monitoring Program is to identify trends in water quality and quantity, to help guide management actions or trigger new inquiries. The report summarized herein represented the second phase of a study that examined water quality issues. In the course of 2 years of research, the authors evaluated threats to park water quality, data needs, current methodologies, and quality assurance/quality control protocols. Using a mixture of concerns including data usefulness, ease of use, and pricing, the authors identified a series of water quality parameters and protocols to monitor them that the National Park Service may choose to implement as part of a third phase in the Vital Signs Inventory and Monitoring Program.

Vegetation in Transition: The Southwest's Dynamic Past Century

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Abstract—*Monitoring that follows long-term vegetation changes often requires selection of a temporal baseline. Any such starting point is to some degree artificial, but in some instances there are aids that can be used as guides to baseline selection. Matched photographs duplicating scenes first recorded on film a century or more ago reveal changes that help select the starting point. Interpretation of the observed changes may be strengthened by quantitative measures from permanent long-term study plots established at sites near the photo stations. The gradual infusion of exotic plants and animals into ecosystems may complicate baseline selection. Because these new additions often interact with the native biota, the timing of their appearance on the scene should be recognized, and provides further direction for judging appropriate temporal baselines.*

Introduction

Long-term monitoring may help direct the destiny of ecosystems by providing a foundation from which to judge change. Reconstruction of any region's past vegetation requires establishment of a temporal base from which changes can be measured. Selecting this base is charged with obstacles. Changes undoubtedly occurred during the period prior to European intrusion into southern Arizona and bordering regions, but, in general, detailed descriptions of vegetation and associated fauna are missing from that era. However, by setting the biological clock to a time when descriptions are more precise and human impact still slight, the difficulty of selecting a base is greatly diminished. A method that provides partial access to vegetation history is the art of photographic matching or repeat photography. Fortunately, landscape photography came into prominence in the late 19th century at about the same time that the human population in our region was beginning to expand, making this a convenient point to start the clock. In rare instances, detailed quantitative data are also available, bolstering the photographic evidence and further enhancing our ability to establish an ecosystem time base.

In the following pages, repeat photography will illustrate the importance of defining a temporal base when making judgments about change. Examples will also be provided to show how detailed quantitative measurements may complement findings from photographic matches or the quantitative measures may even stand alone. Whether our forests and creosotebush stands are shrinking or expanding, whether bird and fish populations are declining or irrupting are all judgments that must be made in the context of appropriate time intervals. Any temporal baseline is artificial and requires consideration of what transpired during previous time periods. Some examples will illustrate how matched photographs and quantitative data, alone or together, can assist in defining time zero when conducting monitoring programs. In addition, because many ecosystems have gained new species from afar, the timing of the recent arrivals may help define a baseline.

Cienega Creek and the 90 Percent Decline Myth

One of the region's frequently recited statistics is the assertion that the riparian communities of our area have experienced large declines in extent, quality, diversity, or some other descriptor (Tellman et al. 1997; Arizona Daily Star 2003). Where this notion originated is not easily determined, but it has been amply repeated in the literature, and has sometimes been bolstered by wild claims that the decline in vegetation has been preceded by a large decline in streamflow. The false assertions that "steamboats once navigated all the way to Charleston [along the San Pedro River] to supply Tombstone and Bisbee with goods…" (Blake and Steinhart 1994) or that "When Anglo-Americans first came to the Southwest, much of the Gila River was navigable [by steamboat]" (McNamee 1994) have only deepened the conviction of some that the changes have been very large indeed.

Shortly after the railroad reached Tucson in 1880, Carleton E. Watkins, noted photographer, stepped off the train at a station east of town and recorded a view of Cienega Creek (figure 1A) that serves as a base for judging change in riparian habitats. The freshly laid tracks of the Southern Pacific Railroad run alongside Cienega Creek, a barely discernible treeless runnel that crosses a shrub-free valley floor that is covered by grasses. One-hundred-eighteen years later the scene is vastly altered (figure 1B). The grass-covered valley floor is now dominated by a dense mesquite forest; the Cienega Creek channel is deeper and supports a forest of cottonwoods and willows. The original railroad bridge washed away and has been relocated upstream.

This photograph pair, and many others like it (Turner et al. 2003; Webb et al., in press), reveal the status of many of our

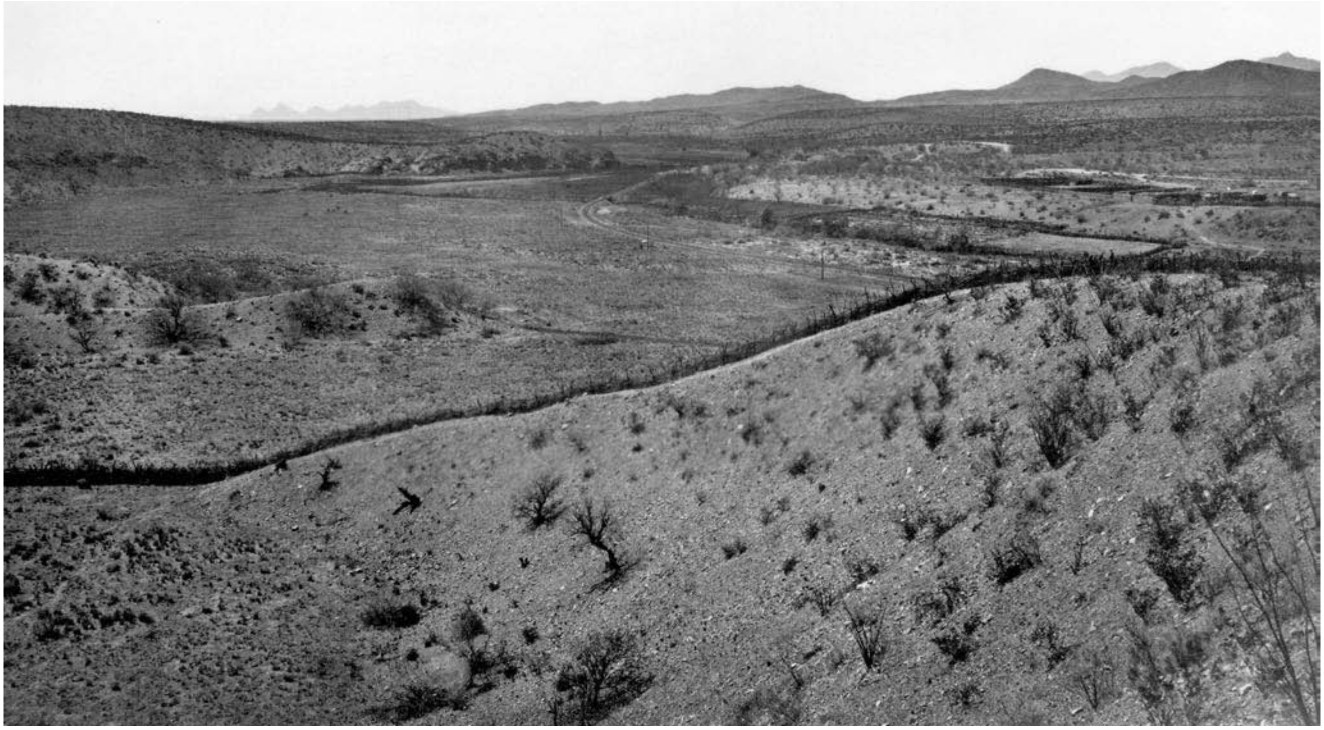

Figure 1A—1880. Freshly laid tracks of the Southern Pacific Railroad run alongside Cienega Creek, represented here by a narrow, essentially treeless channel. The valley floor is covered by grasses and is free of mesquite and other woody plants, although shrubs are common on the adjacent uplands. (Note the brush fence running along the ridge at midground.) C. E. Watkins photograph. Copyright Huntington Library.

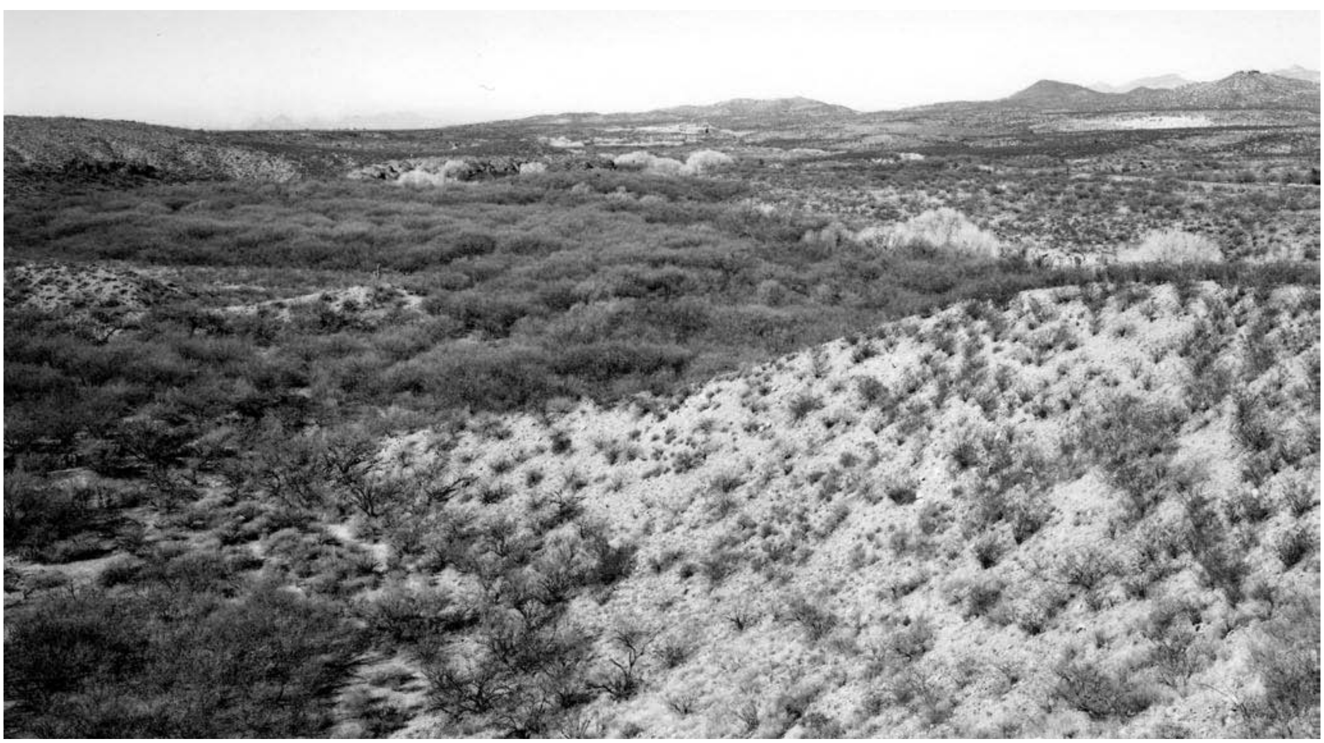

Figure 1B—January 1998. The earlier grass-covered valley floor is now occupied by a dense mesquite forest. The Cienega Creek channel is deeper and broader and supports a forest of cottonwoods and willows. The railroad tracks were moved across the river after the original bridge washed away and a new bridge was built upstream in 1912. R. M. Turner photograph, courtesy of the Desert Laboratory Photograph Archive.

river valleys in the late 1800s and establish the foundation for judging subsequent changes in these riparian habitats. The sequence of changes along our major valleys started when sluggish streamflow across flat, seasonally flooded swards of sacaton became forcefully erosive during the last decades of the 19th century. The bottomlands were cut by narrow defiles. The deepened channels produced a drop in the water table, cessation of overland flooding, and, with subsequent widening, a new habitat ideal for the establishment of riparian trees, such as cottonwood and willow. The grassland, now lacking the seasonal flooding and the alternately dry and waterlogged conditions that excluded woody plants, became an ideal habitat for mesquites and shrubs found on the surrounding uplands (Shmida and Burgess 1988).

The vegetation changes were accompanied by dramatic changes in the fauna. The former grassland was ideal habitat for numerous sparrows, including Baird's and Botteri's, both of which are now Federally listed "species of concern." As noted by Phillips et al. (1964), "Until about 1878 [Baird's sparrow was] an abundant transient and doubtless winter resident in the grasslands of southeastern Arizona…; until 1920 decidedly uncommon but still a winter resident about the bases of the Chiricahua and Huachuca Mountains. Now apparently much rarer." And regarding Botteri's sparrow, these authors note that it is a "rather uncommon summer resident… Usually in giant sacaton… Formerly much more common, especially before 1895…"

Although the virtual loss of some grassland sparrows may seem dramatic, the changes in bird life brought about by growth of the new forests of cottonwood and willow are certainly even more dramatic. The new riparian forest along the San Pedro River is home to a biota that reportedly includes two-thirds of the birds known from North America and more mammals than occur in any comparable area on the planet, save for tropical cloud forest in Costa Rica (Glennon 2002). Among the birds in this new gallery forest are the southwestern willow flycatcher and the yellow-billed cuckoo; the first, a "listed" species, and the second, a bird whose numbers are said to be dwindling.

The changes along our streams, probably more dramatic than changes in most other habitats, are stark examples of the importance of defining the starting point in any program designed to monitor long-term changes. In addition to temporal beginnings, one must ask: What species are being affected? For Baird and Botteri sparrows, habitat decline has indeed approached 90%.

The increase in riparian species along Cienega Creek and the San Pedro River represents a large increase in biodiversity, but, as the next example shows, there are implications beyond mere numbers that must be considered.

Exotic Plants at the Desert Laboratory and Biodiversity

Early workers at the Desert Botanical Laboratory, established by the Carnegie Institution of Washington in 1903, were leaders among scientists interested in measuring vegetation change via monitoring. In one study at the Tucson preserve, Volney Spalding carefully mapped the location of all the exotic plants then known to occur on the 869 acre preserve. This 1906 survey uncovered three exotic species: filaree (*Erodium cicutarium*), mouse barley (*Hordeum murinum*), and Bermuda grass (*Cynodon dactylon*) (Spalding 1909). By 1983 this number had swollen to 52 (Bowers and Turner 1985; Turner and Bowers 1988; Burgess et al. 1991), and the distribution of all three species at the Desert Laboratory had greatly expanded (figure 2). In just under 80 years on a preserve protected from livestock since1907, the number of non-native species had escalated to levels more than 15 times greater than at the time of the original survey. (Two woody species, ironwood [*Olneya tesota*] and jojoba [*Simmondsia chinensis*], were lost during the same period. The status of sixteen other less conspicuous forbs and grasses that have not been seen in recent surveys is less certain—they may still be present.) Clearly, monitoring in such rapidly changing habitats as those represented by the Desert Laboratory must deal with the presence of the newly arrived exotics. Looking into the future of our own region, at a time several centuries from now when buffel grass and other exotics will probably have won the battle that we are now waging against them, biodiversity estimates that ignore the exotics will have little meaning. In the British Isles, for example, where "natural" vegetation has long since given way to highly altered landscapes with many exotic species, biodiversity estimates that exclude exotics would be quit meaningless.

Figure 2—Distribution of filaree (*Erodium cicutarium*) at the Desert Laboratory in 1906 (stippled areas) and in 1983 (dots) (from Turner and Bowers 1988).

At a time when the concept of biodiversity has become a critical criterion for judging ecosystem health, the use of this term needs careful definition. These definitions often assume that biodiversity is just a numbers game, yet where exotics are concerned, their numbers are sometimes ignored. In refining the definition, exclusion of exotics from the tabulations may not be wise.

Saguaro National Park (Rincon Unit): Centuries of Change in a Saguaro Forest

In many instances where matched photographs show change, the earlier photograph is too recent to provide a desired temporal baseline. In such situations, long term monitoring plots may serve the purpose. An example from Saguaro National Park illustrates this problem. Photographs from the 1930s greatly under-represent the saguaro numbers that were actually present a century earlier. The earlier population numbers, for a time well before the advent of field photography, are derived by estimating the age of all saguaros present in 1961 when the plot was established.

Saguaro National Monument (now Saguaro National Park) east of Tucson was established in 1932 to protect the dense saguaro forest at the base of the Rincon Mountains. The Santa Catalina Mountains provide the backdrop for a view of that same saguaro forest taken in about 1935, shortly after the Monument's establishment (figure 3A). The camera overlooks a long-term saguaro study plot established in 1961, and although this photograph series does not span a century, saguaro survivorship data from a plot with many plants over 100 years of age allow us to look much further back in time than the 1930s.

Investigators at the time of the first photograph noted the near absence of young saguaros and predicted that this population of predominantly old plants was not sustainable. They anticipated that the old plants, many of which were nearing their upper age limit (ca. 175 years), would inevitably die, leaving Saguaro National Monument without this saguaro forest.

By 1960 (figure. 3B), the predicted decline had begun. A few months after this photograph was taken, a long-term study plot was established on the flat terrain below this station.

By 1995 (figure 3C), the saguaro forest had indeed disappeared, upholding the biological truth that populations cannot be sustained without reproduction. Data from the permanent plot record the saguaro's decline. In 1961, this nine acre plot supported 209 saguaros; by 1983 the number had plummeted to 100. Undetected at that time, reproduction had begun and the many small plants then present were not counted. By 2001, however, when the plot was last examined, they were large enough to be detected and the population stood at 227. Although this is more than the number present in 1961, it is probably well below the value for the 1930s, when the first photograph was taken. An even deeper look into this saguaro forest's past is provided by assigning an age to each of the saguaros located in the plot in 1961. This is made possible by developing a model for converting height to age, based on the annual height growth rate for saguaros of all heights. In figure 4, age distribution of the 201 uninjured and healthy saguaros reveals a robust establishment period from about 1800 to 1870, after which the population has rarely added enough plants to maintain a population of 201. (Eight plants of the 209 were discarded because they had broken tops or some other defect that made age assignment impossible.) It is this 19th-century pulse of establishment that provides the large number of mature plants seen in photographs from the 1930s. If one could view the population in 1870, before mortality took its large toll, most of the saguaros that actually became established during the 1800-1870 period would still be present and the population total would be large, indeed.

The roughly 200-year period spanned by this plot record, with its widely varying population values, provides a complex example illustrating the problem of choosing a baseline for judging change. Use of quantitative permanent plot data sharpens the focus on past conditions and allows a more accurate base with which to compare current conditions than does the use of matched photographs alone.

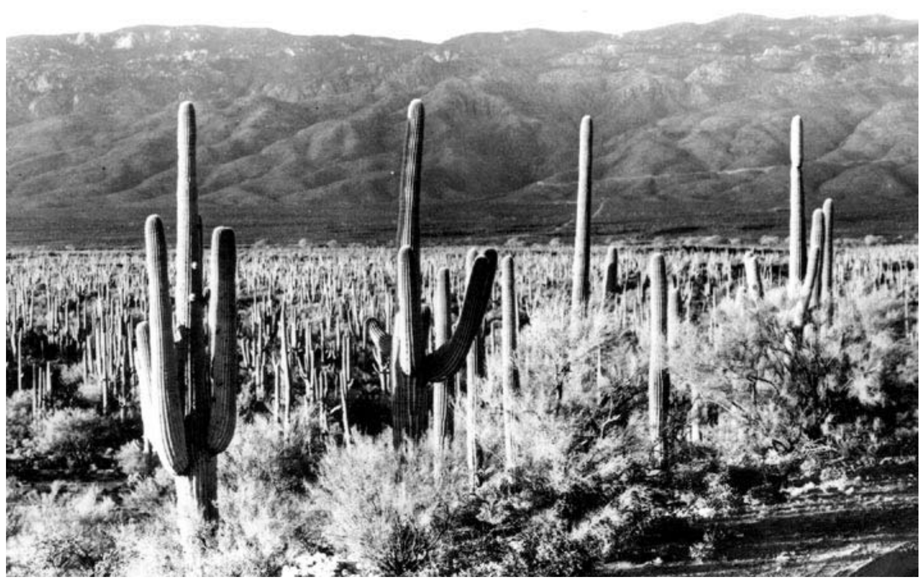

Figure 3A—Ca. 1935.The saguaro forest that prompted establishment of Saguaro National Monument appears across the scene. Photograph courtesy of the National Park Service.

Figure 3B—July 1960. Some foreground saguaros are larger, but many have died here and across the background. Woody vegetation has increased. J. R. Hastings photograph, courtesy of the Desert Laboratory Photograph Archive.

Figure 3C—March 1995. Change is widespread. Most of the saguaros have succumbed to old age, and the distant bajada at the base of the mountain supports many houses. R. M. Turner photograph, courtesy of the Desert Laboratory Photograph Archive.

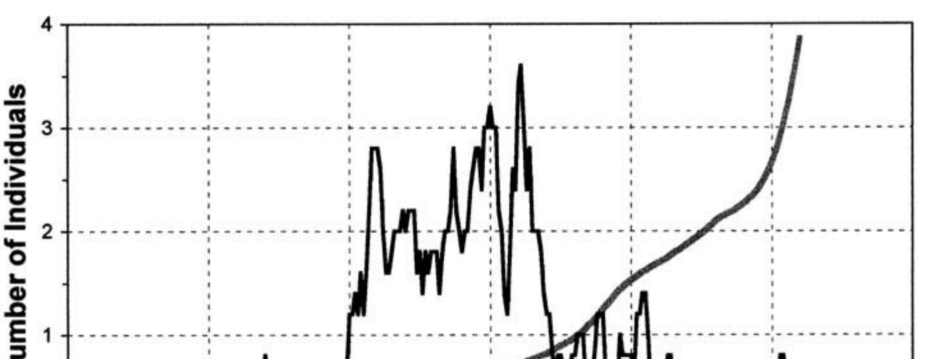

Figure 4—Year of establishment for the 201 healthy saguaros growing in the long-term study plot at Saguaro National Park at the time of plot establishment in 1961. The gray line descending from right to left represents the mortality curve for saguaro populations in this region and shows that a stable population of 201 plants would be maintained by the input of four new plants each year. The black line is a 5-year running mean of establishment numbers.

Conclusions

Monitoring is an indispensable tool for following change in ecosystems, and its application should follow uniform procedures. For those applications aimed at detecting change over long time periods, selection of the temporal base from which to judge change may not be simple because of the lack of adequate ecosystem descriptions from times past. The art of repeat photography can contribute to an understanding of a region's history and be an aid in setting the time from which change is to be measured. Even if the photographs do not record conditions at the exact site of interest, images from nearby locations can provide valuable information for establishing a regional framework. These photographic matches exist in several growing archives and should be used for establishing baselines.

In a few instances, photographic records are bolstered by detailed long-term data that allow refinement of the description of past conditions and may aid in establishing monitoring guidelines.

Acknowledgments

Many people have supported the activities referred to in the preceding pages. I thank Rod Hastings, Terry Gustafson, Al Macias, Lyle Warner, Janice Bowers, Tony Burgess, Jeanne Turner, Elizabeth Pierson, Julia Fonseca, Ed Carter, and Dale Turner who were working companions in the permanent plot, at the Desert Laboratory, or at photo matching sites. Diane Boyer provided the computer interface between original illustrations and publisher. Elizabeth Pierson must be thanked for developing the saguaro height/age model. Thanks also to Janice Bowers and Elizabeth Pierson, who thoughtfully reviewed early drafts and provided helpful comments.

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Science-Based Management

Landscape-Level Impacts of Livestock on the Diversity of a Desert Grassland: Preliminary Results From Long-Term Experimental Studies

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Abstract—*This work is undertaken as a portion of long-term large-scale studies developed to determine how climate and disturbance (primarily fire and grazing) interact to structure desert grasslands. The results presented here are the initial grazing portions of the study. The analysis presented here indicates that following the reintroduction of cattle to the research area in 2000 (following a decade of rest) that the abundance and diversity of vegetation and small mammals increased significantly on the treatment plots ($P < 0.05$), while remaining unchanged on the control plots.*

Introduction

Conservationists, land managers, and scientists have debated the role of livestock grazing in the degradation of rangelands for more than a century (Powell 1878; Bentley 1898; Leopold 1924; Sears 1935; USDA 1936; National Research Council 1994; Laycock 1994; Donahue 1999; Curtin et al. 2002; Knight et al. 2002). This debate has peeked in recent years as conservationists and researchers increasingly view ranching and the associated livestock grazing as either a crucial conservation strategy (Starrs 1998; Knight et al. 2002; Maestas et al. 2002) or a major threat (Fleischner 1994; Donahue 1999; Wuerthner and Matheson 2002). It is impossible to after the fact tease-out the effects of a century of grazing or how the introduction of cattle may have altered the land at the time of European settlement. Yet, landscape level studies can provide important insights into the current effects of livestock. This analysis asks: Do cattle reduce the abundance and diversity of key taxa in a desert grassland? Acceptance of the hypothesis would be the result of demonstrably lower biomass and diversity; a negative answer would be the result of no effect or demonstrably higher biomass and diversity following reintroduction of cattle.

Studies such as those at Konza Prairie have investigated the role of grazing and fire in more temperate grasslands in the Eastern Great Plains (Knapp et al. 1998). Yet relatively little work has experimentally examined the landscape-level role of grazing in arid lands west of the 100th meridian where most public lands ranching, and the debate of the appropriateness of grazing, occurs (Fleischner 1994; Laycock 1994; Donahue 1999; Wuerthner and Matheson 2002; Curtin et al. 2002; Knight et al. 2002). Generally grazing has been documented to be more damaging in more arid ecosystems (Milchunas and Laurenroth 1993), with grazing in landscapes with rainfall below the 300–360 mm (12–15 inches) threshold often considered intrinsically damaging and unsustainable (Fleischner 1994; Donahue 1999). The conflict over the ecological effects of grazing is compounded by troubles with experimental design and statistical analysis that has plagued much of the grazing literature (National Research Council 1994; Hurlbert 1984; Brown and McDonald 1995; Stohlgren et al. 1999; Jones 2000; Curtin 2002a). In this study we seek to mitigate many of the short-comings of previous studies by conducting replicated experimental research at a landscape level.

Methods

In 1998 we initiated a study on the McKinney Flats grassland on the Gray Ranch (Diamond A) in Hidalgo County in southwestern New Mexico, U.S.A. (E721033, N3472587). The study is designed to continue for at least 15 to 20 years and forms the anchor for cross-site studies developed in collaboration with The Nature Conservancy to examine the biotic and abiotic interactions associated with grazing and fire across the Intermountain West. Ungrazed from 1990 until cattle were reintroduced in 2000, the McKinney Flats pasture is located at an elevation of 1,767 m (5,300 ft). It contains a gradient from Plains-Great Basin grasslands (Bouteloua association), to semidesert grasslands (Bouteloua-Hilaria-Sporobolus association), to Chihuahuan Desert grassland/shrubland (Prosposis association). The average rainfall on McKinney Flats measured at four recording stations once a month (one at each study block) between 1999 and 2002 was 292 mm (11.3 in). The period from 2000–2002 is considered a drought according to the Palmer Drought Index (Center Assessment for the Southwest 2002). Soils on McKinney Flats range from gravelly loams (aridisols) in the uplands to silty clay loams (mollisols) in drainage basins.

The fundamental underpinning of our research design was the need for independent replication of study plots (Hurlbert 1984; Hairston 1989). This means that there must be a minimum of four replicates of each treatment. Each treatment must, while being comparable to others in biotic and abiotic components, be independent of the others. In this paper analysis of results was conducted using paired t-test through the statistical program Statview ™. The sampling unit for both vegetation and vertebrate samples were the study plots containing the

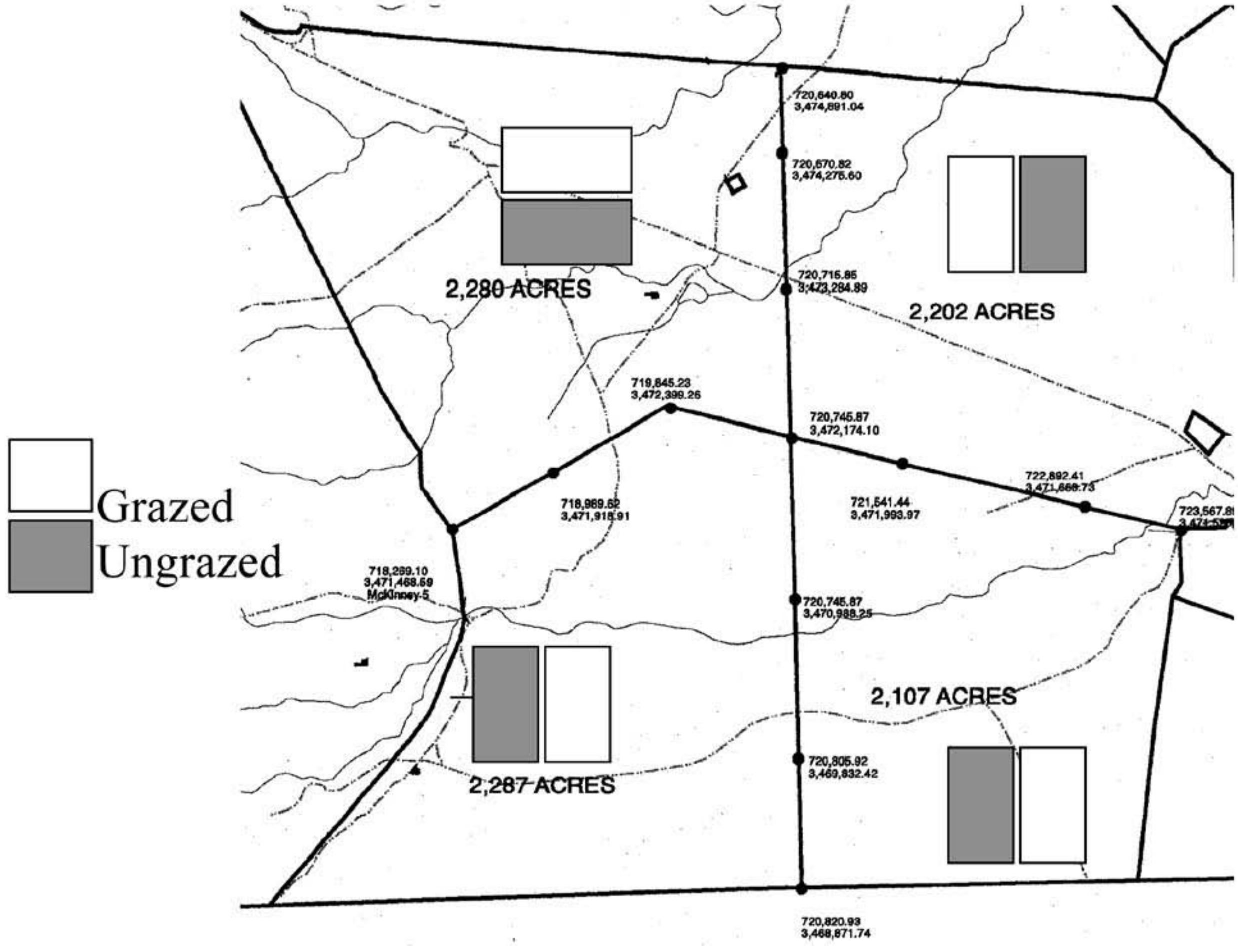

Figure 1—Map depicting the 3,668 ha (8,800 ac) McKinney Flats research site. The pasture was divided to create four, roughly 917 ha (2,200 ac), research blocks. The blocks, in addition to creating a four pasture rest-rotation grazing system typical of conventional land management, also creates four replicate landscapes for research purposes. Within each block a 1 x 1 km study area was divided into research plots containing grazed and ungrazed sections.

sampling area, with results pooled for each season resulting in 16 treatment plots each year (8 grazed and 8 ungrazed). After applying grazing to treatment blocks in 2000 and 2001, in 2002 the blocks were rested one season to measure the post-treatment response to removal of livestock.

The original 3,668 ha (8,803 ac) pasture was divided into four research blocks of about 917 ha (2,200 ac) through the use of a three strand "wildlife fence" in which the top strand is set low, and the bottom strand is smooth and set high to facilitate deer and antelope movement (figure 1). To mimic conventional livestock management of the region, and to create the four replicate treatment blocks, a four-pasture rest-rotation grazing system was used in which three pastures are grazed and one is rested each season. In this portion of the study we timed the treatment to include grazing of all four pastures within each calendar year to establish complete replication in each of the treatment years. Rather than removing cows from a grazed landscape, we instead introduced cattle into an ungrazed matrix following 10 years of rest (figure 2). Baseline sampling was conducted for two years prior to reintroduction of cattle, and the treatments were stocked at 200 to 250 head (cow/calf pairs). Cattle used in the study were primarily Hereford F1 crosses that are typical of herds in the borderlands. Targeted vegetation utilization was 50% as measured by conventional ocular estimates used by the U.S. Forest Service and local land managers. This approach to livestock management was selected because it is consistent with Federal land management guidelines and is typical of grazing practices on public and private lands in the region.

Data are collected at each of the treatment plots within 200 x 200 m focus areas creating a 100 m buffer around each sampling plot (figure 3). Driving variables measured are rainfall, livestock activity, and soils (not used in this analysis). The major response variables measured are vegetation (the primary production in the system), small mammals (primary consumers and keystone guild in many grassland and shrubland ecosystems), and lizards (secondary consumers and an assay of invertebrate abundance).

Vegetation (Primary Production)

Vegetation composition was sampled once a year (October–November) following the growing season by measuring frequency and cover within 0.40 m^2 quadrates set at two

Figure 2—1 km x 0.5 km grazing exclosure in the southeast study block is one of four distributed across the research area located on a northeast facing bajada adjacent the Sierra San Louis in Chihuahua, Mexico. In contrast to many grazing studies, the reintroduction of cattle into an ungrazed matrix allows a landscape level analysis of the effects of grazing, and its interaction with other processes in desert grasslands.

m intervals along 5, 150 m transect lines within each sampling block (Curtin 2002b). Vegetation biomass was measured at 30 m intervals along the 150 m transect lines within 0.40 m^2 square quadrates using techniques developed by the USDA ARS research center in Tucson, AZ (R.C. Marsett, AR –Tucson, personal communication 2002). Following this technique representative samples were clipped and weighted until the sampler's ability to estimate cover was consistently accurate with less that 5% variation. After the sampler's eye was trained, the technique was applied to measurements taken within the study plots. Samples are periodically retested to assure that the ability to estimate biomass is consistent throughout the sampling period. Though less accurate than weighing and clipping every sample, the variance in ocular estimates is considerably lower than the variation in biomass due to placement of sampling frames. Because this is a long-term study where repeated measures are sought through time from the same plots, nondestructive approaches to sampling were our only option to assure the continuity of the project.

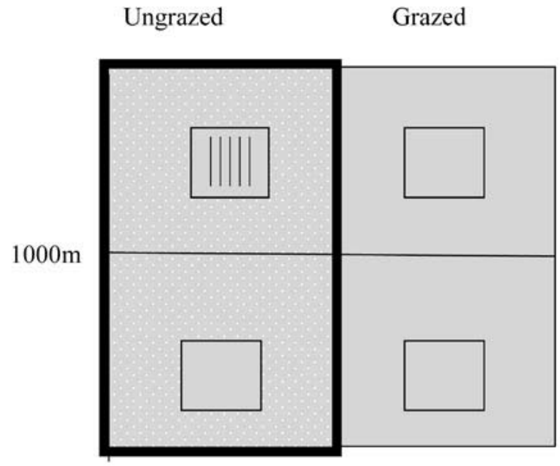

Figure 3—Experimental design of the McKinney Flats project is intended to examine at a landscape level the interaction of grazing and climate, with additional fire treatments scheduled for later in the life of the project (Curtin 2003). This core experimental protocol with five 150 m transect lines we repeated in blocks in all four sub-pastures as depicted in figure 1.

Small Mammals (Primary Consumers)

Three times a year Sherman traps were placed one meter to the east of the base of an orange 7/16 inch fiberglass stake located at 30 m intervals along the five 150 meter transects in each study plot. This sampling coincides with the lizard sampling to more efficiently use resources and to make lizards and rodents as comparable as possible. To ensure the traps are all picked up by the heat of the day only one-half of the site was trapped at a time (240 traps per night). The duration of trapping is three days in each location, three times a season for a total of 9 sampling nights per year. Due to relatively high mammal densities and diversities on the site (roughly 12 species on the site at a given time and two to ten captures per 200 x 200 m sampling area), this approach proved effective at documenting small mammal species composition. After capture species, sex, weight, body and tail length, and hind foot length are measured. All mammals are individually marked using ear tags.

Reptiles/Amphibians (Secondary Consumers)

In order to facilitate direct comparison between lizard and mammal populations, we have elected to place pit-fall traps along the same mammal trap lines one meter west of the stakes used for small mammal sampling. Pit-fall traps were censused three times yearly for three days each (total field time is 9 days to allow for lizard processing and data collection). These periods include the late spring, after adults emerge and become active (early June), in early summer before the hot dry periods prior to the monsoon (early July), and in mid August after the monsoon (when heat and drought sensitive species are likely to be active). After capture weight, sex, snout-vent length, tail length and condition, and morphometric measurements to analyze changes in body size are recorded. All animals are individually marked through a system of toe clips.

Results

A significant difference in the vegetation biomass in grazed and ungrazed portions of the pasture (P = 0.0001) existed with mean biomass per 0.40 m^2 quadrate 41.6 (SD = 28.6) and 61.9 (SD = 37.6) gms in grazed and ungrazed plots, respectively. These recorded differences are conservative because fall rains cause some vegetative regrowth prior to sampling. Following a season of rest from livestock the mean biomass of grazed (30.5 gms, SD = 19.9) and ungrazed (29.9 gms, SD = 1.4) plots were not significantly different (P = 0.77). Vegetation richness was not significantly different between grazed and ungrazed plots in 1999 and 2000 prior to livestock reintroduction (P = 0.69 and 0.18, respectively), was significantly higher on grazed plots in 2001 following reintroduction (P = 0.03), and returned to non-significant levels in 2002 after a season of rest (P = 0.84) (table 1). Climatic factors correlate with greater change than grazing effects with species number in 1999 prior to the drought in the low 30s, whereas by 2002 species number had dropped to the low 20s. Increases in species number on grazed plots were not the result of colonization of exotic species for no detectable shift in species composition occurred during, or following, implementation of the grazing treatments. A detailed analysis of species composition is beyond the scope of this paper and is currently being prepared as part of a separate analysis of the interaction of climate, grazing, and fire (Curtin and Traphagen, in preparation).

Small mammal biomass was not significantly different between plots in 1999 and 2000 prior to livestock reintroduction (P = 0.34), yet was significantly higher on grazed plots in 2002 following reintroduction (P = 0.01). Small mammal richness (species number) was also not significantly different prior to livestock reintroduction (P = 0.61), but was significantly higher on grazed treatment plots following reintroduction (P = 0.02; table 2). Overall mammal biomass on both treatment and control plots increased during the sampling period (from 1998 to 2002), while diversity declined (P < 0.05).

Response to grazing by lizards was non-significant with biomass 341.8 gms (SD = 204) in grazed, and 408.8 (SD = 262) in ungrazed treatments (P = 0.78). Species richness per plot averaged 5. 2 (SD = 1.3) in grazed and 4.6 (SD = 0.9) in the ungrazed treatment (P = 0.32).

Table 1—Average vegetation species richness on treatment plots for two years prior, immediately following, and one year after removal of livestock grazing.

	Grazed	Ungrazed	P-Value
Pre-treatment (1999)	32.8 (3.8) (N = 8)	33.2 (4.1) (N = 8)	P = 0.69
Pre-treatment (2000)	23 (4.3) (N = 8)	20.5 (3.1) (N = 8)	P = 0.18
Treatment (2001)	13.7 (1.4) (N = 8)	13.1 (1.3) (N = 8)	P = 0.03*
Post-treatment (2002)	20.3 (3.7) (N = 8)	20.5 (3.7) (N = 8)	P = 0.84

Table 2—Values of Mean and standard deviation (inside parenthesis) Biomass and Species Richness of small mammals two years before and following livestock grazing treatments. Due to the relative timing of grazing treatments and vertebrate sampling, the 2001 season did not contain sufficient replicates for all the study plots and was therefore excluded from the analysis.

	Small Mammal Biomass		
	Grazed	Ungrazed	P-Value
Pre-treatment (1999-2000)	405.1 (232) (N = 8)	354.2 (213) (N = 8)	P = 0.34
Post-treatment (2002)	971.7 (429) (N = 8)	662.5 (214) (N = 8)	P = 0.01*
	Small Mammal Species Richness		
	Grazed	**Ungrazed**	**P-Value**
Pre-treatment (1999 -2000)	7.0 (1.2) (N = 8)	7.1 (1.6) (N = 8)	P = 0.61
Post-treatment (2002)	6.1(1.3) (N = 8)	4.8 (0.75) (N = 8)	P = 0.02*

Discussion and Conclusions

Globally, and particularly in North America, rangelands composed of grasslands and savanna have been disproportionately damaged or lost to human activities (Manning 1997; Frank et al.1998; Dinerstein et al. 2000; Curtin et al. 2002). At the core of the debate over how best to develop long-term, large-scale conservation strategies to sustain rangelands is the role of livestock grazing. On the one hand grazing has been a leading cause of declines in biodiversity and ecosystem function (USDA 1936; Bahre and Shelton 1993; McPherson and Weltzin 2000; Curtin et al. 2002). On the other hand ecological theory states that moderate levels of disturbance maintain biodiversity (Darwin 1872; Lewontin 1969; Connell 1978; Hobbs and Huenneke 1992). Understanding the effects of livestock as a disturbance agent is crucial to understanding if grazing is an appropriate, or inappropriate, conservation strategy in the arid West.

The initial results of the McKinney Flats study reviewed here are consistent with those from other large-scale studies at Konza Prairie in Kansas (Collins 1987; Knapp et al. 1998) and in more arid landscapes Southern and Eastern Africa (McNaughton 1984; 1985; Walker 1988; Frank et al. 1998). The results of McKinney Flats and these other landscape-level studies support the "Intermediate Disturbance Hypothesis" (Darwin 1872; Lewontin 1969; Connell 1978; Hobbs and Huenneke 1992) by documenting a positive effect of grazing disturbance on biomass and diversity. While the exact mechanisms by which grazers increase biomass and diversity are not experimentally addressed here, the mechanism has long been generally understood. As stated by Charles Darwin in The Origin of Species (1872), "If turf which has long been mown be let grow, the more vigorous plants gradually kill the less vigorous, though fully grown plants; thus out of twenty species grown on a little plot of mown turf (three feet by four feet), nine perished, from the other species allowed to grow freely."

This pattern is well documented in both marine and terrestrial ecosystems and illustrates the important role engineering species play in sustaining ecological systems (Jones et al. 1994). In research at McKinney Flats the results are particularly significant because lower rainfall levels have often been associated with negative response to livestock (Donahue 1999; Milchunas et al. 1993). The results presented here indicate that moderate stocking levels and rotational grazing programs even in periods of drought can maintain or contribute to system diversity in rangelands at or below the 300 mm (12 inch) threshold.

The results of this study should in no way be interpreted as blanket support for grazing in arid lands. In contrast to many desert grasslands, the region of our study has a recent history of large native herbivores with records of bison (*Bison bison*) on the Chihuahuan frontier extending back to the early 1800s (List 2002). Because an evolutionary history of interaction with large grazers is considered an important factor in determining a system's ability to sustain grazing (Archer and Smeins 1991; Milchunas and Lauenroth 1993), additional studies are needed across sites without a recent history of large native herbivores, and with different climatic patterns or levels of exotic species colonization (such as the Great Basin), to test the broader applicability of the findings presented here. Longer term and cross-site studies of not just grazing, but grazing in interaction with other disturbance factors such as climate and fire, are essential for more accurately documenting the viability of livestock grazing as a conservation strategy in the American West.

Acknowledgments

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The Forest Service, Rocky Mountain Research Station's Southwestern Borderlands Ecosystem Management Project: Building on 10 Years of Success

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Abstract—*The USDA Forest Service's Southwestern Borderlands Ecosystem Management Project mission is to contribute to the scientific basis for developing and implementing a comprehensive ecosystem management plan to restore natural processes, improve the productivity and biological diversity of grasslands and woodlands, and sustain an open landscape with a viable rural economy and social structure in the borderlands of southeastern Arizona and southwestern New Mexico. The Project works closely with its numerous research and management partners from Federal and State agencies, universities, conservation organizations, non-governmental organizations, and private landowners. Approximately 180 research and resource publications, academic theses and dissertations, and other reports have resulted from this cooperation since 1994. Future research will determine the effects of rangeland restoration techniques and fire at landscape levels on Borderland ecosystem components, and develop and evaluate integrated cost-effective monitoring methodologies.*

Introduction

The Forest Service's national headquarters developed a nationwide initiative in 1993 to encourage ecosystem research (Carlson and Weldon 2000). Proposals for projects were solicited from throughout the United States; a requirement for a proposal was that it should involve National Forest Management, the public, and the universities. The Rocky Mountain Research Station's Southwestern Borderlands Ecosystem Management Project, which was initiated in 1994, is the result of a successful proposal by Dr. Leonard F. DeBano (Rocky Mountain Research Station, retired) and Larry Allen (Coronado National Forest, retired). It is one of 19 ecosystem management units in the country and one of six in the Western United States. A main factor behind the success of their proposal was the broad support of the Coronado National Forest, the Malpai Borderlands Group, The Animas Foundation, The Nature Conservancy, the USDA Natural Resources Conservation Service (NRCS), the Bureau of Land Management, and the University of Arizona's School of Renewable Natural Resources (Edminster and Gottfried 1999). The ecosystem unit's mission is to: "Contribute to the scientific basis for developing and implementing a comprehensive ecosystem management plan to restore natural processes; improve the productivity and biological diversity of grasslands and woodlands; and sustain an open landscape with a viable rural economy and social structure in the region." Fragmentation of landscapes and land ownerships is a threat to the natural environment in the region and to rural societies. A viable local economy, where people can earn a decent living, is indispensable to reducing fragmentation. This paper describes activities and accomplishments over the past ten years since the project was established and discusses its direction into the next decade.

The Southwestern Borderlands

The Southwestern Borderlands are located within the Madrean Archipelago, a region of the Basin and Range Physiogeographic Province between the Rocky Mountains to the north and the Sierra Madre Occidental to the south. The borderlands are located in southeastern Arizona, southwestern New Mexico, northeastern Sonora, and northwestern Chihuahua. This location between two major biological provinces accounts for the region's great biological diversity where individual mountain ranges can support more than 1,000 native plant species. The biogeography, ecology, biology, hydrology, and management of the Madrean Archipelago are described fully in numerous articles and presentations including those in the current conference and in the proceedings of the first Madrean Archipelago/Sky Islands Conference in 1994 (DeBano and others 1995).

The Southwestern Borderlands Ecosystem Management Project has concentrated most of its activities in southeastern Arizona and southwestern New Mexico, in a unique, relatively unfragmented landscape containing exceptional biological diversity and natural beauty. The geographic location includes the San Bernardino Valley, the San Simon Valley, southern Peloncillo Mountains, Animas Valley, and the

Animas Mountains. The area is under multiple ownerships and administrations: 53% is in private ownerships; 23% is in State ownership by Arizona or New Mexico; 16% is administered by the Coronado National Forest; 7% is administered by the Bureau of Land Management; and 1% is administered by the Fish and Wildlife Service. This complex ownership pattern requires that the research program be based on a partnership among private and public interests and that desired future conditions be developed through an evolving adaptive ecosystem management process. The dominant land uses on the program area are livestock grazing and recreation (primarily hunting and some eco-tourism).

Related research also is being conducted by collaborators in the Chiricahua and Huachuca Mountains, and in adjacent deserts and grasslands. Results from the research in the southwestern borderlands program region are applicable to other sites within the Southwestern United States and Northern Mexico. Most of the research is conducted under joint venture agreements with cooperators from universities or with scientists from other Federal and State agencies.

The Initial Problem Areas

The objectives of the project are to fulfill the mission goal of contributing to the scientific basis for developing and implementing a comprehensive ecosystem management plan for the Borderlands. To accomplish the mission, the Project identified two problem areas (Edminster and Gottfried 1999):

- Provide the scientific basis to establish the desired future condition for the planning region based on highest quality biological science integrated with desired social and economic conditions within the context of private and agency partnerships.
- Plan and implement a long-term systematic program of basic and applied research and monitoring to integrate past and future research findings and contribute to developing guidelines for sustaining a viable rural economy and landscape.

Three focus areas were identified within these problems. The first focus area was to determine what was known about the region and to summarize and synthesize the existing information. A key effort was the development of an annotated bibliography of literature pertaining to the northern Madrean Archipelago (Ffolliott and others 1999). Other studies documented: the role and importance of human and natural disturbances on plant communities; an archeological synthesis of pre-historic and early historic evidence; the status of wildlife information and a comparison of hydrological information for major watersheds in the general region. A related study examined the cultural and environmental history of the region.

The second focus was to develop a comprehensive landscape inventory and monitoring system to serve research and management needs. Several studies have been completed in this category; they include the mapping of current vegetation using TM imagery and ground validation; delineation and interpretation of geomorphic surfaces, integrating geology with the NRCS soil maps; photographic monitoring of landscape changes; and a digital archive of the long-term records at the Santa Rita Experimental Range.

The third focus area was the specific research studies identified as having a high priority to filling gaps in the existing knowledge base. One of the key land management objectives is to reintroduce fire into the region's ecosystems. The Coronado National Forest and its cooperators are developing the Peloncillo Programmatic Fire Plan to facilitate landscape scale prescribed fires in the mountain range. Fire was the most common natural disturbance prior to the1880s, when cattle ranching rapidly grew following suppression of the Apache Indians and the construction of the transcontinental railroad through the region. The loss of the herbaceous cover prevented wildfires from spreading and contributed to the increase of woody vegetation and soil erosion. Many of the studies in this focus group are designed to support this programmatic plan by determining information to aid in its development and sound implementation. Some of the research is designed to determine past fire regimes or the consequences of reintroducing programmatic prescribed fire onto the landscape. A cross-section of the fire-related studies include: a reconstruction of fire regimes in the Southwestern United States and Northern Mexico; effects of different fire frequencies; fuel accumulations in forests, woodlands, and savannas, and effects on nutrient budgets within grasslands; understanding the spatial patterns of fire regimes and fire behavior at landscape scales; effects of prescribed fire on vegetation, bird populations, and selected endangered species; techniques for fuels visualization, mapping, and fire spread modeling; and developing riparian ecosystem recovery priorities for the region. Another study is examining the archeological implications of using intensive cattle grazing as a site preparation tool to increase native perennial grasses prior to initiating a prescribed fire program.

The Coronado National Forest in cooperation with the Malpai Borderlands Group, the Animas Foundation, Bureau of Land Management, the Natural Resources Conservation Service, and other Federal and State agencies has conducted three landscape level prescribed fires within the Southern Peloncillo Mountains. The objectives of these burns are to reduce tree cover and to create a mosaic of cover types across the landscape. The Baker Canyon Fire occurred in 1995 and the Maverick Fire occurred in 1997. The Rocky Mountain Research Station assisted in the planning and monitoring of the fires. Two important efforts concerned the impacts of fire on threatened or endangered species; one examined the impacts of fire on *Agave palmeri*, an important source of food for lesser long-nosed bats (*Leptonyceris curasoae*), and the other studied populations and impacts of fire on the New Mexico ridge-nosed rattlesnake (*Crotalus willardi obscurus*). This information was used as part of the planning and approval process for the 46,000 acre Baker Canyon II Fire in 2003. This burn is on record as the largest successful prescribed fire in the United States and involved both Federal and private lands.

Major Landscape Studies

The Southwestern Borderlands Ecosystem Management Project and its cooperators have initiated three major long-term landscape scale research studies. The studies will continue into the future. The studies are experimental treatments to restore degraded Apacherian grasslands, the Peloncillo Watershed study, and the McKinney Flat fire and grazing interactions study.

Rangeland Restoration

The objective of the rangeland restoration study is to improve the cover of native perennial grasses on mesquite (*Prosopis glandulosa* var. *glandulosa*) dominated semi-desert grasslands and to create sufficient grass cover so that sites can be maintained by periodic prescribed fires (Gottfried and others 1999). This is a joint study with the NRCS, and is being conducted on three ranches and on State lands in Arizona or New Mexico. Three treatments were selected to be tested: a control; mechanical crushing of mesquite with no grass seeding; and crushing of mesquite with seeding of locally adapted native perennial grass seed. Each site was divided into 12 blocks, and each treatment was randomly assigned to four blocks. A weather station is located at each site. Initial results showed that the seeded blocks had the best results; unfortunately, the continued drought in the region has compromised the treatments because of subsequent mortality and the lack of natural regeneration. The lack of winter rains has also prevented the establishment of an annual grass cover to help carry the fires. However, vegetation cover and production changes are being monitored in anticipation of better climatic conditions. An associated study is examining the feasibility of using cattle as a site preparation tool on a site with significant archeological value.

The Peloncillo Watersheds

One of the major questions that has been posed by the programmatic fire plan has been the effects of cool season compared to warm season prescribed burning. The region generally has burned naturally during the warm season prior to the onset of monsoon rains. These fires tend to be hot. Some people maintain that cool season burning would be less harmful to the ecosystem and some of the component species. There also is a lack of knowledge about the hydrology of oak savannas and woodlands. A landscape-scale study was established on 12 small watersheds that support typical oak savannas on the east side of the Peloncillo Mountains of the Coronado National Forest and adjacent private lands (Gottfried and others 2000). The objective is to examine the effects of seasonal burning on as many ecosystem attributes as possible. Each watershed has been instrumented with a pair of Parshall flumes, and weather stations and supplemental rain gages have been established throughout the area. In addition, studies are being conducted to determine the impacts of burning on erosion and sedimentation, overstory and understory vegetation, small and large mammals, bird populations, and soil nutrient dynamics. Scientific partners include the NRCS; Rocky Mountain Research Station's riparian and watershed project at Flagstaff; the University of Arizona's School of Natural Resources; and the Arid Lands Project. Pretreatment measurements are currently being conducted prior to burning by the Coronado National Forest. The study is planned for a minimum of 10 years.

McKinney Flats

The McKinney Flats Fire and Grazing Interactions Study will be described in more detail by Charles Curtin (Curtin, this proceeding). The Southwestern Borderlands Ecosystem Management Project is one of the main sponsors of this research. The objective is to better understand how fire and livestock grazing can be used as management tools to sustain ecological processes, biological diversity, economically viable ranching, and to restore degraded habitats in Southwestern grasslands. One component of this study examines the interactions between prairie dogs (*Cynomys ludovicianus*), livestock, and vegetation.

Dissemination of Results

Scientific information only is useful if it can be disseminated to other scientists and to managers. The Rocky Mountain Research Station through the Southwestern Borderlands Ecosystem Management Project was the main organizer and sponsor of the 1994 Madrean Archipelago Conference that brought together representatives of a large and diverse group of agencies, universities, and conservation organizations to exchange information and to examine future activities and goals (DeBano and others 1994). Similarly, the Station and Project are a main sponsor and organizer of this 2004 conference. The project also has organized and supported a number of regional and international conferences in the interim, which have been discussed by DeBano and Ffolliott (this proceedings).

The Project's scientific dissemination accomplishments between 1994 and November 2003 number 175 publications, including 23 in peer reviewed or refereed journals, 16 in peer reviewed management journals, 9 conference proceedings, 6 Station peer reviewed publications, 17 M.S. theses or Ph.D. dissertations, and 4 GIS maps of soils, vegetation, and geology. Research and management results have been presented at local, regional, and international conferences and workshops and reported in the resulting proceedings. There also have been formal and informal tours of research sites for scientists and public and private land managers. The current conference includes about 14 presentations based on research that was fully or partially funded by the Project. Many of our regular cooperators also are presenting their independent research and views.

The Future

The Project is embarking on its second decade and will build on the established 10-year research foundation. The basic mission statement will remain the same; however, there will be a shift in specific assigned problems. Research will continue to develop an understanding of the effects of rangeland health restoration techniques, including mechanical treatments and prescribed fire, and interactions with grazing management strategies on the components of Borderlands grassland, savanna, and woodland ecosystems. This research is critical because of the need for both management and restoration guidelines to evaluate the ecological consequences of competing human demands. The second problem will attempt to increase our understanding of the effects of fire at a landscape level on ecosystem components, including soils, water, vegetation, wildlife, and cultural resources. This problem not only includes the determination of prescribed fire effects but also the ability to assess fuel conditions and predict fire behavior and effects before ignition. Monitoring the effects of land management activities is a required activity for public land managers and is desirable for private land owners; this is the third problem. Monitoring is a key component of the adaptive management process. Managers often lack appropriate and comprehensive methods for evaluating the status of Borderlands ecosystems and the impacts of their activities. Monitoring methodologies need to be integrated to encompass a wide range of biological and physical conditions and trends as well as past and future management goals. The value of monitoring data for discerning long-term changes on the land requires that they be stored in well-documented and accessible archives for scientists and managers alike.

Cooperators

The Project could not have been successful without the cooperation of a large number of land managers and scientists, and their help is greatly appreciated. We hope for continued cooperation and success in our next ten years.

The list of private and agency partners includes: the Malpai Borderlands Group; The Animas Foundation; Coronado National Forest; Douglas Ranger District; Natural Resources Conservation Service; U.S. Fish and Wildlife Service-Ecological Service Division and San Bernardino National Wildlife Refuge; Bureau of Land Management; Arizona and New Mexico Land Departments; Arizona and New Mexico Game and Fish Departments; Whitewater Draw and Hidalgo Conservation Districts, Fort Huachuca; and the Secretaria de Media Ambiente, Recursos Naturales y Pesca of Mexico.

The research partners include: the Rocky Mountain Research Station; Agricultural Research Service; USGS Desert Laboratory; The Nature Conservancy; New Mexico Heritage Program; Audubon Society; Desert Botanical Garden; University of Arizona; Arizona State Museum; Office of Arid Land Studies (U of A); Arizona Geological Survey; the Forest Service's Southwestern Region's Terrestrial Ecosystem Survey; Arizona State University; New Mexico State University; University of New Mexico; California State University; Indiana State University; University of Notre Dame; Oklahoma University; University of Sonora; Arid Lands Project; and Society for Ecological Restoration.

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The Research Ranch—What Do You Do With a Grassland Besides Raise Cows?

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Abstract—*For most of the past 10,000 years, semi-arid grasslands of Southeastern Arizona have not been heavily impacted by large herds of hoofed animals. This began to change in the 1500s with the introduction of domestic livestock, primarily cattle. Impacts of this major ecological force on a native system were widespread. In 1968, Frank and Ariel Appleton created an outdoor laboratory, the Research Ranch, to examine the consequences of removing that major ecological force. The Audubon Appleton-Whittell Research Ranch is an 8,000-acre exclosure and living laboratory where short-term research projects are conducted and repeated, and where long-term study sites can be established. Results of these studies are providing sound scientific information that is being used to formulate policy on regional planning and land management issues.*

Perhaps the most useful role for the facility continues to be its use as a control for the many "environmental experiments" going on throughout the Southwest as the human population of the region increases. Impacts of road building, recreational usage, conversion of once open spaces to exurban home sites, and a shrinking, but usually locally valued, cattle industry can be evaluated with more insight when compared to conditions on the Research Ranch.

Introduction

The Research Ranch (TRR) was founded by the Appleton family in 1968 when they, along with partners (Arizona State Lands, U.S. Forest Service, and later Bureau of Land Management) converted their 8,000 acre cattle ranch into a foundation and removed all livestock from the premises. Their purpose was to determine the response of the land when grazing by domestic livestock ceased. The goal was and is to enable the biota and physical environmental features of the land to proceed undisturbed. TRR thus serves as a reference site, or control, for the many "environmental experiments" underway in the Southwest, such as ranching, exurbanization, and recreational use.

In 1980, with financial support from the Whittell Foundation, the National Audubon Society assumed responsibility for the site and designated TRR as an Audubon Sanctuary. The sanctuary and living laboratory remains true to the founders' precepts: conservation of indigenous species, non-destructive ecological research, and education, especially of professional scientists and their advanced students. Scores of scientific papers and several books have been published (Dyson 2001), primarily on two major topics: monitoring changes through time on TRR, and comparative studies with nearby sites whose functions differ from those of the Sanctuary, notably agriculture and real estate development. As an independent research station, TRR accepts proposals from academics, independent researchers, and agency representatives that meet the criteria—non-destructive studies that will help us understand and protect the environment. Land managers and policy makers have been guided by the results from these studies, further underscoring the value of TRR as a reference area.

Nestled in the Sonoita Plain of southeast Arizona, ecosystems on TRR are primarily grassland and oak savanna. Virtually all grasslands around the globe, including those being treated in this symposium, share the common influences of herbivory, fire, and drought. Many research projects on TRR have focused on one or more of these impacts.

Herbivory

Since the end of the last Ice Age there have been shifts in climatic patterns and the accompanying biota. However, there is evidence that the grassland characteristics persisted throughout the last dozen millennia (Martin 1977). Notably missing here were American bison, that excellent analog to cattle that roamed the Great Plains. Doubtless, bison wandered onto the Sonoita Plain from the grassland-mountain corridors to the east from time to time, but no fossil and historic records on the scale of those in the Great Plains have been found near the Sonoita plain (Lott 2004, Truett 1996, McDonald 1981). In the recent past at TRR and elsewhere on the Sonoita Plain, common native herbivores include white-tail and mule deer, pronghorn, collared peccaries, and a host of other, smaller herbivores, notably grasshoppers.

It is likely that cattle and horses first moved into the region in the 1500s. From the middle of the 19th century to the present, the region became known as cattle country. Data are not available to describe all the impacts by cattle on a native environment, but certainly there were effects on plant communities and the fauna associated with those communities (Sohn and Qi 2004; Milchunus et al.1988).

At the initiation of TRR some suggested that the grassland would degenerate into a shrub-land of dying ("decadent") grasses due to a lack of stimulation provided by domestic grazers (Savory 1988). So far, they are wrong. An inventory of ecological sites indicates healthy plant communities (Breckenfeld and Robinett 2001). More than 500 species of vascular plant have been identified on the Sanctuary (McLaughlin et al. 2001). Although a few sites on the Research Ranch show record species richness (*ibid.*), for the most part the plant species found on the Research Ranch are the same as those found on neighboring ranches. The differences are in patterns of distribution, i.e., some species are more common on grazed versus the ungrazed lands and vise versa (Bock et al. 1984; Bock and Bock 2000). A generalization is that total cover is significantly higher on the Research Ranch (Bock and Bock 1999; Brady et al. 1989; Qi and Wallace 2002; Sohn and Qi 2004). The birds and other animals tend to sort themselves as well. Those animals preferring heavier cover for feeding and nesting are more common on the Sanctuary (Bristow and Ockenfels 2000), while those seeking grassland with less cover are found on the ranches (Bock and Bock 1999). Observations show distinctions among game species may exist as well. Pronghorn are found in both areas, but may prefer sites where grazing continues for general foraging, but seek the Research Ranch for fawning (personal observation).

Fire

Indirect evidence indicates a fire return interval of less than ten years in desert grasslands, prior to introduction of large scale grazing operations (McPherson 1995). Fires, usually consuming a few acres at most, are frequent events at TRR, often ignited by lightning preceding summer monsoons. Only two large fires have occurred on the property since 1968, when livestock were removed: one in July 1987, and the second one at the end of April 2002. Also, there have been some small controlled burns for research purposes in the 1980s. The 1987 burn of 2,000 acres was ignited on the property by lightning, and was stopped at the TRR boundary due to efforts of fire fighters and reduced vegetation cover on the neighboring cattle ranch. After three post-fire growing seasons, the pre-burn conditions were again present (Bock and Bock 2000 and references therein). In contrast, the 2002 fire was of anthropogenic origin. Known as the Ryan Wildfire, this blaze was ignited on a working cattle ranch several miles to the southwest of TRR, burned through several ranches before reaching TRR, covered approximately 90% of the Research Ranch, and continued on to other ranches to the east and northeast, finally stopping after burning nearly 39,000 acres. The effects of this fire are under current study by many researchers who are examining such topics as surface energy balance, infiltration and soil erosion, impacts on native and non-native grasses, encroachment by woody species, and summer and winter bird populations. Preliminary findings by the authors and others suggest that the effects of this fire will be in evidence longer than three growing seasons and that its effects on vegetation, especially trees and shrubs, were much greater on the ungrazed sides than on the adjacent cattle ranches. Also, distinctive patterns in small mammals and changes in avian communities are being documented. Vegetation changes are under study and some preliminary reports are available (McLaughlin and Bowers 2004a,b).

Drought

We currently are in a prolonged period of drought in southeastern Arizona, although inter-year variation in precipitation makes such generalizations difficult. The link between drought and fire often is cited, especially in light of our growing concerns about global warming. The strongest correlation with the two large fires (1987 and 2002) that we have noted to date is not only with drought conditions, but also with heavier winter rains over a year before each fire (1985-1986 and 2000-2001, respectively) leading to a flush of herbaceous species (forbs), many of which store highly volatile oils. These unique fuels that remained from the growing seasons preceding each fire appear to have formed a heavily combustible fuel source (Bock et al. 2004). The relationship between drought and fire also has been observed at the species level. Native plains' lovegrass (*Eragrostis intermedia*) was dying in specific places on TRR during this drought in the late 1990s—except in those places that had burned in 1987 (Bock et al. 1995). This suggests the rejuvenating power of fire, perhaps through removing accumulating standing dead grass. This, of course, might be accomplished by the presence of grazing cattle as well (Robinett and Kennedy 2004). Many workers have pointed out the rejuvenating power of grazing in the Great Plains and in Southwestern grasslands (Milchunas et al. 1998 and references therein). During times of drought, this picture is complicated by reduced primary production of plant cover.

Of all the grassland features studied by ecologists, drought likely is the most neglected. Relatively few long-term monitoring programs have been implemented, yet accurate assessments can only be based on long-term data sets. The most significant work has come from climatologists whose field fosters longer term views than the career life spans of ecologists.

The Future

The grasslands are a grossly underestimated source of well-being in the United States. The Great Plains and the Intermountain West including our own Madrean section, contain the corn and wheat belts and the North American rangelands. It never ceases to amaze us how under-valued these areas are by the citizenry at large. Some of these areas have been degraded through our lack of proper understanding of their vulnerability. Testimony to this comes from the Dust Bowl episodes, ongoing topsoil erosion, and desertification of some of our precious rangelands.

Predictions came from a conference of scientists, managers, and ranchers in 1979 when our ranching neighbor, Bill Brophy, pointed to the flaw in our meeting organization. We had not included realtors. He further noted that cattle prices had been down for so long that ranching was less and less a sound business.

Mr. Brophy had observed some old ranches were being subdivided into smaller pieces for new owners. This process, now called exurban development, differs from the formation of suburbs because the new homes do not move outward from the heart of a city, but rather originate on open land "out in the middle of nowhere" and are unattached to an urban locale. Many big ranches remain intact in the Sonoita Plain, although in the past few decades many privately owned spreads have been subdivided into smaller lots for new owners, especially winter residents, workers who commute to Tucson, and retirees.

TRR provides a reference point (scientific control) against which other land uses in the region can be compared and contrasted. Three sorts of patterns can be studied by monitoring with cross fence and regional comparisons: (1) TRR, one wag suggested, should be renamed "the unranch," (2) the remaining big cattle ranches, and (3) the emerging exurban sites. A current study is comparing and contrasting the biodiversity of these three settings. It is beyond the space provided here to give preliminary findings. However, we know there are surprises in store. All three areas tell an important part of the story of our rich flora and fauna.

The full value of the Research Ranch as an un-manipulated place for comparison with other land uses is yet to be realized. However, its findings to date have been propagated widely from the scientific community to others including exurbanites, ranchers, politicians, and community planners. And this value and role will increase as its promise of being "left alone" continues into the decades and centuries to come. It has been pointed out to us that the National Park system has a clear directive to maintain "natural" ecosystems, the position we are championing. But they, unlike the managers of TRR, must contend with enormous and increasing impacts from the presence of millions of tourists and other recreationists.

Our greatest concern is that the findings obtained from the Sonoita Plain here on this 8,000 acre set-aside will be unaccompanied by other sites in American grasslands and savannas. In 1993 there were 212 million acres of Federal land being used for grazing by domestic stock. Most of this land is in the care of the U.S. Forest Service and the Bureau of Land Management. Some few places among these holdings have been set aside as reference points with their functions similar to those of the Appleton Ranch. However, most of these exclosures are much smaller than 8,000 acres (Turner et al. 1980). Similarly, the agencies often are too short-handed to maintain, let alone monitor, their exclosures. Long-term monitoring of such set-asides is essential. Similarly, monitoring is not popular with academics because it is anethma to those places where we seek most of our research funding. Short-term studies of an experimental nature are built into the academy for ecological researchers—publish quickly and often—or perish. The record for significant control areas appears to be even weaker for non-governmental organizations' (NGOs) lands. These conservation groups appear often to be loathe to set aside reference lands within their holdings. We are urging here that that both the USFS and the BLM along with the NGOs should make appropriately large exclosures a high priority. We will reiterate a challenge that was greeted with a serious lack of enthusiasm when it was first presented (Bock et al. 1993). Perhaps we will have better success now.

If even 5% of such public and private holdings were made into reference points where manipulative activities such as agriculture, tourism, and recreation were curtailed and long-term monitoring established, rewards would start immediately and be increasingly revealed with each passing decade. The rewards would result from acknowledgment of what nature can do without human interference. This sort of information is essential to sound resting, rest-restoration, and rest-rotation management strategies. Further, the reference lands contain gene banks of indigenous species that will be essential to agricultural well-being in the ongoing climatic shifts. Also, these will be water preserves, and most knowledgeable Westerners agree that water or the lack thereof defines our future. At first glance, doing nothing but watching (monitoring) how nature works on its own without human interference may appear to be un-American because we are definitely a nation of doers! But careful consideration can convince that this is one of the most active and least implemented actions we can undertake. There is an urgency to our having more reference areas set aside for the multitude of environmental experiments we carry out. Many, if not most, of these are informed by incomplete knowledge. As we Americans enter a period of climatic change, such knowledge may facilitate our maintaining these precious grassland and savanna ecosystems.

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Management and Conservation of Tree Squirrels: The Importance of Endemism, Species Richness, and Forest Condition

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Abstract—*Tree squirrels are excellent indicators of forest health yet the taxon is understudied. Most tree squirrels in the Holarctic Region are imperiled with some level of legal protection. The Madrean Archipelago is the epicenter for tree squirrel diversity in North America with 5 endemic species and 2 introduced species. Most species of the region are poorly studied in keeping with an international dearth of data on this taxon; 3 of the 5 native species are the subject of <3 publications. Herein, I review literature on the response of squirrels to forest management from clearcutting to less comprehensive operations. Major threats to squirrel diversity in the Madrean Archipelago's Sky Islands are the introduction of species, altered fire regimes, and inappropriate application of forestry practices.*

Introduction

The Madrean Archipelago is renown for its biodiversity (Lomolino et al. 1987). The area is considered a hotspot of evolution (Spector 2002) and contains the greatest diversity of mammals in the United States (Turner et al. 1995). Despite this megadiversity, the fauna is poorly represented in peer-reviewed scientific literature (Koprowski et al., this proceedings). The dearth of knowledge is an impediment to effective conservation and management. The persistence of mammalian diversity in relictual forests is dependent on the development of prudent and efficacious management strategies.

Tree squirrels are excellent indicators of forest health and structure (Carey 2000; Steele and Koprowski 2001) due to a dependence on mature forests for seed, nest sites, cover, and microclimates for food storage (Gurnell 1987; Steele and Koprowski 2001). The presence, demographics, and habitat use of tree squirrels can indicate the status of forested ecosystems. Herein, I review the unique nature of tree squirrel diversity in the Madrean Archipelago and address major issues of import to conservation in our forests through a literature review of the effects of forest condition on tree squirrels.

Species Diversity and Endemism

Tree squirrels across the globe are considered at risk (Koprowski and Steele 1998). Holarctic squirrels are of precarious conservation status with 88 % of 9 *Sciurus*, 67% of 3 *Tamiasciurus*, and 100% of 2 *Glaucomys* receiving legal protection due to concerns about persistence in a portion of the species' range (table 1). Fully 85% of squirrels are potentially imperiled. Furthermore, the ecology of squirrels is poorly known. I queried Web of Science (1945-2000; Thomson ISI, Stamford, CT) for all *Sciurus* (n = 28), *Tamiasciurus* (n = 3), and *Glaucomys* (n =2) species. Of 33 species, only 32% were the focus of ≥1 publication. A similar search for all species of arboreal Sciuridae world-wide yielded a bleak picture with 13% of known species the subject of ≥1 publication.

Five *Sciurus* and *Tamiasciurus* are native to the Sky Islands; 2 *Sciurus* were introduced (table 1), the greatest diversity in the Holarctic Region. When including 16 unique subspecies, the Madrean Archipelago's diversity doubles that found elsewhere. Most forms diverged in isolation in the Madrean Archipelago (Brown 1984) and are endemic to the Madrean Archipelago (81%, 13 of 16 forms). Thus, the area serves as an epicenter of tree squirrel diversity in North America. This diversity is at risk, and each native species receives legal protection. Furthermore, while squirrels of Arizona are poorly represented in the scientific literature (Koprowski et al., this proceedings), native tree squirrels of the region are especially so. No publications occur on the ecology of two endemic species, *Sciurus arizonensis* or *Tamiasciurus mearnsi*. *S. nayaritensis* has only 2 ecological papers on its ecology.

The unique diversity of squirrels in the Madrean Archipelago and its continued persistence are influenced by exotic species, forestry practices, and fire. Three tree squirrels were introduced to the Madrean Archipelago region. Fox squirrels (*S. niger*) were introduced to eastern New Mexico, dispersed, and are vagile to continue to do so (Frey and Campbell 1997). Eastern gray squirrels were released in Sierra San Pedro Martir in Baja California in 1946 (Huey 1964). Abert's squirrels were introduced to Sky Islands in Arizona and New Mexico in the 1940s (Davis and Brown 1988) and may have contributed to decline in native species in Arizona (Hoffmeister 1986).

Squirrel Responses to Forest Management Strategies: A Review

Squirrels rely on mature forests that produce quantities of seed, shaded microclimates for fungal growth and seed storage, and nest cavities (Gurnell 1987; Steele and Koprowski 2001). Disturbance of such conditions is not conducive to short-term

Table 1—Tree squirrel species of special concern in the Holarctic Region including the species of the Madrean Archipelago.

Species	Range	Status	Number of subspecies
Abert's Squirrel (*Sciurus aberti*)	Wyoming, Utah, Colorado, New Mexico, Arizona, Northern Mexico	Threatened in Mexico Kaibab Plateau Arizona IUCN	8
Persian Squirrel (*S. anomalus*)	Middle East Western Asia	Threatened in Israel	3
Arizona Gray Squirrel (*S. arizonensis*)	Arizona, New Mexico, Sonora	Threatened in Mexico USFS Sensitive	3
Western Gray Squirrel (*S. griseus*)	Washington, Oregon, California, Baja California	Threatened in Washington	3
Japanese Squirrel (*S. lis*)	Japan	Threatened	1
Mexican Fox Squirrel (*S. nayaritensis*)	Arizona, Sierra Madre Occidental	USFS Sensitive in Arizona	3
Fox Squirrel (*S. niger*)	Eastern United States	Endangered in Maryland, Delaware, Virginia	10
Eurasian Red Squirrel (*S. vulgaris*)	Europe and Asia	United Kingdom Protected	>20
Mearns's Squirrel (*Tamiasciurus mearnsi*)	Baja California	Threatened	1
Red Squirrel (*Tamiasciurus hudsonicus*)	North America	Endangered in southeastern Arizona	25
Southern Flying Squirrel (*Glaucomys volans*)	North and Central America	Threatened in Nebraska	10
Northern Flying Squirrel (*Glaucomys sabrinus*)	North America	Endangered in Appalachian Mountains	25

persistence of populations in a local area; management schemes that do not promote return of forests to such conditions after disturbance will impede reestablishment and persistence of squirrels. Unfortunately, few studies have been conducted specifically to quantify impacts of forestry practices.

Impacts of clearcuts

Clearcuts remove habitat directly, degrade habitat by edge effects, decrease squirrel activity, and potentially increase vulnerability to predation (Wolff 1975; Anderson and Boutin 2002). Squirrel densities are often significantly higher in mature forests compared to clearcuts (Nixon et al. 1980a; Bayne and Hobson 1997; King et al. 1998). Red squirrel densities decreased from 1.2 to 0/ha in clearcut blocks of spruce (Wolff 1975). Seed predation declines greatly in single seed tree cut blocks due to decrease in use by red squirrels (Peters et al. 2003). The scale of clearcutting operations appears important. Red squirrels persist for ≥3 to 5 y in residual forest and corridors in clearcuts and cutblocks (Cote and Ferron 2001). Small (<8 ha), narrow clearcuts (<160 m) did not change densities or demographics in eastern gray squirrels, a non-territorial species (Nixon et al. 1980b).

Impacts of thinning regimes

Squirrel densities decline in thinned sites that include a significant (>50%) reduction in stems (Nixon et al. 1980b; Sullivan and Moses 1986; Sullivan et al. 1996). Red squirrels decreased from 1.5 to 0.5 squirrels/ha in thinned blocks (83% removal), while edge and interior habitats of uncut forest did not change in density (Wolff 1975). Thinning of lodgepole pine (*Pinus contorta*) by 73% resulted in an 80% decline of red squirrels compared to unthinned sites (Sullivan and Moses 1986). Heavily thinned stands of juvenile lodgepole pine had reduced densities of pine squirrels (Sullivan et al. 1996). Sites with post-thinning densities of 1,000 to 2,000 stems/ha had more immigrants than intensively thinned (500 stems/ha) sites; populations in these treatments did not differ consistently in demography (Sullivan et al. 1996). Red squirrel demographics did not differ in second growth or old growth spruce-fir and lodgepole pine forests (Ransome and Sullivan 1997). Douglas's squirrel (*Tamiasciurus douglasii*) abundance was similar in young, mature, and old growth forests (Anthony et al. 1987; Carey 2000, 2001). Douglas's squirrels were most common in 80 to 100 y mature fir (*Abies*) forest compared to shelterwood cut (harvested in 2 stages with regeneration under partial canopy) or old growth forests (Waters and Zabel 1998).

Seed and shelterwood tree cuts may retain habitat components but often stem density is too low to provide squirrel habitat (Waters and Zabel 1998). In black spruce (*Picea mariana*), red squirrel demography did not differ between residual uncut forest strips or blocks and controls in continuous forest for 3-5 years post harvest suggesting minimal impact; however, middens were less common in residual forests (Cote and Ferron 2001). Thinned sites that become open and permit increased ground and shrub cover are avoided by *Sciurus vulgaris* (Gurnell et al. 2002).

Stringers of habitat often along riparian areas appear important. Eastern gray squirrels are less common in even-aged pine stands compared to mixed aged stands and mixed forests, especially those with hardwood stringers (Fischer and Holler 1991; Lurz et al. 1995). Similarly, southern flying squirrels did not use young (<15 y) and immature (15-40 y) pine plantations and harvest sites except if 10 to 20 m wide riparian forest strips were retained (Taulman 1999). Use of linear habitats and stringers may be important for other squirrels including red squirrels (Goheen et al. 2003), Eurasian red squirrels (Verbeylen et al. 2003), and fox squirrels (Goheen et al. 2003).

Selection cuts that remove a low number of the largest trees or thinning from below with the removal of pole size ladder fuels may provide the least impact by retaining snags and mature overstory seed producers. The retention of biological legacies and the management for decadence and variable stem densities are promising approaches to region wide management of forests for mature and old-growth conditions favorable to red squirrels while also permitting extraction of resources and management for forest health and fire (Carey 1995, 2000, 2001).

Nest availability is important for some species. Douglas's squirrels benefit from retention of ≥20 snags/ha in thinned forests (Carey 1995). At least 1 den/0.8 ha is required to maintain densities of >1 eastern gray squirrel/1.6 ha (Sanderson 1975). Artificial nests increase eastern gray squirrel and southern flying squirrel densities (Burger 1969; Nixon and Donohoe 1979; Goertz et al. 1975), but only impact male fox squirrels (Nixon et al. 1984).

Forestry practices in the Madrean Archipelago

Sorely little is known about management of most tree squirrels. Abert's squirrels are likely to be negatively impacted by forestry practices that include widespread thinning (Dodd et al. 2003). The impact appears to occur due to reduction of an interlocking canopy and decreased production of fungi (Dodd et al. 2003). These impacts led Dodd et al. to suggest that squirrels would be negatively impacted by traditional large-scale restoration methods, and that a large landscape mosaic that retains 35% of the area in high quality habitat patches with multiple management schemes applied to the matrix would be most beneficial. Red squirrels in the White and Pinaleno Mountains of Arizona prefer dense patches of moderately sized trees and high levels of canopy closure for storage and nest sites (Vahle and Patton 1983; Mannan and Smith 1994; Young et al. 2002). Linear riparian habitats appear crucial to nesting in Mexican fox squirrels (Pasch and Koprowski, this proceedings). Little work on the relationships between forest condition and tree squirrels exists for the Archipelago.

Fire

In the Western United States, fire is considered the major disturbance under heavy anthropogenic influence (Smith 2000; Brown and Smith 2000). Policies of suppression for nearly 100 y in the United States have resulted in significant changes in cool and catastrophic fire frequencies, as well as forest structure (Brown and Smith 2000). Ponderosa pine and Douglas-fir forests are typically characterized by frequent, low intensity ground fires, or mixed fire regimes; rarely stand replacement fires (table 2: Brown and Smith 2000). Conversely, mixed and stand replacing fires most likely occur in high elevation spruce-fir forests only every 100 to 400 y with particularly moist spruce-fir forests burned only once every 800 to 2000 years (Brown and Smith 2000). Such temporal scales suggest that human disturbances and suppression may have had much less impact on fire cycles for high elevation species. Restoration of natural fire frequencies is likely desirable but difficult.

The response of any tree squirrels to fire is poorly known and no studies have examined explicitly the relationships between fire and squirrel populations. No direct mortality due to fire has been reported (Smith 2000). Stand replacement fires result in the direct and immediate loss of habitat, yet pine squirrels continue to use areas of less intensive fire and on the fringe of the burns (King and Koprowski, in review). The short-term loss of habitat and concomitant changes in microclimates that result from ground and mixed fires must be considered in relation to the long-term term gains in habitat quality due to retention of open forest structure, increased productivity and seed production, and decreased risk of catastrophic fire (Brown and Smith 2000). Red squirrel population responses to habitat fragmentation appear to be similar to that resulting from fire (Bayne and Hobson 1997). Because squirrels routinely move distances of 1 km and have high biotic potential, displacement or loss of individuals due to ground fires or patchy, mixed fire regimes is not likely to be a significant problem for squirrel persistence (Gurnell 1987; Steele and Koprowski 2001). Stand replacement fires and less patchy, mixed fire regimes, however, are likely to have greater impact because these fires effectively are experienced as clearcuts by squirrel populations. In addition, the high temperatures at which such fires burn can result in less productive soils and a greater refractory period in recovery than is experienced in more patchy and ground fires (Brown and Smith 2000). Seed producing trees common to the Madrean Archipelago typically require at least 15 years to produce seed (table 3) with the most productive age classes at 50 to 200 y (Burns and Honkala 1991). Given the lengthy associations and coevolution of forests and squirrels, historical temporal and spatial patterns of fire (Swetnam and Baisan 1996) are likely not a problem for the persistence of squirrel populations. Changes in the frequency, intensity, and scale of fires resulting from human activities are the major challenge.

Levels of insect infestation are also linked to fire dynamics due to the fuel increase that results from tree mortality; however, the mosaic pattern that often results may reduce the risk of catastrophic fires (Baker and Veblen 1990; Matsuoka et al. 2001). Little research has been conducted on how squirrels respond to insect infestation. Red squirrel populations decline significantly in areas with >40% mortality of spruce trees due to beetle infestations (Matsuoka et al. 2001), and this pattern of decline has been noted in spruce-fir forests as well (Yeager and Riordan 1953). Importantly, red squirrels did not disappear entirely from areas with high insect infestation and tree mortality. Red squirrels exist within patches of the mosaic where conditions remain suitable (Matsuoka et al. 2001). Red squirrel use of relictual forest patches throughout secondary succession is likely the result of their long association with coniferous forests. Similar results might be expected for other Madrean forest dwelling species.

Table 2—Summary of fire cycles and fire regime types for common forest types in the Madrean Archipelago (after Brown and Smith 2000:98-99; Swetnam and Baisan 1995).

	Fire regime type					
	Understory		Mixed		Stand replacing	
Forest type	Extent[a]	Freq[b]	Extent	Freq	Extent	Freq
Ponderosa Pine						
Southern Rockies	Major	1-25	Minor	35-200		
Southwestern	Major	10	Minor	<35		
Arizona Cypress			Major	<35 to 200	Minor	<35
Douglas-fir	Minor	<35-200	Major	25-100		
Engelmann spruce-Subalpine fir					Major	100-400
White fir-Blue Spruce-Douglas-fir			Major	35-200	Major	35-200
Madrean Pine-Oak	Major	1-25	Minor			

[a] Percentage of stand: Major = >25%, minor = <25%.
[b] Frequency of occurrence in years.

Conclusions

The Madrean Archipelago represents the epicenter of tree squirrel diversity in North America. In agreement with global trends, the diversity of tree squirrels is poorly described and understudied. In the Madrean Archipelago, 5 native species of tree squirrel occur and 3 of these species have not been thoroughly studied. In addition, 3 species have been introduced to sites in the region with the status and impact of these introductions not well documented. This lack of information on the status and ecology of tree squirrels is an impediment to effective conservation and management of some of the mammals most illustrative of the Sky Island region.

Several patterns emerge from a comparison of the response of squirrels in a variety of habitats to thinning. Clearcuts are detrimental to local populations of tree squirrels; however, if part of a large-scale regional plan in a connected landscape, small clearcuts and other management techniques that result in small but temporary fragmentation may have minimal impacts. Thinning treatments that exceed 50% of the stems are nearly always associated with dramatic declines in numbers. Canopy closure is a key factor influencing populations with a number of species favoring dense sites (Gurnell et al. 2002; Vahle and Patton 1983; Dodd et al. 2003; Dodd 2003; Nixon and Hansen 1987). Dense ground cover in open forests is often avoided by squirrels (Gurnell et al. 2002). Retention of biological legacies to increase cavities also appears important (Sanderson 1975; Carey 2000). Our knowledge of the impacts of forestry practices and fire management on squirrels remains scant and we are especially poorly versed in the interactions between multiple disturbances.

Working on different species in diverse habitats in different regions of North America (Carey 2000, 2001; Dodd et al. 2003; Taulman 1999; Nixon and Hansen 1987) and Europe (Gurnell et al. 2002), researchers concluded that the most successful approach to conservation of tree squirrels is the promotion of a mosaic landscape. The mosaic should contain patches of dense vegetation (high canopy cover, stem densities, interlocking canopies) while the matrix contains thinning regimes that serve as lower quality habitat, fire breaks, corridors for movement, and/or timber extraction depending on management goals. Perhaps most clear is that successful management and conservation of the unique tree squirrel diversity of the Madrean Archipelago will require that we increase our knowledge of this diverse assemblage and the impacts of management schemes on their demography and persistence.

Table 3—Seed crop characteristics of major conifer species in Madrean Archipelago. Mean values provided when available, otherwise ranges are provided. Cone crop failures can occur at any time and data here provide a generalized assessment (Fowells 1965; Burns and Honkala1990).

Species	Common name	Age at 1st seed[a]	Mast year interval (yr)
Abies concolor	White fir	40	3 to 9
A. lasiocarpa	Subalpine fir	20 to 50	3 to 5
Picea engelmannii	Engelmann spruce	15 to 40	2 to 5
P. pungens	Blue spruce	20	2 to 3
P. ponderosa	Ponderosa pine	7	3 to 8
P. edulis	Piñon pine	25	4 to 7
Pseudotsuga menziesii	Douglas-fir	10 to 30	7

[a] Earliest age at which cones are produced. Most productive age is usually 3 to 5 times older than minimum age.

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The Development of Landscape-Scale Ecological Units and Their Application to the Greater Huachuca Mountains Fire Planning Process

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Abstract—*The multi-partner Greater Huachuca Mountains fire planning effort involves over 500,000 acres of public and private lands. This large area supports distinct landscapes that have evolved with fire. Utilizing GIS as a tool, the United States Forest Service (USFS), General Ecosystem Survey (GES), and Natural Resources Conservation Service (NRCS) State Soil Geographic Database (STATSGO) maps were refined using digital elevation model derived data, geology maps, existing vegetation maps, and expert knowledge. The resulting seamless map coverage will help define and characterize fire management units. It stratifies the planning area into distinct units suitable for modeling landscape-scale historical fire regimes and determining current condition classes.*

Introduction

Landscape-scale ecological units, such as landtype associations (LTAs), have been mapped and used successfully to address numerous resource concerns. A recent conference held in Madison, Wisconsin, was devoted to their development and use in natural resource management, planning, and research (Smith 2002). A number of States, mostly in the Eastern United States, have or are the in process of developing seamless LTA coverages. A good example is the state of Missouri (Nigh 2002). These products have proven to be an excellent context for interpreting historical vegetation and fire regimes relative to current conditions.

LTAs represent the landscape level of a scale-dependent hierarchy described in the National Hierarchical Framework of Ecological Units (Cleland 1997). Within southeastern Arizona, LTAs are nested within subsections comprised of large mountain ranges, mountain range complexes, and valleys. They reflect local influences of geologic materials, geomorphic processes, and climatic characteristics that are expressed as distinct topographic, soil, and vegetation patterns.

Landscape-scale ecological units were mapped to provide an ecological context for the Greater Huachuca Mountains fire planning process. These units were derived by applying expert knowledge, spatial modeling techniques, and field validation. Spatial data layers used include USFS General Ecosystem Survey (GES), NRCS State Soil Geographic Database (STATSGO) maps, digital elevation model derived data, geology and current vegetation maps. A geographic information system was used to define spatial relationships between the various spatial coverages and to create digital elevation model derived information, such as shaded hillside relief, aspect maps and the elevation ranges and means for the units. They constitute an interim product developed by applying the mapping concepts used to formulate LTAs. Additional refinement and characterization, as well as additional peer review, is needed for these units to meet LTA standards.

In addition to providing benefits to the fire planning process, these units may serve as a valuable prototype for the future development of LTAs in southeastern Arizona and Sonora, Mexico. LTAs and similar map products also provide landscape-scale context to: (i) evaluate and address natural resource conservation issues, (ii) assess and monitor the status of key ecological processes such as fire regimes and ecological patterns, (iii) stratify landscapes for monitoring and inventory purposes, (iv) facilitate improved communication and collaboration among land managers and partners, and (v) help define feasible ranges of desired conditions to be achieved through collaborative planning and land management. In the Northern Region of the U.S. Forest Service, landtype associations are being used to develop landscape character descriptions and to map scenic attractiveness for the their Scenery Management System (personal communication with Larry Blocker, Regional Landscape Architect, Missoula, MT).

The Units and Their Application to the Fire Planning Process

Interim landscape-scale units were developed to provide an ecological context for the Greater Huachuca Mountains (GHM) fire planning process. The GHM Fire Management Group involves a number of land managers, including Arizona

State Parks, Arizona State Lands, Audubon Research Ranch, Coronado National Forest, Coronado National Memorial, Fort Huachuca, The Nature Conservancy, the San Pedro Riparian National Conservation Area (Bureau of Land Management), and private ranches. A separate paper in these proceedings (Gebow and Lambert) describes the current progress of this planning effort.

The initial step in the mapping process was to identify and compile relevant data that might be useful in developing a seamless coverage for the half million acre planning area. Such data included spatial layers critical to defining landscape unit mapping criteria and boundary placement. Of equal importance was local knowledge and data related to current vegetation structure and composition, fuel conditions and trends, fire occurrence and behavior, historical fire regimes, and erosion events. To no one's surprise we encountered relevant spatial coverages of varying scales, vintage, and reliability. Simply overlaying this assemblage of data layers would have provided a relatively meaningless map with confusing polygons and "slivers." We elected instead to assess the individual coverages and attempt to understand how the layers related to each other; in other words, we tried to determine linkages between layers and, if they seemed in conflict, identify the nature and cause of the discrepancy. For example, differences in mapping scale and delineation criteria were often problematic on the surface but could be addressed more effectively once they were recognized and understood. GIS was also used to construct and characterize the units. Unit formulation was an interactive process utilizing existing data layers, expert input, field validation, and feedback from the fire planning group. The units were delineated to represent land areas that were relatively consistent in terms of geologic material, landform, and vegetation patterns. The USFS General Ecosystem Survey and NRCS STATSGO mapping on other ownerships, mapped at a scale of 1:250,000, provided us with an excellent preliminary base map. The mapping units were described utilizing existing data, such as soil survey information, GIS generated data, local knowledge, and field observations.

Twelve interim landscape scale ecological units are currently mapped, and have been individually field validated, in the planning area. Several more may be established following additional refinement. They are named based on their assumed historical vegetation and landform(s).

Table 1 list the units and illustrates how they relate to fire regime and condition classes on a landscape basis. "Historical" vegetation assumptions and fire regime condition classes in table 1 are estimated for the landscapes of each interim ecological unit based on local knowledge and expert opinion.

Figure 1 displays the interim ecological units in relation to the local topography and roads. Detailed narrative map unit descriptions are being developed that more fully describe their characteristics and fire management implications.

In addition to providing a basic ecological template for the fire planning effort, the interim units provide an effective stratification for estimating natural (historical) fire regimes on a landscape level. Natural fire regimes are based on fire frequency and amount of replacement required following fire (Hann 2001). These units and their landform components, in combination with awareness of broader climatic influences, provide logical strata for a landscape-scale assessment and context for finer scale documentation of fire regime condition classes. They can be used to develop finer resolution maps of potential natural vegetation groups (PNVGs) and can form the basis for finer resolution VDDT (vegetation dynamics development tool) models of PNVG and current condition maps. Such information is useful for determining local fire management strategies, project priorities, and funding needs. An opportunity exists to further validate our assumptions by studying similar units in neighboring Sonora, Mexico, where higher elevation systems show less departure from historical fire regimes due to less fire suppression and grazing.

These landscape-scale ecological units vary in terms of other characteristics important to fire management including landscape accessibility, soil and watershed characteristics, and species richness and diversity.

Future Implications

The Greater Huachuca Mountains mapping effort has given us insight into the existing spatial data available in the region and the capability of GIS analysis and modeling to define the relationships between coverages and help us integrate them. The NPS is exploring options to collaborate with a number of government and non-government partners to develop a seamless LTA coverage for southeastern Arizona. The Southern Arizona Office has an interagency agreement with Dr. David Cleland of the U.S. Forest Service Southern Research Station to develop LTAs for a proof of concept area in the Sky Islands region with involvement of local experts. This test area includes the Greater Huachuca Mountains fire planning area. The interim units developed specifically for this fire planning effort will be refined and more completely characterized as a result of Dr. Cleland's work.

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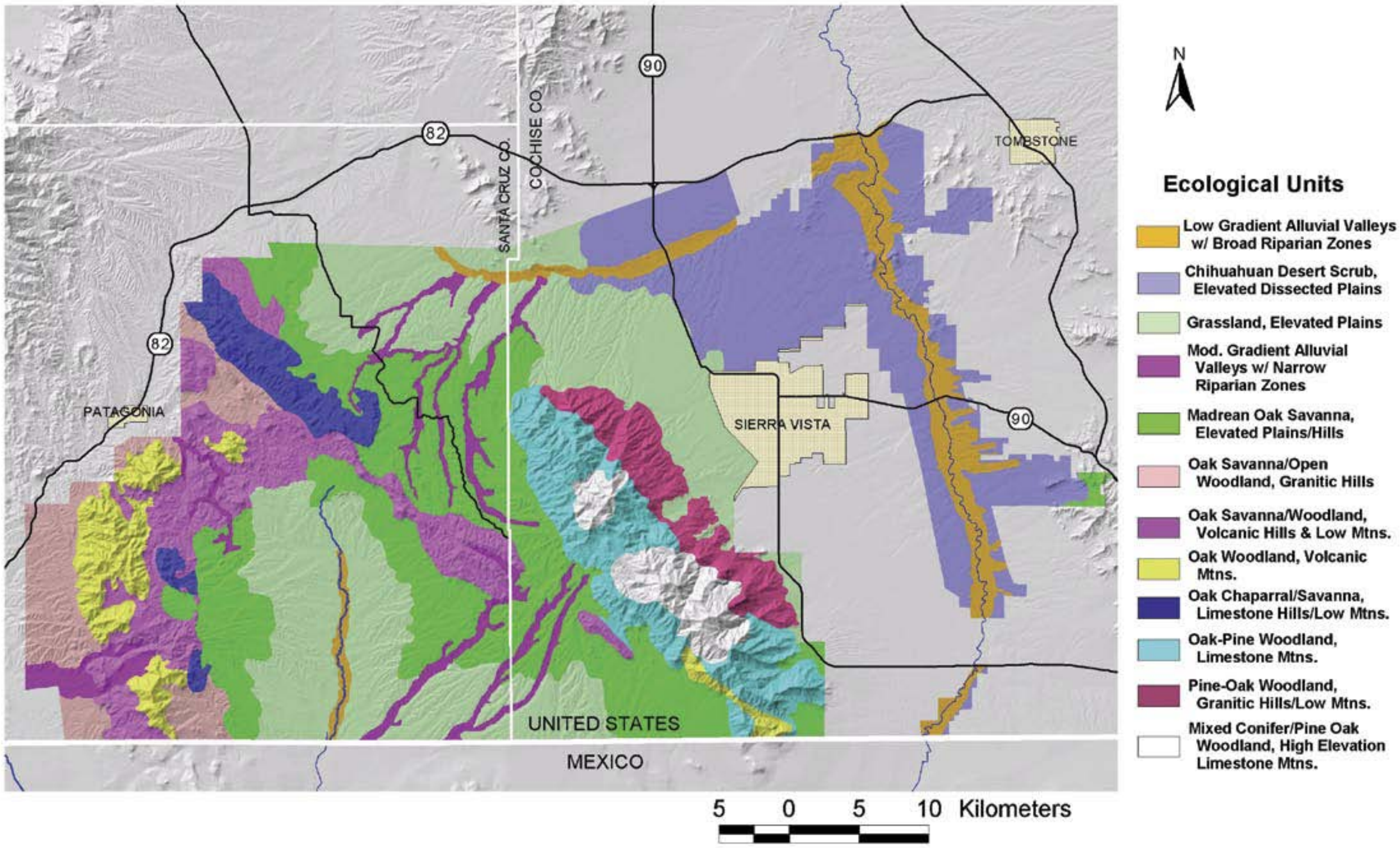

Figure 1—Interim landscape-scale ecological units of the Greater Huachuca Mountains fire planning area.

Table 1—Landscape-scale fire regime and condition class estimates for the interim ecological units.

Map unit	Current vegetation	"Historical" vegetation
1 Low gradient alluvial valleys with broad riparian zones	Riparian; sacaton with some young willow and cottonwood along Santa Cruz; galley cottonwood/willow forest along San Pedro River	Riparian: wet grass (sacaton dominated), sedges and other hydrophytic vegetation more extensive on some reaches; scattered cottonwood and willow
2 Chihuahuan desert scrub and grassland mosaic on elevated and dissected plains	Desert scrub/grass	Grass
3 Grassland on elevated plains	Grass	Grass
4 Moderate gradient alluvial valleys with narrow riparian zones	Riparian forest or scattered trees/oak savanna	Riparian forest/oak savanna—more extensive wet zone on low gradient reaches
5 Madrean oak savanna on elevated plains and hills	Madrean oak woodland/Madrean oak savanna	Madrean oak savanna
6 Madrean oak savanna and open woodlands on granitic hills	Madrean oak woodlands	Madrean oak savanna/Madrean oak open woodland (associated with rock outcrops)
7 Madrean oak open woodland and savanna on volcanic hills and low mountains	Madrean oak woodlands	Madrean oak open woodland/Madrean oak savanna
8 Madrean oak open woodland on volcanic mountains	Madrean oak woodland	Madrean oak open woodland
9 Madrean chaparral and oak savanna on limestone hills and low mountains	Madrean chaparral/oak savanna	Madrean chaparral/ oak savanna
10 Madrean oak-pine woodland on limestone mountains	Madrean oak-pine woodland	Madrean oak-pine woodland
11 Madrean pine-oak woodland on granitic hills and low mountains	Madrean oak-pine woodland	Madrean pine-oak woodland
12 Mixed conifer and Madrean pine-oak woodlands on high elevation limestone mountains	Mixed conifer/Madrean oak-pine woodland	Mixed conifer/Madrean pine-oak woodland

Soils	Disturbance processes	"Historical" fire regime	Fire regime condition class
Very deep, finer textured, high organic matter, high water tables—wet soils more extensive historically on many reaches	Beaver, floods, fire	I (0-35 years, <75% dominant overstory replaced)	Depending on reach, class 1 (within "historical range) or 2 (moderate departure due to invasive species and soil/channel degradation)
Very deep, subsurface clay, gravel and cobbles	Fire, herbivory	II (0-35 years, >75% upper layer replaced)	Class 3 (high departure due to extensive soil loss and shrub increase at expense of grasses; also exotics in some areas)
Very deep, moderate amounts of gravel and cobble, clay accumulations more pronounced in absence of lime	Fire, herbivory	II (0-35 years, >75% upper layer replaced)	Class 1 in San Raphael Valley; Class 2 or 3 in Sonoita-Elgin area and east side of Huachuca Mountains depending on extent of invasive species and shrub/tree encroachment
Very deep, generally loams and sandy loams with varying amounts of gravel and cobble	Floods, fire, beaver (on lower gradient reaches)	I (0-35 years, <75% dominant overstory replaced)	Depending on reach, class 1 or 2 (due to soil/channel degradation and exotic species)
Very deep, high gravel and cobble contents, clayey subsoils on mesas and ridge tops	Fire, herbivory	I (0-35 years, <75% dominant overstory vegetation replaced)	Mostly Class 3 (high departure due to greater tree and shrub densities and increasing prevalence of fire-intolerant species); Class 1 or moving toward Class 1 in areas of large fires (Merit and Ryan Fires)
Deep, gravelly or very gravelly sandy loams and sandy clay loams dominate, ridges tend to have clayey subsoils; bedrock control with deeper soil pockets	Fire, herbivory	I (0-35 years, <75% dominant overstory vegetation replaced)	Class 3 in areas east of Patagonia Mountains (high departure due to greater tree and shrub densities) and west of Patagonia Mountains due to added influence of uncharacteristic states of exotic grass species
Shallow, high cobble and gravel contents, sandy loam texture dominates, weakly developed	Fire, herbivory	I (0-35 years, <75% dominant overstory vegetation replaced)	Class 3 (high departure due to greater tree and shrub densities and increasing prevalence of fire-intolerant species)
Shallow, high cobble and gravel contents, sandy loam texture dominates, weakly developed, extensive rock outcrops	Fire	I (0-35 years, <75% dominant overstory vegetation replaced); II (0-35 years, >75% dominant vegetation replaced)	Mostly Class 3 (high departure due to greater tree and shrub densities and increasing prevalence of fire-intolerant species)
Shallow and very shallow, very cobbly loams, weakly developed, rock outcrops	Fire, herbivory	II (0-35 years, >75% dominant overstory [shrub] vegetation replaced)	Class 2 (moderate departure due to greater tree and shrub densities and increasing prevalence of fire-intolerant species)—trend is moderated by extremely limey soils and extensive bare ground
Shallow and very shallow, very cobbly loams, weakly developed, rock outcrops	Fire	I (0-35 years, <75% dominant overstory vegetationreplacement)	Class 3 (high departure due to greater tree and shrub densities, increasing prevalence of fire intolerant species, and replacement of understory vegetation by litter and woody debris)
Moderately deep and deep, gravelly sandy loams	Fire	I (0-35 years, <75% dominant overstory vegetation replaced)	Class 3 (high departure due to greater tree and shrub densities, increasing prevalence of fire intolerant species, and replacement of understory vegetation by litter and woody debris)
Shallow and very shallow, very cobbly loams, weakly developed, rock outcrops	Fire	I (0-35 years, <75% dominant overstory vegetation replaced)	Class 3 (high departure due to greater tree and shrub densities, increasing prevalence of fire intolerant species, and replacement of understory vegetation by litter and woody debris)

Analysis of Landscape Fragmentation in the Peloncillo Mountains in Relation to Wildfire, Prescribed Burning, and Cattle Grazing

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Abstract—*This paper examined the application of state-of-the-art remote sensing image enhancement and classification techniques for mapping land cover change in the Peloncillo Mountains of Arizona and New Mexico. Spectrally enhanced images acquired August 1985, 1991, 1996, and 2000 were combined with environmental variables such as slope and aspect to map land cover modifications using a machine learning classifier. Change-map accuracies ranged between 68% and 80%. Maximum land cover change occurred in grassland ecosystems (>25% change in cover), caused primarily by prescribed burning practices in the region.*

Introduction

Land cover is defined as the biophysical attributes of the Earth's surface, typically based on a classification system consisting of discrete classes and formulated for a specific purpose. Land cover patterns and related processes in the Southwest United States have recently received considerable attention in the conservation literature, due to the high levels of floral and faunal biodiversity in the region. In particular, the Peloncillo Mountains of southeastern Arizona and southwestern New Mexico have been the focus of long term ecosystem monitoring efforts (Rogan and Yool 2001).

Three general properties of land cover attributes affect the quantity and quality of information (signal) received by remote sensing instruments: (1) abundance (i.e., relative or absolute amount of an attribute, per amount of ground area); (2) composition (i.e., spatial and spectral properties of an attribute); and (3) condition (i.e., biophysical traits of an attribute). Therefore, alterations in any one, or all of these properties over various spatial and temporal scales may be detected as "change" (Singh 1989). Land cover change scientists are typically interested in either the magnitude (i.e., degree of modification) or direction (i.e., extent of modification) of change, or both.

Detection and monitoring land cover change across large areas are two of the most important tasks that remote sensing data and technology can accomplish. Land cover change detection, one of the most common uses of remote sensing data, is possible only if changes in the surface phenomena of interest result in detectable changes in radiance, emittance, or microwave backscatter values, which implicitly involves spatial patterns of change. The purpose of this paper is to map land cover changes, from 1985 to 2000, in a portion of the Peloncillo Mountains using state-of-the-art remote sensing data enhancement and classification techniques.

Study Area

The Peloncillo Mountains extend north/south along the Arizona-New Mexico border into Mexico (figure 1). The Peloncillos are one of a series of ranges in the Mexican Highlands section of the basin and range physiographic province (Rogan and Yool 2001).

Recently, maps of current vegetation, soils, and geology have been completed within the Malpais Borderlands area of southeastern Arizona and southwestern New Mexico (Muldavin et al. 1998; McGuire 1998; Biggs et al. 1999). Dominate vegetation types include mixed woodland, chaparral woodland, desert scrub, and mesquite scrubland (Muldavin et al. 1998). Two prescribed fires were ignited in the region: Baker Canyon in 1995, and Maverick in 1997. Other vegetation-disturbances in the region include cattle grazing and various human activities including mining and off-roading.

Data

Remote Sensing Data

Three Landsat Thematic Mapper images (August 1985, 1991, and 1996) and one Landsat Enhanced Thematic Mapper image (August 2000) were acquired for land cover characterization over a 15-year time period. Additional remote sensing

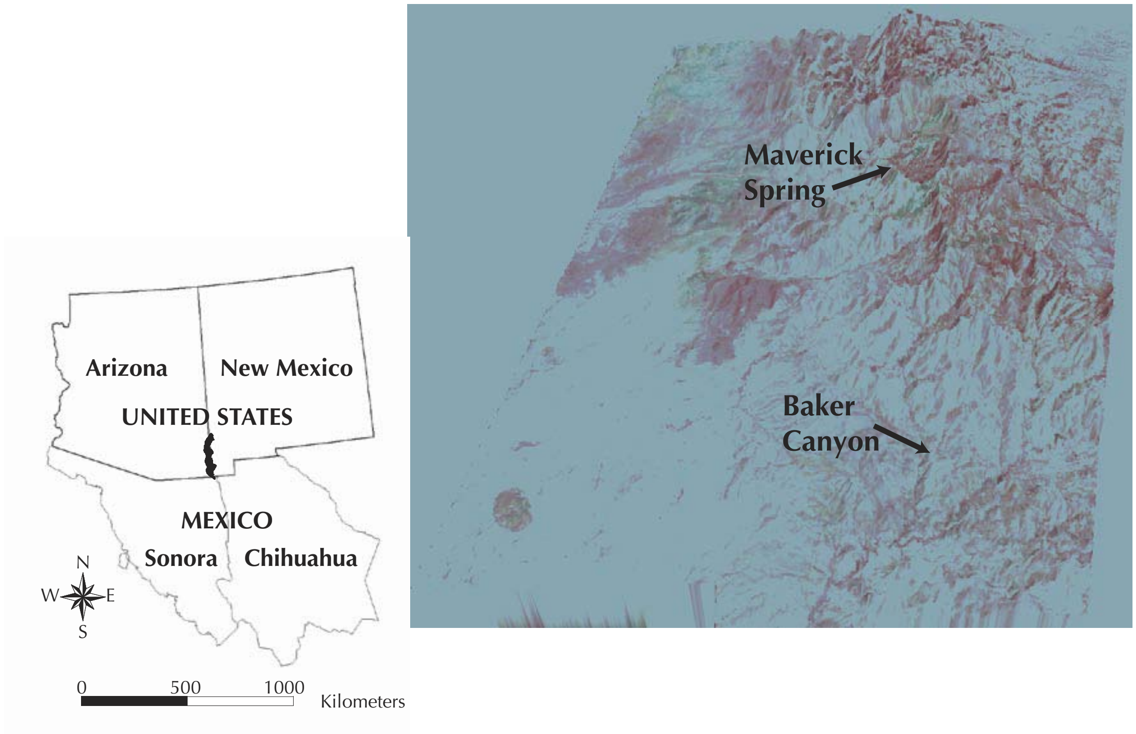

Figure 1—Location of the study area.

data included digital orthorectified photographs and hardcopy U.S. Forest Service resource aerial photographs.

Ancillary Data

Non-spectral ancillary data included a 30 m spatial resolution Digital Elevation Model mosaic that was then manipulated to produce slope and aspect spatial variables for inclusion in the change detection classification process. 60 x 60 m ground cover information was also available to aid in the change classification process. For more details on the collection of these data see Rogan and Yool (2001) and O'Neal (2004).

Methods

Image Pre-processing

Each scene was geometrically registered to the UTM WGS84 projection with an independent root mean square error of 0.4 pixels. A nearest neighbor algorithm was used to resample each image to 30 m. All images were then normalized for atmospherical illumination differences independently and converted to reflectance values using a dark object subtraction (DOS) approach described by Chavez (1989). Recent change detection studies have found the DOS approach robust for correction of atmospheric effects for change detection and mapping (Song and Woodcock 2003). Overlapping scenes in both study areas were then mosaicked and subset to the study area boundaries shown in figure 1.

Image Enhancement

In order to produce a suite of spectral features for change mapping the data sets were transformed using a Spectral Mixture Analysis (SMA) algorithm. Four endmembers were chosen for each study area because previous SMA-based change detection studies have found the dimensionality of Landsat data suited to spectral unmixing using shade, soil, green vegetation (GV), and non-photosynthetic vegetation (NPV) fractions. Further, the choice of these biophysically based endmembers helps reduce the inherent variability common in natural remote sensing scene elements. For more details on this process, see O'Neal (2004). As a result, four biophysically representative fraction images were generated for each image date in the study area and input to the classification process.

Change Map Legend

Land cover change categories used in this study are shown in table 1. This map legend describes three discrete categories of shrub canopy cover decrease and two classes of canopy cover increase. Further, a single forest cover increase and shrub decrease class is used, along with change in developed (urban) areas, and no change (+/- 15% cover change) categories. The +/- 15% class was designed to reduce the confusion caused by phenological differences between image dates and post-disturbance change classes (Rogan et al. 2003). This classification scheme was modified from that developed and in Statewide use by the U.S. Forest Service in California.

Land Cover Change Classification

Land cover change categorization was performed using an S-Plus classification tree algorithm. Classification trees are a type of MLA used to predict membership of cases or objects in

Table 1—Land cover change classification scheme.

Quantitative land cover change class
+/-15% shrub change
-71 to –100% shrub change
-41 to –70% shrub change
-16 to 40% shrub change
Forest decrease > 15%
+16 to +40% shrub change
+41 to 100% shrub change
Forest increase > 15%
Change in developed areas

the classes of a categorical dependent variable from their measurements on one or more predictor variables. Classification trees are developed using different measures to recursively split data sets into increasingly homogeneous subsets representing class membership, such as a measure of decreased deviance. All classification tree approaches employ hierarchical, non-linear recursive partitioning of the data until all pixels are uniquely identified. Classification trees are relatively easy to use, and the only user interaction required is the selection of a pruning rule, e.g., simple error rate pruning. They have a set of terminal nodes created for all classes and a path of decisions, or rules with associated input data thresholds leading to each node of the tree. All nodes have associated suitabilities or probabilities of class membership. MLAs have emerged as more accurate and efficient alternatives to conventional parametric algorithms, when faced with large data volumes and complex measurement spaces. SMA fraction images were input to the classification tree algorithm with elevation, slope, and aspect ancillary layers. The algorithm was calibrated using ground reference data, described previously, and the final change maps were validated using 20 independent validation points per image date.

Results

A comparison of the variables selected for classification in the S-Plus MLA is presented in table 2. The dominant variables used for change-class discrimination, for each time period, were GV followed by NPV and bare soil. Elevation and aspect variables were not used by any of the trees for the three time periods. The results of the change map accuracy assessment are shown in figure 2. The Kno statistic, representing percent overall map accuracy, was derived to compensate for some of the shortcomings of the kappa statistic, as Kno is not a chance-corrected measure of agreement and does not make distinctions among various types and sources of disagreement (Pontius 2000). The Kno results reveal that the 1985-1991 change map was least accurate (Kno = 68%). The 1991-1996 change map had the second highest accuracy (Kno = 72%), while the highest accuracy was achieved with the 1996-2000 data set (Kno = 80%). These results can be considered reasonable to good when one considers the number of change classed resolved, and the heterogeneity of the study area. The high accuracy associated with the 1996-2000 data set can be attributed to the fact that more ground reference data for model calibration were available for this time period.

The Kno results revealed other important information about the change maps. For example, error due to quantity (disagreement between map categories and validation points) was lower than 10% for each time period. Error due to location (disagreement between position of changed pixels and validation pixels) was lowest for the 1996-2000 time period and highest for the 1985-1991 time period. This was possibly caused by positional errors in ground reference information and/or within-pixel shifting in the geometric registration process.

Finally, the results for the proportion of land cover that underwent change over the 15-year time period are presented in figure 3. Overall, vegetation cover has not changed dramatically over the 15-year time period. Riparian areas changed least (below 5%). Grassland areas have experienced maximum change over time, especially between 1991 and 1996 when the Baker Canyon prescribed burn was ignited. Mixed woodland and chaparral vegetation types underwent intermediate land cover change (i.e., ~15%).

Conclusions

This paper examined 15 years of land cover change in the Peloncillo Mountain region using state-of-the-art remote sensing image enhancement and classification techniques. Overall map accuracies were reasonable for a change-mapping endeavor involving nine land cover change classes in a heterogeneous landscape. Machine learning classification accuracies ranged between 68 and 80%. The most important variables in mapping land cover change were the SMA-based green vegetation and non-photosynthetic vegetation fraction images. Maximum land cover change occurred in grassland ecosystems (>25% change in cover), caused primarily by prescribed burning practices in the region.

Table 2—Variables selected by the S-Plus classification tree algorithm for each time period (numeric subscript indicates the number of times the variable was used as a discriminatory variable in the classification).

Date	Shade	GV	NPV	Soil	Elevation	Slope	Aspect
1985 - 1991	X_1	X_5	X_4	X_2	-	X_1	-
1991 - 1996	-	X_5	X_5	X_3	-	X_1	-
1996 - 2000	-	X_6	X_5	X_1	-	-	-

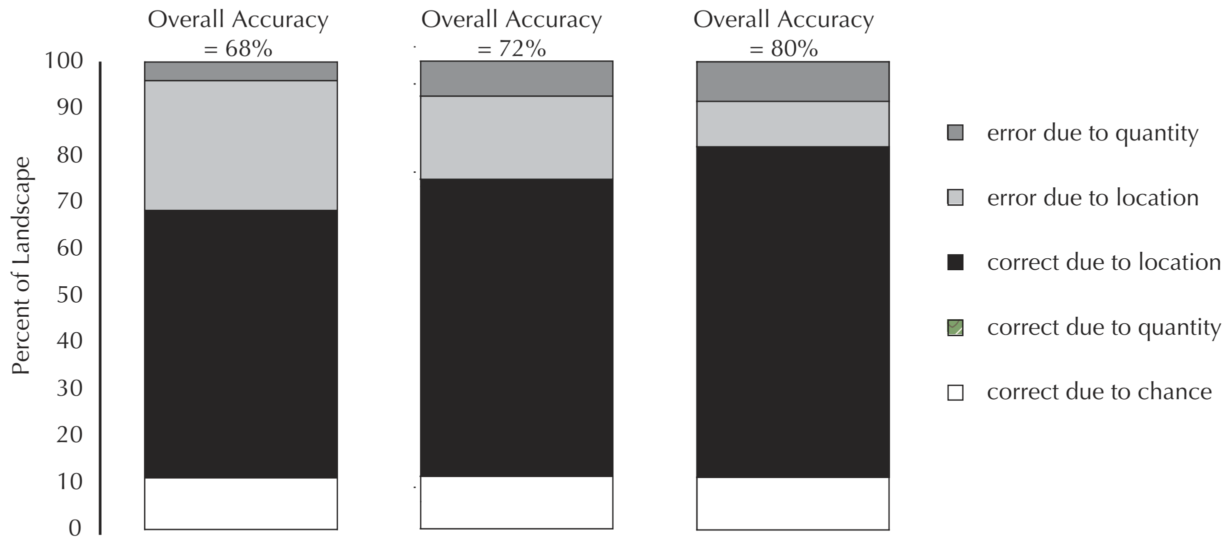

Figure 2—Kno statistic accuracy results for land cover change maps (1985-1991, 1991-1996, and 1996-2000). Contribution to both quantitative and positional errors are shown.

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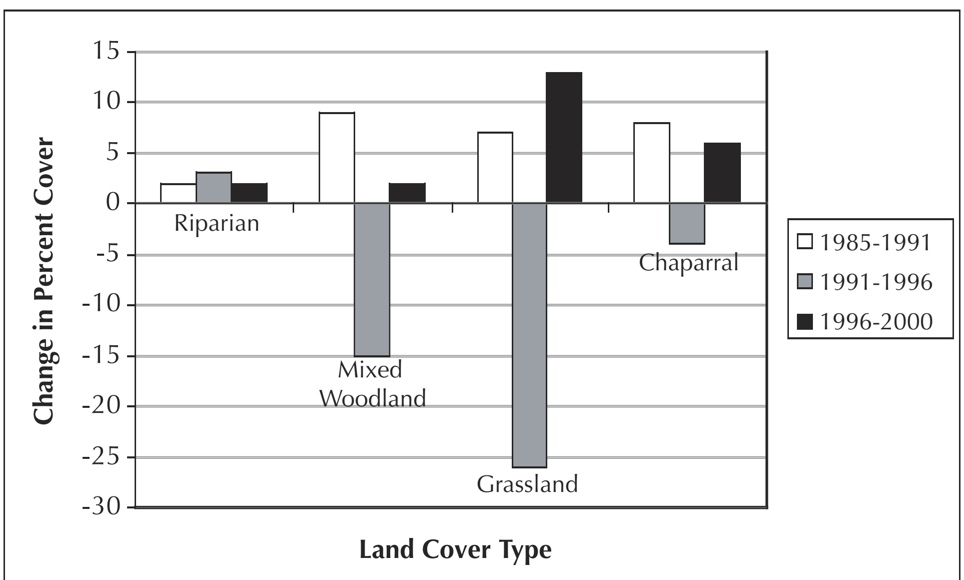

Figure 3—Percent land cover change statistics for dominant land cover types in the study area.

Ecosystem Management and Its Role in Linking Science, Policy, and Management

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Abstract—*The scientific community has recently emphasized the importance of ecological process, structure, and scale in the maintenance of biological diversity. Humans have affected most natural landscapes, and many naturally occurring processes, structures, and species may not rebound to naturally sustaining function without intervention. Ecosystem management relies on science and its transcendence into public policy to assure long-term ecosystem sustainability. This approach is defined, implemented, and understood in vastly different ways. This paper (1) summarizes ecosystem management history and intent, (2) assesses divergent interpretations of ecosystem management, and (3) offers insight into its use and effectiveness in maintaining sustainable ecosystems.*

Introduction and Historical Context

Ecology and Ecosystems

In 1935, the British plant ecologist Arthur Tansley introduced the concept of an ecosystem as "the whole system including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome—the habitat factors in the broadest sense" (Tansley 1935). This new definition departed from traditional biological sciences viewpoints that saw natural processes as separable, distinct functions. As a basis of the Evolutionary-Ecological Land Ethic, the functioning of ecosystems on broad temporal and spatial scales was later emphasized by Aldo Leopold in his classic 1949 "A Sand County Almanac." Since then, scientists have further recognized the importance of an ecosystem-level approach to wildlife management, conservation biology, population ecology, and restoration ecology (Ehrenfeld 1970, 1976; Noss 1983; Noss and Harris 1986; Noss and Cooperrider 1994; Odum 1971; Pickett etal. 1992; Soule and Wilcox 1980; Soule 1985).

Today, ecosystems are generally defined as "any unit that includes all of the organisms in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles" (Odum 1971). Instead of focusing solely on the needs of individual species, an ecosystem approach provides a better context in which to fit a broader array of species' needs within a smaller package of information. In terms of biological conservation or management, ecosystems can vary greatly in spatial scale depending upon the specific question or goal stated—they are not limited by explicit boundaries.

Management

For millennia, humankind has manipulated the natural environment to suit its needs, often with negative consequences. In conformation to Judeo-Christian philosophical underpinnings of land use (see Genesis 1:28), the production of food, fuel, and fiber has historically dominated the goals of land management. With population growth and new technological advances, timber companies traditionally clearcut forests for wood, replant the landscape with fast growing monocultures, then wait to cut the stand once again. Agriculture depends on chemicals to maximize crop yields, and rangelands are usually managed to maximize meat production. These narrowly focused management schemes benefit the consumptive needs of humans but often result in unstable ecosystem process or function, including the extirpation of species from their native ecosystems. Species loss is often attributed to habitat loss and fragmentation, disruption of disturbance regimes, stress-induced or introduced disease, pollution, and exotic species.

In addition, species perceived to hinder maximum production of goods are often purposefully eliminated. The wolf, grizzly bear, and prairie dog are victims of the deliberate hunting, trapping, and poisoning campaigns—the loss of these and other "unwanted species" has had devastating effects upon the natural composition of ecosystems (Leopold 1949; Meffe and Carroll 1997).

Wildlife management has also traditionally targeted huntable game or species that society finds endearing, beautiful, or socially important. Elk, eagles, deer, tigers, lions, elephants, and other large, charismatic species are often the focus of wildlife management (Noss 1999).

Policy

Historically, government policy and social dogma have maintained traditional views of commodity production and single species management. Government-funded campaigns in the early and mid-twentieth century effectively eliminated certain "pest" species from landscapes. The USDA Animal Damage Control (now Wildlife Services) and the now defunct Predatory Animal and Rodent Control (PARC) directed these extermination campaigns. In Arizona and New Mexico, grizzly bears were considered extirpated by 1935 and 1931, respectively (Brown 1985). PARC extermination campaigns helped extirpate wolves from these two States by the 1960s (Brown 1983). Other more subtle policies also led to the degradation of publicly owned lands (see Backiel et al. 1992), introduction of exotic species, and over utilization of croplands.

The Dawn of Ecosystem Management

In the mid-1960s and 1970s, the United States Congress began to specifically protect roadless areas (1964 Wilderness Act) and threatened or endangered species (1973 Endangered Species Act (ESA)). In addition, new laws mandated environmental review of planned actions, examination of general ecological requirements, and input from other agencies (1976 National Forest Management Act, 1969 National Environmental Review Act, and 1976 Federal Land Policy and Management Act). The ESA was the first and only law that specifically mandated the conservation of "the ecosystems upon which endangered species and threatened species depend" (Sec. 2b). While welcomed by conservationists, the ESA alarmed industry and private property rights advocates. Ostermeier (1999) points out that this reaction was based on the ESA's lack of consideration for social and economic issues. The ESA also does not provide management prescriptions for Threatened or Endangered species—it only provides very general direction.

With the dawn of conservation biology as a separate, distinct discipline in the early and mid-1980s, the linking of science, policy, and management began. The utilitarian concept, while encoded within the mission statements of public agencies, was starting to give way to a more evolutionary-ecological approach. Policy makers were seeking more consensus-based law, managers were hungry for more effective techniques, and scientists were trying to supply policy makers and managers with better information.

The term "ecosystem management" first appeared at a 1987 conference hosted by the University of Washington, the USDA Forest Service, and the National Park Service and was coined as "regulating internal ecosystem structure and function, plus inputs and outputs, to achieve socially desirable conditions" (Agee and Johnson 1988). Noss (1999) summarizes definitions below:

…the conservation and stewardship of large areas of land or water containing multiple species, habitats, resources, and (often) ownerships (Noss 1999).

…integrating scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term (Grumbine 1994).

…the goal of the ecosystem approach is to restore and sustain the health, productivity, and biological diversity of ecosystems and the overall quality of life through a natural resource management approach that is fully integrated with social and economic goals (Interagency Ecosystem Management Task Force 1995).

…a resource management system designed to maintain or enhance ecosystem health and productivity while producing essential commodities and other values to meet human needs and desires within the limits of socially, biologically, and economically acceptable risk (American Forest and Paper Association 1993).

A comprehensive definition of ecosystem management comes from "The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management." The authors of this 1996 article first state that ecosystem management is ".... driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem composition, structure, and function." The authors then further define ecosystem management as possessing (taken from Christensen et al. 1996):

Sustainability. Ecosystem management does not focus primarily on "deliverables" but rather regards intergenerational sustainability as a precondition.

Goals. Ecosystem management establishes measurable goals that specify future processes and outcomes necessary for sustainability.

Sound ecological models and understanding. Ecosystem management relies on research performed at all levels of ecological organization.

Complexity and connectedness. Ecosystem management recognizes that biological diversity and structural complexity strengthen ecosystems against disturbance and supply the genetic resources necessary to adapt to long-term change.

The dynamic character of ecosystems. Recognizing that change and evolution are inherent in ecosystem sustainability, Ecosystem management avoids attempts to "freeze" ecosystems in a particular state or configuration.

Context and scale. Ecosystem processes operate over a wide range of spatial and temporal scales, and their behavior at any given location is greatly affected by surrounding systems. Thus, there is no single appropriate scale or timeframe for management.

Humans as ecosystem components. Ecosystem management values the active role of humans in achieving sustainable management goals.

Adaptability and accountability. Ecosystem management acknowledges that current knowledge and paradigms of ecosystem function are provisional, incomplete, and subject to change. Management approaches must be viewed as hypotheses to be tested by research and monitoring programs.

Concurrently, Grumbine (1994) delineated ecosystem management themes: hierarchal context, ecological boundaries, ecological integrity, data collection, monitoring, adaptive management, interagency cooperation, organizational change, humans embedded in nature, and values.

Today, almost every land management agency within the United States has adopted ecosystem management into its planning and regulatory activities. In 1992 at a Congressional hearing, Forest Chief Dale Robertson stated "Ecosystem management means that the Forest Service will use an ecological approach to achieve multiple-use management of the National Forests and Grasslands by blending the needs of people and environmental values to sustain diverse, healthy, and productive ecosystems. We will combine our scientific knowledge and experience about patterns of relationships among organisms and their environment with the 'land wisdom' of people from the many sectors and cultures of our society to care for the land and serve the people." The BLM, Natural Resources Conservation Service, U.S. Fish and Wildlife Service, and others have similarly followed suit.

One criticism of ecosystem management policy is that it may facilitate neglect of single species conservation requirements (Goldstein 1999). Definitions of ecosystem management are fuzzy and leave much to interpretation. Nevertheless, the integration of such principles, as general as they may be, into public policy and lands management elucidates the shift from strictly utilitarian-based management to an evolutionary – ecological land ethic.

Discussion

Today, commodity-based industry emphasizes the integration of human needs in ecosystem management while conservationists stress ecological preservation aspects. Policy makers and practitioners stand at the sidelines trying to figure out which way the ball is rolling. Yaffee (1999) describes three different conceptualizations of ecosystem management that fit into the general boundaries described above:

Environmentally sensitive, multiple-use management. Realizing that traditional land management practices often failed to produce desired conditions or precipitated unwanted effects, industry, agriculturalists, and certain land management agencies find that managing lands within their ecological tolerances will result in more sustainable yields of goods and services.

Ecosystem-based approaches to resource management. Ecosystem management prescribes deeper understanding and explicit goals for improving the ecological integrity of lands. Often, whole ecosystems are not managed, but they influence planning activities, restoration methods, and collaborative communications with neighboring landowners/managers.

Ecoregional management. Projects such as Yellowstone to Yukon, The Sky Islands Wildlands Network (see Noss 1992), or other ecoregional plans emphasize restoring landscape-level processes, connections, and species compositions. Success depends on policy and management changes that better fit within a larger, ecoregional perspective.

People, however, are still part of the equation. Noss (1999) eloquently states, "a science based approach is not one that ignores other concerns, such as socioeconomic and cultural issues. Rather, it permits reasoned discussion of such concerns against a backdrop of ecological reality." Ecosystem management clearly implies that collaboration and communication among interested parties is essential in promoting a more unified approach to managing landscapes on larger spatial and temporal scales. If this collaborative effort is to be successful in on-the-ground improvements of ecological components, science must not be simply an equal opinion among others, but the basis from which to start from.

Conclusion

While ecosystems and ecosystem management are relatively new terms to policy makers, managers, and even ecologists, the fundamental concepts that these terms convey are popular and in-demand at all levels of biological conservation and management. Due to the inadequacy of traditional methods for approaching land management issues, ecosystem management has quickly risen as an answer to policy formation and land management decisions. The ambiguity of ecosystem management has resulted in different interpretations that sometimes conflict with one another, but the general theme of such management looks to forming a basis for how ecological processes and components are approached, and to defining the context surrounding sustainable human uses.

It is paramount that ecosystem management retain and grow its roots within the foundation of science. Scientists bear the heavy burden of clearly defining ecosystem management parameters, while taking into account social and economic considerations. Policy makers must realize that while ecosystem management may bring them more consensus-based, collaborative ideas on how policy might best serve the public, there are bottom lines that cannot be breached if true ecological sustainability is to be realized. Practitioners, land managers, and the public must realize that while ecosystem management will solicit their ideas for inclusion into the political and scientific formulation of land practices, there are also limitations to the flexibility of the land. Ecosystem management has the potential to become a highly effective vehicle for linking science, policy, and management. How effective it becomes will decided on how willing scientists, conservationists, policy makers, industry, and practitioners are to use a new science that incorporates, to varying degrees, information from a wide variety of interests above a foundation of scientific principle.

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Environmental Change at Kartchner Caverns: Trying to Separate Natural and Anthropogenic Changes

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***Abstract**—Cave temperature and moisture levels are important factors in the environmental health of Kartchner Caverns. Monitoring indicates the cave has warmed and moisture levels have fallen over the past 14 years. Timing and patterns of change within the cave suggest that changes are due to development as a show cave. However, changes in other caves, surface temperature and precipitation, and in shallow local aquifers suggest that cave changes relate to regional patterns. Changes at Kartchner Caverns represent a combination of anthropogenic and regional natural causes. Separating these different factors is an important on-going goal in protecting the cave.*

Kartchner Caverns State Park (KCSP) is a show cave in southeastern Arizona. The cave was discovered in 1974 and became a State Park in 1988 (Tufts and Tenen 1999). After pre-development studies to assess the condition of the cave, to establish baseline data, and to determine how best to develop the cave, Arizona State Parks began development of the cave for ecological education and tourism. The development included creating tunnel entrances to the cave, building trails for tours, and installing a lighting system. In November 1999 tours began in the Rotunda-Throne Room section of the cave. Development of the Big Room section of the cave continued until November 2003 when it opened. Since 1999 approximately 750,000 people have toured the cave. One of the primary goals during the development of Kartchner Caverns was to develop it in as ecologically sensitive manner as possible (Travous and Ream 2001).

Caves often house extremely sensitive ecosystems. Small changes in the temperature, humidity, water quality, nutrient inputs, or other environmental parameters can lead to major, potentially detrimental, changes to how a cave functions. Kartchner Caverns is a wet cave with dripping and pooling water, periodic flooding, and high ambient humidity. This water is crucial to maintaining the cave environment, the growth and appearance of cave formations, and possibly the vitality of the *Myotis velifer* maternity colony in the cave. In an arid environment, such as the one in which Kartchner Caverns occurs, caves can be especially sensitive to environmental changes. If development of Kartchner Caverns caused a significant increase in the exchange of cave air and the outside air, the cave could dry out. Because of concern for this possibility, the cave microclimate was studied prior to development (Arizona Conservation Projects, Inc., 1991; Buecher 1999) and has been monitored through development and operation (Toomey 2003). A variety of cave microclimate parameters have been studied at Kartchner Caverns. This paper will focus on cave air temperature and relative humidity data collected at Kartchner Caverns. These parameters have been consistently monitored, are available for several caves near Kartchner Caverns, and are relatively easily interpreted.

The primary long-term temperature and humidity data from the cave come from Environmental Monitoring Stations (EMS) within the cave (figure 1). These are locations at which air, water, and soil temperature, relative humidity, and pan evaporation are measured manually on a periodic basis, usually weekly or monthly. Temperatures are measured with small, digital probe thermometers; relative humidity is measured using a digital probe thermometer equipped as a sling psychrometer. During pre-development studies Arizona Conservation Projects, Inc., personnel took measurements; since those studies ended, Arizona State Parks personnel have continued to monitor these stations. The EMS dataset is the most complete microclimate dataset for the cave. In addition, the temperature readings from these stations are all calibrated against a single master mercury thermometer that has been used since the beginning of Kartchner Caverns studies. The use of this calibrated dataset eliminates problems from varying instruments and instrument drift.

Measurements from the stations show that the cave has warmed and dried since monitoring began in 1989. The largest change is found at stations in the Rotunda-Throne area of the cave such as the Lower Throne EMS (figure 2). The data from Lower Throne shows an approximately 4 ºF rise in temperature between the beginning of 1997 and the present. The temperature rise peaked with a running mean of approximately 71.9 ºF early in the summer of 2004. This temperature is approximately 4.5 ºF degrees warmer than the pre-development levels in the same area. However, the trend has reversed slightly since that peak and the mean temperature at the station is now around 71.6 ºF. Accompanying the temperature increase at this station is a decrease in humidity. Between 1989 and the end of 1996 the humidity at the station had a mean of 99.43% (standard deviation 0.71%). For the period from the beginning of 1997 through early 2004, the humidity at the station was generally lower and more variable (mean 97.45%, standard deviation 1.32%). The difference in the humidity between two periods (1989-1996 and 1997-2004) is highly significant statistically (unpaired, one-tailed, heteroscedastic, t-test probability $P \ll 0.00001$).

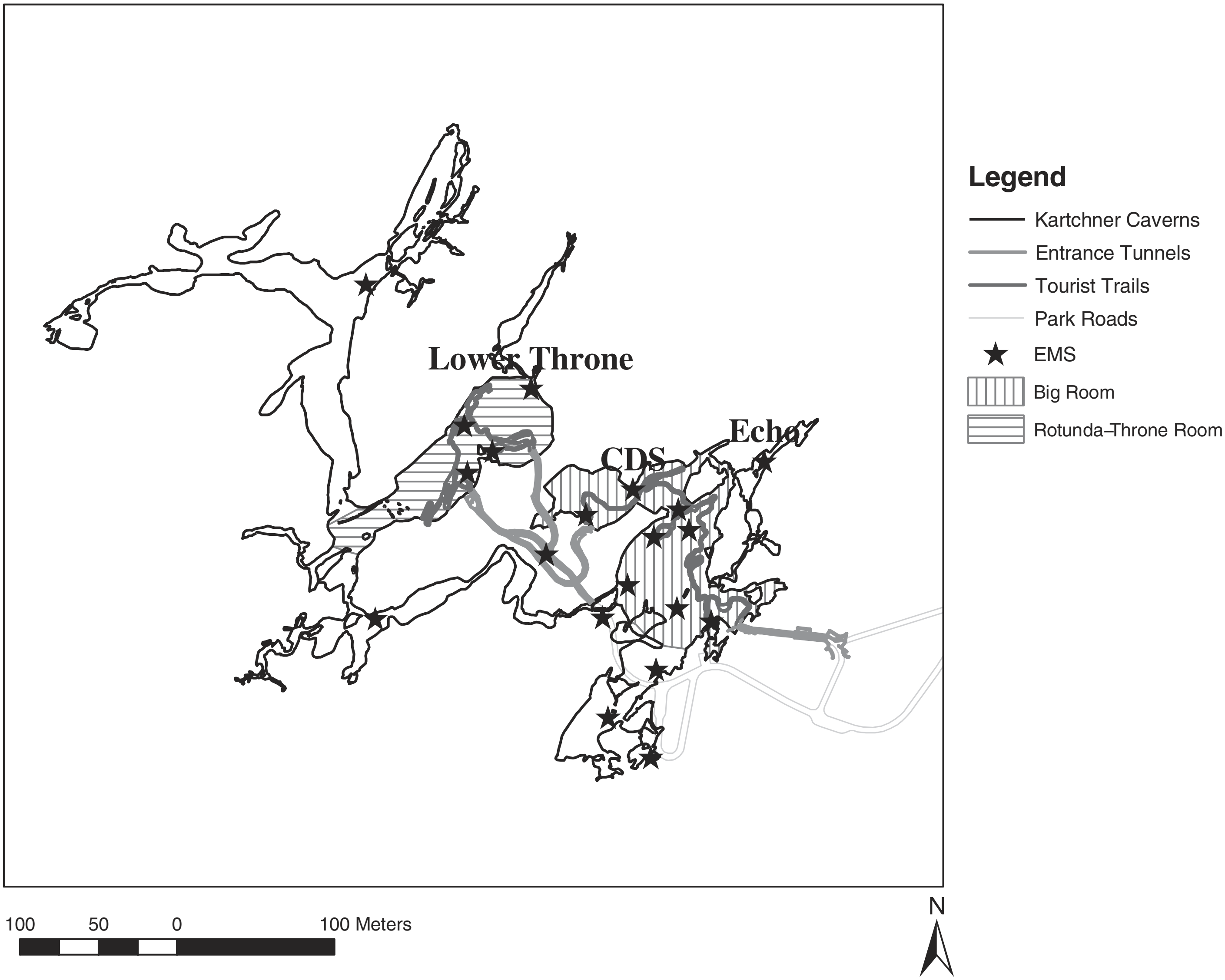

Figure 1—The location of Environmental Monitoring Stations for cave microclimate in Kartchner Caverns. Three stations are labeled with their names: Lower Throne, Echo, and Cul De Sac (CDS).

These data and those from other stations indicate recordable and statistically significant climate change in portions of the cave that coincide with the show cave development and cave tour operations. At this point, data from the most developed and high-traffic areas demonstrate larger changes than data from areas peripheral to human use (figure 3). However, at least some change is evident in all monitored areas of the cave. For the continued management of the cave, understanding the source of the observed temperature and humidity changes is vital.

Two basic classes of mechanisms (or a combination of them) may be responsible for the changes observed in the cave. The first class would be anthropogenic (human generated) causes related to the development of the cave. This class would include various factors that increase the amount of energy in the cave and thus raise the temperature and increase evaporation of available water. Among these factors would be metabolic heat generated by humans while in the cave, heat from the lighting systems used in the cave, and heat from the hydration of concrete. Anthropogenic causes could also include changes that affect the airflow in the cave to either increase temperature or allow the loss of moisture. This could include leaking of air through airlocks and tunnels.

The second class of mechanisms would be local, regional, or larger scale natural factors, changes, and trends that may be reflected in the microclimate of the cave. These factors, changes, and trends may include regional warming and major droughts.

Identifying the influence of each class of mechanisms at Kartchner Caverns is important for understanding the changes and to determine future courses of action. Several approaches to data analysis can be combined to help determine whether regional climate change, anthropogenic changes related to development, or both are responsible for the changes in temperature and moisture.

The first approach is to examine patterns within the Kartchner Caverns data to see if they are consistent with any one cause. Using this approach alone suggests that development is overwhelmingly the cause of the observed changes.

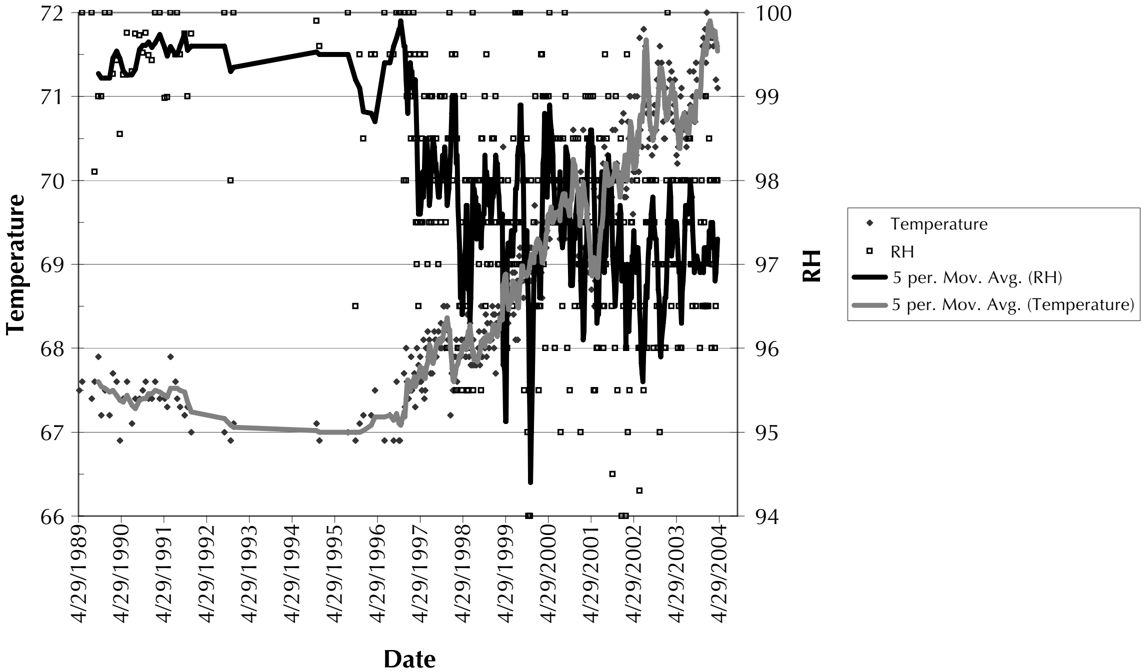

Figure 2—Air temperature and relative humidity as measured at the Lower Throne Environmental Monitoring Station. Points are individual weekly measurements. The lines show five-measurement moving averages.

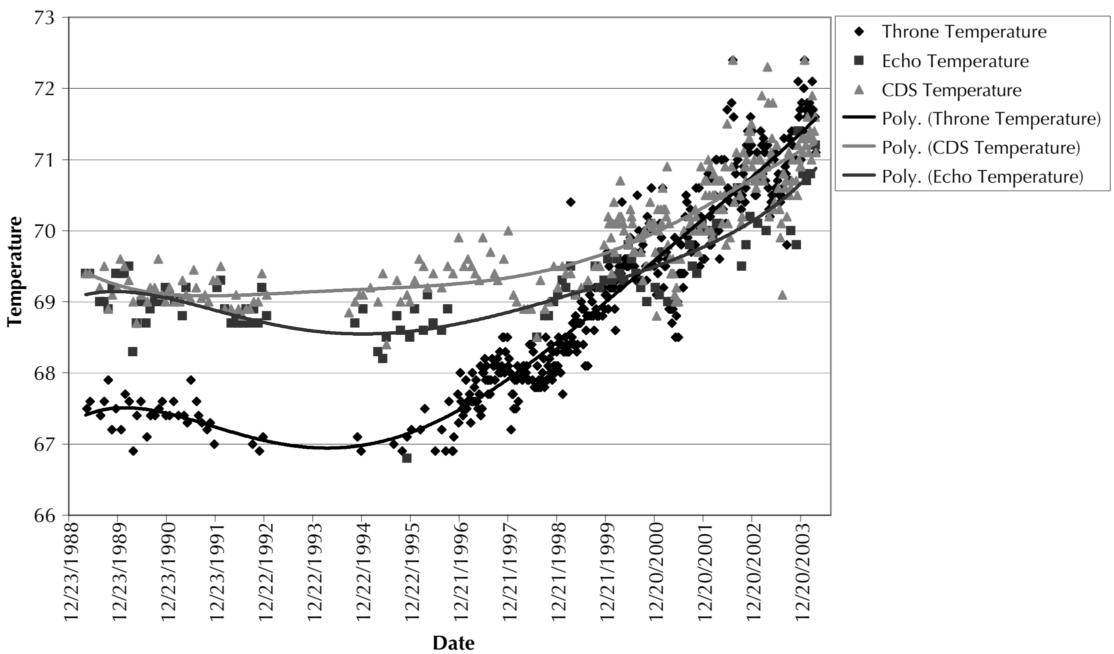

Figure 3—Temperature change at three Kartchner Caverns Environmental Monitoring Stations. The Throne station is in the Rotunda-Throne section, which has been toured since 1999. The CDS station is near the Big Room tour route, along which tours began in 2003. The Echo station is off the tour routes in an undeveloped section of the Big Room. Note the differences in the amount and timing of warming in the different areas.

The timing of the changes corresponds with the timeframe of development. That is, the changes seem to start at about the same time the tunnels were completed and subsequent development ramped up (figure 2 and 3). In addition, the pattern of change, with larger amounts of change in more developed areas, also supports the conclusion that the observed changes are related to development (figure 3). Toomey (2002) basically came to this conclusion.

However, if we also compare the data from Kartchner to a larger regional dataset and to other lines of evidence, the conclusion is a bit more complicated than presented in Toomey (2002). A small regional dataset of temperature measurements from four caves and humidity measurements of two of them provides some comparison data. In addition, water levels from four wells near Kartchner Caverns and the temperature data from the KCSP weather station also provide useful information. These datasets indicate that at least some (perhaps most) of the climate change observed in the Kartchner Caverns record is probably related to regional climate patterns.

Jerry Trout (National Cave Program Manager, USDA Forest Service) provided temperature and humidity data from four caves on the Coronado National Forest, southeastern Arizona. These caves are Whetstone Cake Cave #1, Whetstone Cake Cave #2, SP Cave, and Cave Mine Cave, which are all located within 35 miles of Kartchner Caverns. Whetstone Cake Cave #1 and #2 are small caves (300-450 feet long) with relatively large entrances in the Whetstone Mountains above Kartchner Caverns State Park. Although they are not particularly good analogues to Kartchner Caverns, because their small size and large entrances result in large seasonal differences in temperature, they do provide data from undeveloped caves that are quite near the park. Cave Mine Cave and especially SP Cave are much better analogues for Kartchner Caverns. Each is a relatively extensive, undeveloped cave. They are located in the Huachuca Mountains near Sierra Vista.

The Forest Service has been collecting limited data on these four caves for approximately 13 years. This data consists of quarterly to semiannual temperature readings in each cave. In addition, relative humidity was measured in both Cave Mine Cave and SP Cave quarterly to semiannually. These data were not all taken by the same people or with the same instruments. However, the data comprise the best long-term cave data for comparison with the Kartchner Caverns data.

The data from the two Whetstone Mountains caves demonstrates a warming trend over the past 13 years. The mean annual temperature for each has warmed between 3 and 4 ºF between 1991 and 2002 (figure 4). The data from the Huachuca Mountains caves also show warming over the past 15 years (figure 4). SP Cave shows about 2 ºF warming, and Cave Mine Cave shows about 1.5 ºF. The warming in these four undeveloped caves is similar to that seen in Kartchner Caverns.

Like the temperature record, the relative humidity records from SP Cave and Cave Mine Cave indicate that some undeveloped caves in the region show climate change similar to that seen at Kartchner Caverns (figure 5). Since 1990, the humidity measured in SP Cave has decreased to a similar degree as that measured in the Echo Passage. The humidity in Cave Mine

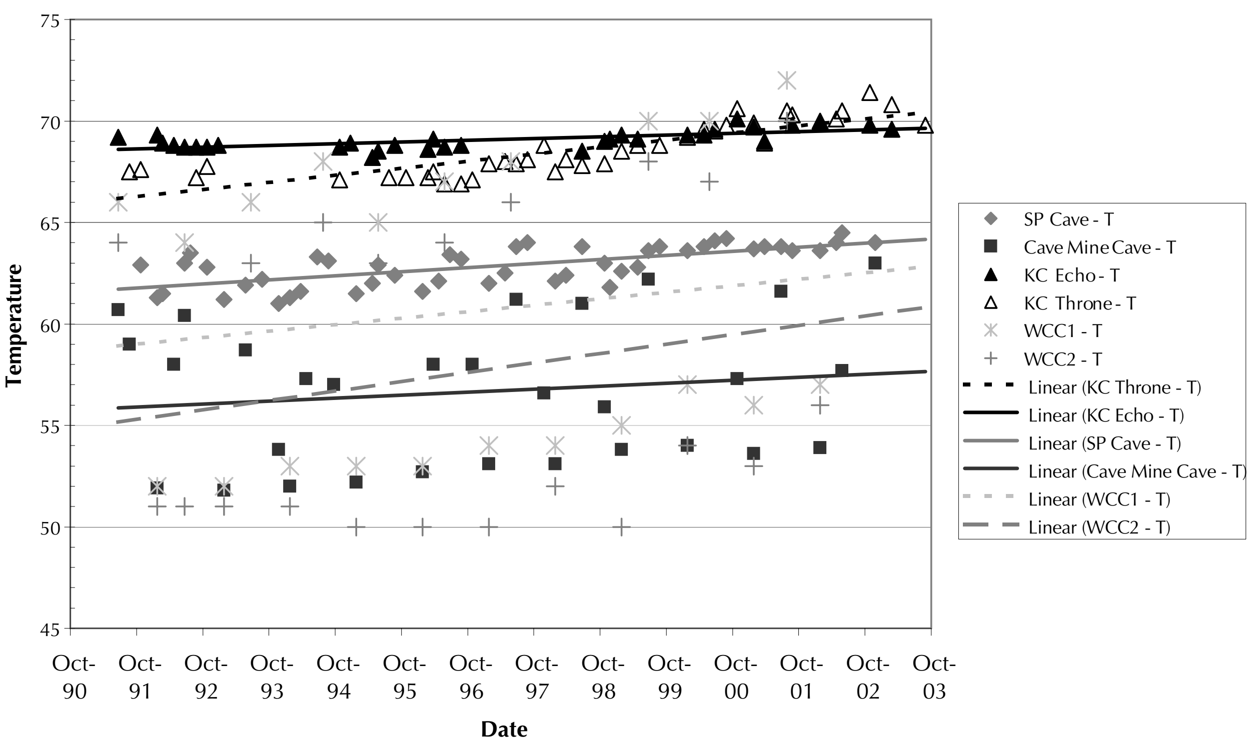

Figure 4—Temperature (and linear least squares best-fit lines for the temperature) of SP Cave (Huachuca Mountains), Cave Mine Cave (Huachuca Mountains), Whetstone Cake Cave 1—WCC1 (Whetstone Mountains), and Whetstone Cake Cave 2—WCC2 (Whetstone Mountains). A portion of the temperature data from the Echo Passage EMS and Lower Throne EMS at Kartchner Caverns is also shown for comparison.

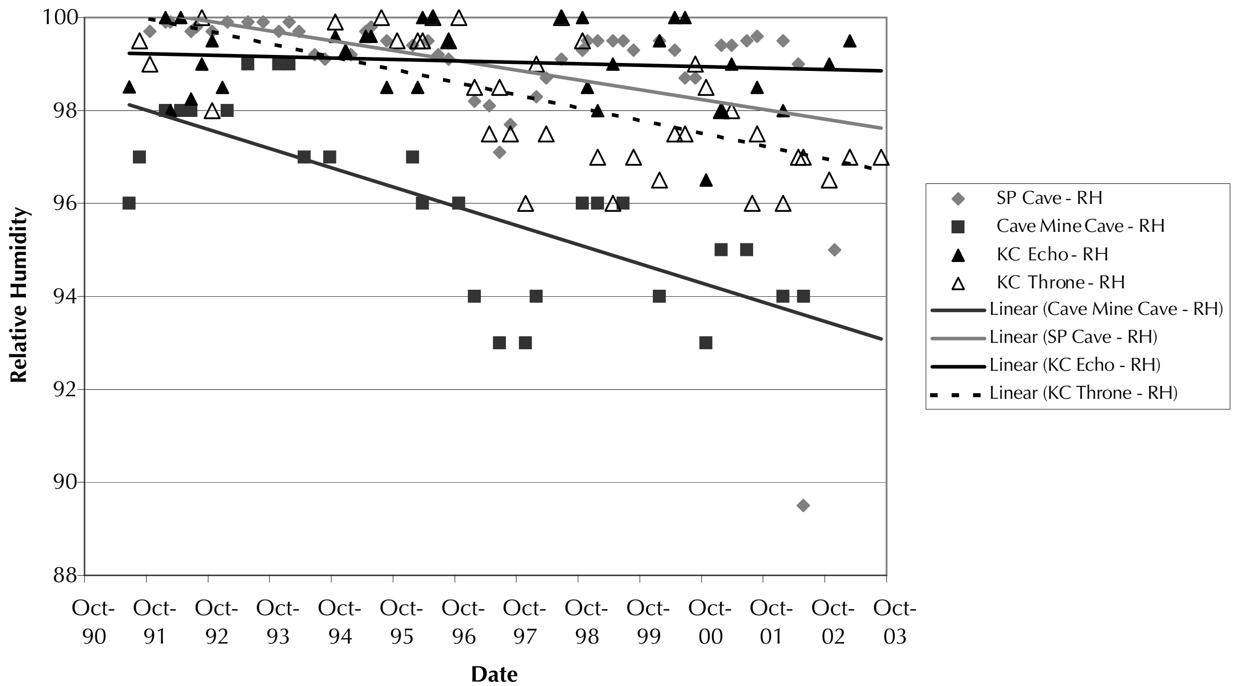

Figure 5—Humidity (and linear least squares best-fit lines for the humidity) of SP Cave, Cave Mine Cave, and the Echo Passage EMS and Lower Throne EMS at Kartchner Caverns.

Cave has decreased to even a greater degree than the humidity in the Lower Throne Room area of Kartchner Caverns.

Additional evidence of regional cave drying comes from Arkenstone Cave (Rincon Mountains, Pima County, AZ). Pool levels in the cave have been consistently falling over the past three years. The drying appears to be in response to regional drought (William Peachey, personal communication, 2003).

An additional useful dataset for evaluating humidity and temperature change in Kartchner Caverns is water levels in wells on and near the park. The wells measure the level of the ground water in several small, shallow aquifers in the area surrounding the cave. In particular, shallow, unpumped wells that sample water levels in the near-surface ground water systems around the cave provide useful information. These wells are not in the same perched aquifer as the cave; however, they still record the general area ground water responses to climate change. Because the cave water, including humidity, mud, and pooled water, is a portion of the local ground water system, regional changes reflected in the wells may also affect the cave. If the cave showed significant drying while the rest of the groundwater system did not, it would be reasonable to attribute the drying to causes other than regional climate response. However, as figure 6 shows, this is not the case. The water level in all wells has been generally falling since 1996. The water levels track the general drought conditions in the area fairly well as shown by the Palmer Drought Severity Index data in the graph. Like the changes at SP Cave and Cave Mine Cave, this evidence suggests that the drying in the cave is, to at least some extent, the result of regional climate conditions.

An additional dataset that provides some information on possible regional ties to climate changes observed at Kartchner is the surface climate data for the park. The surface temperature of the area, as reflected by the mean daily temperatures recorded at the park's weather station between 1989 and 2003, has increased by about 3 ºF (figure 7). Kartchner is not unique; National Weather Service data from Sierra Vista shows about 2 ºF increase while that from Tombstone exhibits about 1 ºF increase over the same period. The rise in the surface temperature in the area is potentially significant to understanding climate change in Kartchner Caverns. Although the temperature at Kartchner Caverns does not directly reflect the mean annual surface temperature (it is a few degrees higher than the surface mean annual temperature), it would be reasonable to expect that a rise in mean annual surface temperature to be reflected in a rise in the cave temperature.

Together, the data on Kartchner Caverns' climate change from the cave itself and from other regional data sources suggest that the climatic shifts seen at Kartchner Caverns are the result of both regional climate factors (probably a combination of both temperature increase and drought) and development-related activities (such as lights, tourists, and modification of airflow). Although the regional datasets indicate a strong regional signal for the cave, the pattern of variation within the cave shows that a development signal is also present.

Determining the extent to which the changes observed at Kartchner Caverns are caused by development-related causes rather than regional climate changes is more than an academic exercise. Many management decisions depend on understanding that balance. As Arizona State Parks tries to preserve the cave environment, many actions may help mitigate the changes. For example, misting in the cave with local well water may add moisture to the air to either compensate for increased temperature or moisture loss. However, mitigating natural changes could easily interfere with the natural function of the cave and would not be desirable. Understanding the balance

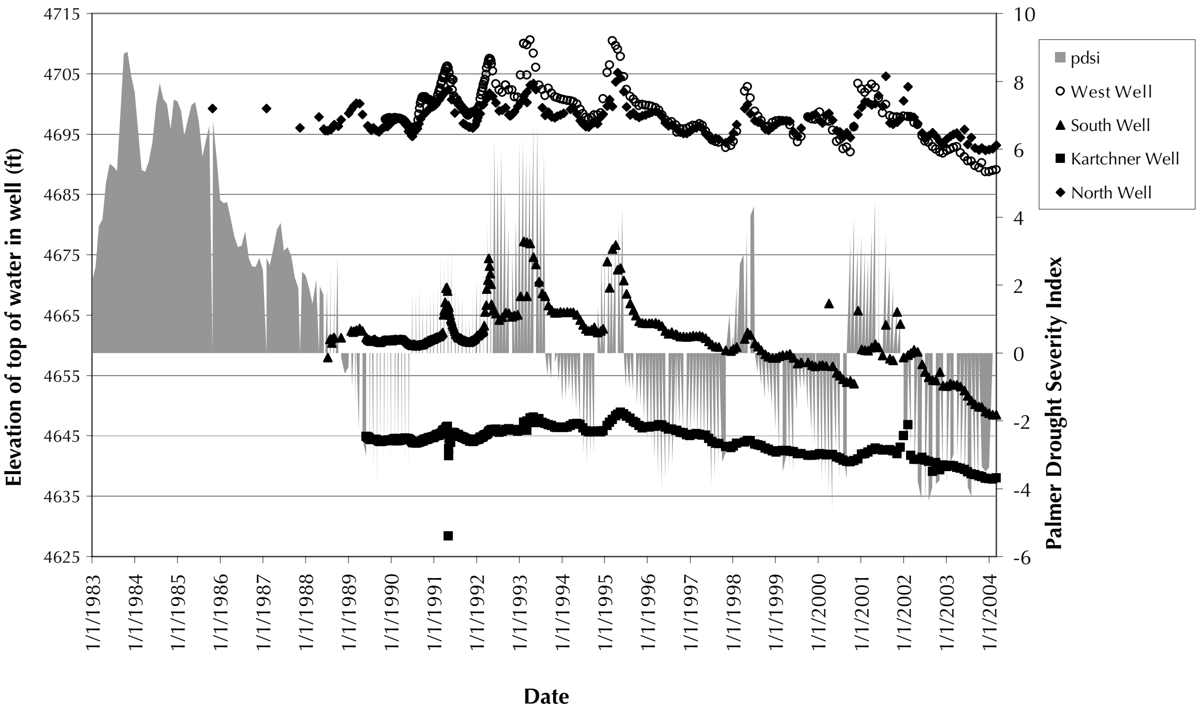

Figure 6—Water levels in unpumped wells around KCSP. These static levels represent the elevation of ground water in the well. Generally speaking, the higher the elevation in each well the more water within the aquifer. As levels fall, this represents less water stored in the aquifer. In addition, the graph shows the monthly Palmer Drought Severity Index (PDSI) for southeastern Arizona (NOAA-NSW AZ Region 7). The PDSI is an index of regional moisture conditions. Negative values indicate a moisture deficit; positive values indicate a surplus. Values below about –2 indicate significant drought conditions; values greater than about 3 indicate very moist conditions.

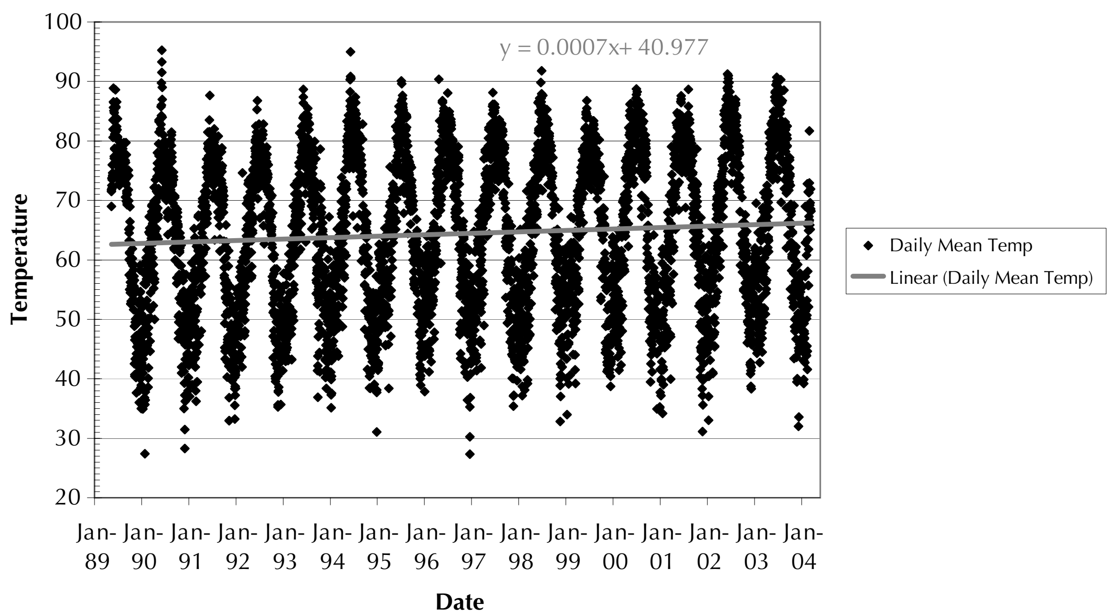

Figure 7—Mean daily temperatures (and linear least squares best-fit line) measured at Kartchner Caverns State Park weather station. The best-fit line demonstrates a trend toward rising surface temperatures at the park over the last 15 years.

of natural and anthropogenic changes will allow managers to make the correct decisions on how to address changes in cave environment.

Continued study and an expansion of regional monitoring networks will be necessary to better understand the roles of anthropogenic and natural regional changes in the warming and drying at Kartchner Caverns. An important by-product of this research will be developing datasets on cave climate that will help address related issues such as bat habitat requirements and regional patterns of climate change.

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We would like to thank Joanne Roberts (Arizona State Parks), J. Judson Wynne (USGS-BRD), and William D. Peachey for suggestions that greatly improved the manuscript. Jerry Trout (USDA Forest Service) kindly provided data on Coronado National Forest Caves. We would also like to thank the Cave Unit at Kartchner Caverns for their work collecting Kartchner environmental data.

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Cultural Resources/ History

Natural Setting as Cultural Landscapes: The Power of Place and Tradition

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Abstract*—The natural environment of the Madrean Archipelago comprises a mosaic of cultural landscapes. Throughout human history, people have imbued the natural environment with meaning by layering cultural values and historic contexts onto the natural world, allowing them to situate themselves in time and space. Cultural landscapes contain special places that have power associated with important events, people, or critical resources. Effective conservation and management of the Madrean Archipelago require an understanding of the complexities and intricacies of the storied cultural landscapes layered upon the natural environment.*

Natural Setting and Cultural Landscapes

The Madrean Archipelago is a natural wonder, encompassing a unique diversity of landforms and life. It is, quite understandably, a focus of much environmental research and management by a variety of government agencies and private sector organizations. Almost all this research and management is conducted within a scientific framework, bringing with it a set of prescribed constructs and values. In effect, the scientific framework provides the individual scientist viewing the natural setting with his or her cultural landscape, in which meaning is ascribed to the natural environment.

The Madrean Archipelago has been the home of many peoples over the past 13,000 years, all of whom have projected their own constructs and values onto the natural environment. While we cannot know what past peoples believed and what values they held, their descendants encapsulate fragments of this knowledge in present-day cultural and oral traditions. These descendant American Indians bring constructs and values to the Madrean Archipelago that imbue the natural setting with meanings different from those of us with scientific training.

It is our impression that few scientifically trained researchers and managers are cognizant of American Indian cultural landscapes within the Madrean Archipelago. We believe that an appreciation of these cultural landscapes will inform and enrich natural resources research and management, thus encouraging a more holistic approach to conserving this unique region.

For humans, as for other life forms, water is a critical resource. Not surprisingly, archaeologists find that most ancient habitation sites in the Madrean Archipelago are situated along the rivers and at other hydrologically advantageous locations. The San Pedro Valley is no exception. Because so many archaeological sites are located along river courses, and because the conservation of biodiversity in the Madrean Archipelago includes the critical river corridors, there is substantial locational overlap in central components of the cultural landscapes of ecologists, environmentalists, archaeologists, and American Indians. This is not to say that river valleys are the only overlap in these varied cultural landscapes, as mountain ranges and other places have importance in all these perceptions of the Madrean Archipelago. It is fair to say, however, that rivers have a special place in these various cultural landscapes. It is also fair to say that any natural resources research or management along the river corridors is highly likely to impinge upon cultural resources and the cultural landscapes within which these resources play a pivotal role.

In this paper we present some theoretical, methodological, and practical results of a recent three-year long cultural landscapes project conducted in the San Pedro Valley in collaboration with the Tohono O'odham, Hopi, Zuni, and the San Carlos and White Mountain Apache Tribes (Ferguson et al. 2004a,b). This research was funded and facilitated by The National Endowment for the Humanities, the Salus Mundi Foundation, and the Center for Desert Archaeology.

The cultural landscapes of the Tohono O'odham, Hopi, Zuni, and Western Apache incorporate vast geographical areas and considerable time depths. While each group has its own unique cultural landscapes with varied geographical areas and temporal ranges, the San Pedro Valley is a common element linking them all. The natural setting of the San Pedro Valley, consisting of its terrain and biota, provides the canvas upon which mythical and historical events are perceived and situated. Some of these events are understood as creating elements of the land itself, while other events produced the material culture of past people, what we today call the archaeological record. All of these events, whether natural or cultural, form palimpsests of history—the cultural landscapes that are layered throughout the San Pedro Valley. These landscapes consist of a rich tapestry or mosaic of space, time, and cultural traditions.

Conceptually, cultural landscapes encompass both the land itself and how individuals perceive the land given their particular values and beliefs. Cultural landscapes are fashioned by cultural groups from the natural environment. As Carl Sauer (1963: 343), a prominent geographer, has noted, "culture is the agent, the natural area is the medium, the cultural landscape is the result." Cultural landscapes have complexity and power as a result of their creation by people through experience and encounters with the world. People understand cultural landscapes in relation to specific events and historical conditions, and these provide the context for their comprehension (Bender 1993: 2).

Cultural landscapes are created and maintained by cultures that instill values, beliefs, and historical memory in the people belonging to a community. Consequently, cultural landscapes can be sustained for long periods without physical use. Even after a long absence, the cultural processes of memory and history renew links with places that may have been forgotten, irregularly visited, or occupied by others (Morphy 1993: 239-240; 1995). This is not a reinterpretation of landscape but a process of discovery and revelation in which ancestral presence is palpable and immutable. We found this to be the case for each of the tribes conducting research in the San Pedro Valley.

Archaeologists divide the human occupation of the San Pedro Valley into a number of periods (Clark 2004). In the broadest terms, between about 11,000 and 2,500 B.C. people relied on hunting and gathering for subsistence. After about 2,500 B.C. domesticated crops were grown. Around A.D. 500 the Hohokam archaeological culture becomes defined and continues until about A.D. 1450 when it is no longer evident. While the Hohokam occupied the San Pedro Valley, there was a migration of Western Pueblo people from what is now northern Arizona between about A.D. 1200 and 1350. Sometime after A.D. 1450 the Sobaipuri, who were close relatives of the O'odham, inhabited the San Pedro as seen in the archaeological record and historical Spanish documents. In the 1760s, the Spaniards convinced the Sobaipuri to leave the San Pedro Valley in favor of living in places like the Santa Cruz River Valley. Thereafter, the Apache, who had been present in the area for some time previously, lived in the San Pedro Valley, where even today they own land in the valley. For most of these 12 or 13,000 years people derived sustenance from the natural environment of the Madrean Archipelago, supplemented with some trading. The intensity of human occupation along the San Pedro Valley is evident in more than 500 identified archaeological sites within a half-mile of the river between the modern towns of Benson and Winkleman.

Tohono O'odham Cultural Landscapes

The Tohono O'odham, who have a long and complex history in the Madrean Archipelago, retain oral traditions that explain their relationships to the Hohokam and Sobaipuri. One portion of a traditional narrative recalls the story about *I'itoi*, the Elder Brother, who, following a period of discord with the ancient *Huhugkam*, led an army of people who emerged with him from underground in the east and swept across the region, killed the *Huhugkam*, and settled on the land. This narrative has different variations, with some O'odham believing their ancestors were the conquerors while others saying the O'odham ancestors were the conquered. Tohono O'odham advisors recalled this narrative while conducting research in the San Pedro Valley.

The complex social relations and interactions of the past, that are so eloquently elucidated in O'odham traditional narratives of the *Huhugkam* and *I'itoi*, do not reflect the rather homogeneous and uniform concept of an archaeological culture such as the Hohokam. However, recent historical linguistic research is beginning to illustrate that the Hohokam archaeological culture very likely constituted a "multiethnic community" (Shaul and Hill 1998). In this respect, archaeologists are starting to think of ancient archaeological cultures as being vibrant multifaceted societies that are somewhat reminiscent of the dynamics of ancient life portrayed in O'odham narratives.

Hohokam and Sobaipuri archaeological sites, features, and artifacts that the Tohono O'odham research team saw and studied on the San Pedro Valley project were to them tangible evidence of their history. They feel a strong affinity to the ancient people who lived in the San Pedro Valley. It is clear from our research that the Tohono O'odham people recognize salient features in the Hohokam and Sobaipuri archaeological cultures, just as many of them experience palpable connections to both the *Huhugkam* and those who emerged from the underground with *I'itoi*.

Hopi Cultural Landscapes

For the Hopi, their long journey to the Hopi Mesas was accomplished by a multiplicity of clan migrations, and this is monumentalized in the many thousands of ancestral homes that are found throughout the Madrean Archipelago and beyond. The ruins, potsherds, petroglyphs, and other remains that people now call archaeological sites are recognized by Hopis as the footprints of their migrating ancestors, the *Hisatsinom*. The concept of footprints constitutes the historical metaphor by which the Hopi people comprehend the past and give meaning to the archaeological record.

Clan histories are closely guarded at Hopi, intended primarily for the spiritual education of clan members. Consequently, only abstracts and fragments deemed relevant to our research in the San Pedro Valley were made available by the Hopi research team. Much of the clan migrations that relate to the San Pedro Valley involve more than 30 Hopi clans associated with *Palatkwapi*, a pivotal place and time within the Hopi migrations that began from a place of origin far to the south. In Hopi history, the Hohokam sites in the Madrean Archipelago are the footprints of Hopi clans and ancestors migrating toward the Hopi Mesas from *Palatkwapi*. Eventually, when they arrived at the Hopi Mesas, these clans brought with them ceremonies and knowledge gained along the way. For example, knowledge of canal irrigation from rivers, an aspect of Hohokam archaeology, is still an important component of Hopi ceremonies involving the Water Serpent. Agave, which does not grow at the Hopi Mesas but is plentiful in the Madrean Archipelago, has ongoing important roles in Hopi ceremonialism.

Hopi clan migrations were neither directionally linear nor uniform. Clans sometimes journeyed together. At other times they split into smaller groups, then regrouped in different configurations. Some clans or individuals may have spiraled in directions visiting new places or revisiting ones different. These migration paths are symbolized by petals on a flower or the fourfold swastika designs painted on rattles used in Hopi ceremonies. For the Hopi advisors on the San Pedro project, the Western Pueblo intrusions into the San Pedro Valley, most clearly seen at the Davis and Reeve Ruins, are vivid evidence of the complex history of Hopi migrations. At the Davis site, archaeologists have excavated a kiva. Kivas are highly symbolic structures in Hopi culture, and are found throughout the Colorado Plateau yet are not present in Hohokam sites in the Sonoran Desert.

To some degree, Hopi history in the San Pedro Valley has become attenuated by time and distance. One indication of this is that the historically documented trade fairs between the Hopi and Sobaipuri in the early eighteenth century have faded from memory. Even so, the Hohokam and Western Pueblo archaeological sites are stark evidence that the *Hisatsinom*, Hopi ancestors, migrated through the Madrean Archipelago. These footprints bring the past into the present, and according to at least one Hopi advisor this cultural landscape recalls songs, and therefore history.

Zuni Cultural Landscapes

The Zuni origin talk has different versions, incorporating numerous levels of meaning, many of which are only entrusted to certain initiates of religious societies. All of these accounts tell of Zuni emergence onto the Earth's surface in a deep canyon along the Colorado River, from where the people began a long journey to the Middle Place, present-day Zuni Pueblo. Of significance to the San Pedro Project is the history of the "Lost Others." At a point on their migration in the Little Colorado River Valley, the people were given a choice of two eggs, one multicolored and one dull. The group that chose the dull egg, from which hatched a brightly colored parrot, were told to go south. They left and went southward, never to return, and are now referred to as the "Lost Others."

When the Zuni research team visited the San Pedro Valley, they were intrigued by the pueblos they saw. They knew the story of the "Lost Others," but had not seen these sites before. To the Zuni research team, the Puebloan sites in the San Pedro Valley constitute evidence that there is a historical relationship between the ancient people who lived in the Madrean Archipelago and the modern Zuni people.

Many other connections exist between the Zuni people and the ancient peoples of the Madrean Archipelago. When studying collections removed by archaeologists from archaeological sites in the San Pedro Valley, the Zuni advisors interpreted many ceramic design motifs based on their cultural knowledge, and, based on present-day Zuni cultural practices, explained the functions of many artifacts, functions that had previously proved elusive to archaeologists.

While viewing the San Pedro Valley and contemplating the archaeological sites, the Zuni advisors correlated their traditional history of the "Lost Others" with the geographic setting of the Valley. They actively engaged the archaeological record in an interpretive and historical exposition that drew it into the Zuni cultural landscape. It is through the cognition and use of this landscape that the ancient past is projected into the contemporary world and kept alive.

Apache Cultural Landscapes

The San Pedro Valley sits between the four sacred peaks of the Western Apache. It is, therefore, an integral component of their traditional geography and their cultural landscapes. The Valley is the origin place of two Apache clans, and the home of others. During the historical period, the Dark Rocks People, or Aravaipa band, made the San Pedro their home. The Cottonwoods In Grey Wedge Shape People, or the Pinal band, also commonly used the Valley.

Apache history along the San Pedro is replete with conflict. By 1700, the Spanish Empire, which had formed an alliance of sorts with the Sobaipuri, was in conflict with the Apache. In the 1760s, when the Sobaipuri left the San Pedro Valley, Apache bands made it theirs. It was not until the United States military campaigns of the late 1800s that control of the Valley changed hands. On the morning of April 30, 1871, a mob of Anglo-Americans, Mexican-Americans, and Tohono O'odham massacred about 100 Apaches, mainly women and children who were living along Aravaipa Creek under the protection of the U.S. military in nearby Camp Grant. Some children were taken as slaves. The collective scars of this tragedy still permeate Apache memory.

Over 60 Apache place names are recorded for locations in the San Pedro Valley and Aravaipa Creek. Place names are particularly important in Apache culture and the construction of Apache cultural landscapes. As Keith Basso (1996) has noted, naming places is a way of doing history, and it provides a way of constructing social traditions as well as personal and social identities. For the Apache, names such as Big Sycamore Stands There, the place along Aravaipa Creek where the Camp Grant massacre occurred, evoke not only tragic memories, but also a salient character of the landscape at this location. Apache place names are more than simply labels: they are poetic expressions signifying the cultural and historical value of places. For example, Mescal Big Resting indicates an important source of food, Mesquite Circle In A Clump is a good place to live, and Water Blue Resting identifies a source of good water. Apache place names constitute one aspect of Apache cultural landscapes that are layered onto the San Pedro Valley and constitute part of a living history of this region.

A Mosaic of Land, History, and Culture

The natural setting of the San Pedro Valley and the remainder of the Madrean Archipelago comprises a mosaic of cultural landscapes. There is not one story or one collective value of place, but a mosaic of histories and meanings.

The lives of Tohono O'odham, Hopi, Zuni, and Apache ancestors are not forgotten by their descendants. The lives of these people are recalled in stories, songs, rituals, names, and the objects they left behind. The lesson here is that it is important to us all to value and protect the legacy of those who came before.

In this brief paper we have touched upon the palimpsest of the Tohono O'odham, Hopi, Zuni, and Apache cultural landscapes that are overlaid on the natural environment. Our purpose in presenting this paper is simple. We wish to draw American Indian cultural landscapes to the attention of people working with natural resources, environmental, and ecological organizations and agencies. It is important to be cognizant of different cultural values that are attached to the natural setting, and take these values into account when planning and implementing actions that affect the natural environment, because these actions may have a profound effect on a living culture (Ferguson and Anyon 2001). For example, a plant may be a Hopi totem, a source of Apache or Zuni medicine, or a basketry resource for the Tohono O'odham. An environmental restoration project that inadvertently disturbs a shrine could have a negative impact on a living culture. By illustrating different cultural values relating to both the natural and cultural resources that are a part of the environment we hope to widen and enrich the discourse concerning the conservation of the Madrean Archipelago.

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CHI CH' IL (Acorns): Dissolution of Traditional Dilzhe'e Gathering Practice(s) Due to Federal Control of the Landscape

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"It is of considerable importance to prevent the encroachment of our citizens on lands belonging to the Indians of our South West frontier" (John C. Calhoun, Secretary of War 1830).

Abstract—*The radical transformation of the Southwestern landscape over the last century has had multiple repercussions. It is our belief that it was confiscation of the Dilzhe'e (Tonto Apache) home country, combined with evolving control of the land by Federal agencies after 1905, as much as the wars of conquest, which caused the dissolution of traditional Dilzhe'e, practice(s) and associated wisdom. In support of that claim this short paper focuses on the personal experience of Dilzhe'e Elders of the Yavapai-Apache Nation.*

Introduction

The Dilzhe'e are a Western Apache people commonly called Tonto Apache who have lived in central Arizona for centuries. Today they live as members of the Yavapai-Apache Nation (located in Camp Verde), the Payson Tonto Tribe, and in limited numbers at San Carlos as the descendants of families who remained in the South after the American wars of conquest. The modern Yavapai-Apache Nation is the amalgamation of two tribes, comprised of Dilzhe'e clans and families of Yavapai (often cited historically as Mohave Apache). The initial physical merger of these two distinct cultures was forced mutual confinement by the Army from 1873 through 1900, beginning on the Rio Verde Reserve and later at San Carlos, with their union subsequently formalized into Federal tribal status under the Indian Reorganization act of 1934.

There are many ways of tracking time, and each culture has its own style of accounting for the landscape that sanctifies the home country and what constitutes someone else's terrain. In 1954 the Indian Claims Commission held hearings to determine "boundaries" as perceived by Indian people in the old days. Senate subcommittee lawyers were pressing an elderly Chemehuevi man, Young Beecher, about where a certain boundary might have existed during his Grandfather's time. Exasperated after repeated questioning Mr. Beecher exclaimed, "I told you, I don't know nothing about no lines!" (Senate Docs. 1954). No amount of badgering would change his perception. For Indian people it was not a system of lines that determined what was considered *ours* and *theirs*, but a precise mental map of the landscape instilling in each person a geomorphic sense of place. This sense of place applies to the Apache mind in particular (Basso 1996).

After the Civil War ended in1865 a series of American presidents established a system of Federal ownership upon the lands of the West. The early decades of the twentieth century would see these lands, then under the marginal influence of the Department of the Interior, transferred to several other agencies: the National Park Service, Department of Defense, Bureau of Land Management, Bureau of Reclamation, and to a larger extent the Forest Service. The goals of this transfer were to: (1) better control access, (2) expedite extraction of resources, (3) oversee allocation of the limited water, and (4) maintain influence over patterns of local economy. Today modern land managers administer this system within a framework of scientifically established lines and exact boundaries.

A Brief Description of Recent Dilzhe'e History

For the Dilzhe'e of the Verde Valley the "line culture people" (EuroAmericans) began showing up in numbers during the 1860s. By 1872, after several years of brutal warfare, nearly 1,700 Dilzhe'e were sequestered on the Rio Verde Reserve. The Reserve was established in October of 1871 by Presidential Executive Order and consisted of 800 square miles along the upper Verde River. In the spring of 1873 an additional 1,000 Yavapai People were brought over Mingus Mountain from Camp Date Creek near Prescott and placed onto the Reserve. (U.S. Government Docs. 1871, 1874).

Throughout 1874 government contractors in Tucson lobbied Washington DC to have the Dilzhe'e and Yavapai removed to a concentration camp at San Carlos, Arizona. So, in the bitter cold February and March of 1875, the Dilzhe'e and Yavapai alike were force-marched cross-country to San Carlos. The horrible trip took 18 days and was described by Army Surgeon W. H. Corbusier as "…a cruel, cruel undertaking…" (Corbusier 1968: 271).

At San Carlos true mobility ceased. Food rationing was instituted, tokens ruled the day, and regulations began to replace traditional wisdom. Without constant access to the landscape, much of the old wisdom served no practical purpose. Without a hunt, hunting songs could not be sung. Without access to special plants, at the proper times, baskets could not be made and the process languished. The old religion was suppressed. The language that transmits the wisdom lost its focus on traditional relationships and the culture began to drift. Vincent Randall recounts when his Grandmother was a little girl her family would slip off in August to gather chi ch'il by the light of the full moon. They still craved the old food after the nutritionally vacant and monotonous government rations of flour, sugar, coffee, and beef.

By 1895 the military reservation system was breaking down due to economic and political constraints. After 1899 many families of Dilzhe'e simply walked away from San Carlos and made their way back to their old haunts, from Payson through the upper Verde Valley and to the forested country south of the San Francisco Peaks.

During their absence the world had been changed. Even though most of the country was still unregulated, all of the good, well-watered parcels had been gobbled up. The government controlled the bulk of it, but as yet was unsure how to deal with it. Land along the Verde River filled with *Inaah* (white) settlers so fast it must have sounded like the coming of a flash flood. After the Dilzhe'e returned to the Verde country from San Carlos, their term for Camp Verde became *Kowa'gola'n* (many houses). Now outcasts in their own country, the Dilzhe'e were pushed into the less desirable corners of it. From now on the fence, the saw, the bull, the dam, and the mine would dominate. These forces gathered momentum as World War II approached.

By 1910 a school superintendent was placed in charge of overseeing the welfare of the Camp Verde Apaches (Dilzhe'e). A few years later in a report to Washington DC, Superintendent Taylor complained that there was little hope of educating or Christianizing these "wild Apaches" because they were "spread out for over 100 miles in camps from Ash Fork to Turkey Creek." He was in the predicament of being a bureaucrat without a budget. In 1914, after more letters and reports, he was given funds to purchase several acres in Middle Verde. A few families settled in at first with many more to come soon after (Tribal Records 1910-1923).

During the first two decades of the twentieth century, development in the old Dilzhe'e range was dramatic; a hydro-electric facility was established in Fossil Creek, Roosevelt Dam was constructed, and mines at Jerome were thriving. There were new roads all over the place. These projects relied upon and provided a steady source of income for hundreds of Western Apache. The men followed the work, their families lived in a camp near the project. The women gathered wild plant food with other Apaches close by and surrounded by the still open country. They sold frybread, coffee, and roasted meat to the laborers, generating a little extra cash (personal communication, EW, VR). These final days of roaming were to be short lived with the coming of regulations, the Great Depression and the Indian Reorganization Act of 1934.

The Government Factor

In 1872 Secretary of the Interior Columbus Delano set the political tone concerning Indians for decades to come when he stated, ……*We therefore claim the right to control the soil which they occupy, and we assume that it is our duty to coerce them, if necessary, into the adoption and practice of our habits and customs* (U.S. Government Docs. 1872, italics added). Wandering the landscape was unregulated behavior and the umbilical cord to a lifestyle that was to be left behind on the rocky road to citizenship.

The same year the Dilzhe'e were marched off to San Carlos (1875) the American Forestry Association was formed. Its mission was to "transform public concern for the forests into effective legislation." One year later the Federal Commissioner of Agriculture appointed an official "forest agent" with the specific mandate to gather information on the economic value of the American forests and "other assets" to be found therein. This assessment took a generation to complete (Bergoffen 1976).

In 1905 the Federal government transferred millions of acres previously termed "forest reserves" or "public domain" to the Department of Agriculture, and the modern Forest Service was created. With the transfer of power to the Department of Agriculture, the economic mission of the Forest Service was initiated with extensive surveys, fencing, logging, and related activities. This was overseen by a large bureaucracy with no tolerance for Indian people moving throughout the forest. The Forest Service refers to the period of 1917 to 1945 as their time of "growing up" (Bergoffen 1976: 11).

In the late 1920s the government was still consolidating jurisdictions and still in a quandary as to what to do with the Indians. In 1929 two million more acres of "public domain" were transferred into the cash register of the Forest Service. At this same time the Hoover administration was to set a course by which they could, "….ultimately discharge *this problem* from the Nation and blend them (the Indians) as a *self supporting people* into the Nation as a whole." (Wilbur and Hyde 1937: 88, italics added), discounting the fact they had been *self supporting people* for untold centuries. President Hoover's Indian Policy consists of a single page set between Slum Clearance and Prison Reform.

Chi ch'il (Acorn)

Western Apache People have a mature understanding of the landscape. This understanding comes from living for centuries in their home country and is expressed in Apache as c*h'igona' ai' nilis dahsol'ees helz'*, literally "don't let the sun step over you," which translates as "wisdom sits in places." Critical knowledge gleaned from the landscape combined with personal experience was forged into wisdom, which was passed on to each generation. Without this wisdom, survival and proper cultural balance on an uncompromising landscape was extremely difficult (Basso 1996; and personal communication).

Alienation from the landscape destroys this wisdom and puts the well being of all Apache people at risk. Elizabeth Smith-Rocha relates the following story; although it is not a chi ch'il story it illustrates the personal pain of being alienated from ones own landscape. “I was about nine or ten years old (circa 1942). The Hamely’s were poor and never had a car so the boys used to take their horse up on the mountain (Mingus) to hunt for deer. They didn’t even have enough money for a hunting license, so they were poaching on their own land and might go to jail if they got caught!”

Commonly enough, after San Carlos, many older Dilzhe’e who witnessed what had happened to those who resisted simply clammed up. Talking about the old ways was at best melancholy and often counter-productive. Cultural information—which had been the domain of all Apaches—was now relegated to the internal archive of individuals and certain families who passed it on in degrees with variable success. Elders often advised children and grandchildren to “keep it in their hearts.” Others were told simply to “forget all about those days,” or words to that effect (VR, RH, VS, ER, RS, DS, personal communication).

The Dilzhe’e were poor even by frontier standards. Store-bought food was not always available or affordable. Traditional foods were (or could be) free and a healthier alternative to the *Inaah* food they were now subjected to. Some of the Dilzhe’e scouts had government pensions and could afford a car; some people had a horse. Those families could reach out even further into the “public lands.” For the most part the Dilzhe’e were still on foot and confined to a postage stamp reservation of less than 600 acres. They were, nonetheless, resourceful and foraged (and poached) in the surrounding Federal countryside. Almost everyone over 55 years old from the Yavapai-Apache Nation can tell a story of gathering wild foods as children. The Dilzhe’e wild versions of spinach, carrots, and onions, as well as acorn, pinyon, walnuts, red berry, mescal, packrats, rabbits, and deer were sought after.

Rosella Hines, a Dilzhe’e woman from Clarkdale remembers as a little girl in the early 1940s “walking seven miles up that Mountain (pointing at Mingus) … just to get acorn.” In August the family would camp out for several days gathering acorn on the eastern slopes and later on, pinyon to the west. If they ran out of flour, Rosella and her sister Jennie were sent down the mountain to intercept the bread truck and buy fresh loaves for a dime apiece. Out on the landscape logging was in full swing, cattle were (over) grazing every acre, but as yet no official body was hassling the Apaches.

Vincent Randall and Elizabeth Smith-Rocha also have very fond memories of gathering and the camp scenes from their youth. Families had personal “little spots.” Clans and the greater tribe would utilize “big groves” such as the modern town-site of Payson (*T’e gotsuge’*, “the yellow place,” referring to the changing leaves of the oak trees). In places like Oak Creek Canyon and around Sedona, the acorns fell in late July. Other places like Payson, Fossil Creek, Clear Creek, the East Verde, and the Mazatzals would produce throughout August. The “last place” was up on Mingus Mountain along Cherry Creek in early September. The Dilzhe’e call August *chi ch’il Naa na’ de*, when the acorns fall (VR, ER).

Families would go out from a day trip up to three weeks at a stretch. Certain locations were known to be “faithful” or “spotty.” Some places were avoided because of inconveniences such as red mites (*chi’ e’*), too many rocks, or concerns over snakes. Flocks of wild pigeons were the most dreaded competition. “They would come in like a locust(s) and go from tree to tree right in front of our eyes, wipe it out, and move on.” This happened at Greenback Ranch east of Punkin Center (VR).

If the picking was good, “word would get out” and other family members would set forth as schedules and transport allowed. Like any treasured resource the exact location of the “little spots” was kept in the family and only “close relatives would be invited.” Provisions included blankets, coffee, flour, lard, an Apache *tus* (for water), a hand axe, a cast iron skillet, some potatoes, “maybe some bacon, maybe some sugar, maybe some peaches” (VR, ER, VS).

The quantity of chi ch’il to be collected was always “as much as they could get.” Vincent Randall relates that “some people could pick real fast, others would sit and scoot.” Flour sacks were the receptacle of choice, but cans, burlap bags, and pillow cases were also employed. “Aunt Daisy used a three pound coffee can.” Usually the chi ch’il was dried in camp on a blanket, “to get the worms out.” The bulk of the haul would be shelled and ground back at home. Ground acorns are a golden color favored by Apaches.

“In the old days it was just common food, it was always on the table like salt and pepper.” They ate them like peanuts, crushed and rolled up in a tortilla, “pâté’d with deer meat,” or “ground up and added to gravy.” The preferred method today is to boil a large pot of short ribs until the meat is “soft” then the ground chi ch’il is added as gruel to the personal taste of the cook (VR, RS, ER).

Extra chi ch’il was shared with Elders who could no longer get out. It was used to trade for other specialty items such as pinyon, deer jerky, or plant medicines. It could be sold for ready cash. Adam Newton was the last serious chi ch’il broker in the Upper Verde Valley. Until the time of his passing in February of this year (2004), Adam would purchase unshelled acorns in bulk from one of the few remaining gatherers at San Carlos or Payson. In August of 2002 I took Adam and his mother to Payson to purchase 100 pounds of chi ch’il. The meeting at their relative Rose’s house turned into a social affair as well as a cash transaction. Later on back at home in Camp Verde, with a profound patience derived from his blindness, Adam would process it all by hand, shelling, grinding, and filling coffee cans of various sizes to store in the cool pantry off the kitchen. For Tribal members who no longer gathered, but sought that nostalgic taste, Adam was about the only show in town. He was fond of saying, “I’m one of the last real Apaches, my prayers are Apache, I listen to Apache songs and I still do acorn” (AN). His passing may mark the official end, be it ever so small, to the traditional processing and distribution of chi ch’il in the Upper Verde. It is our hope his sister will pick up the gauntlet and continue the tradition, where he and Virginia left off.

The consensus amongst Dilzhe’e Elders interviewed on this subject is that World War II is the line in the sand regarding free and unregulated access to the landscape. After the War a feeling reflected by the following comments became standard: “They were fencing it all in, where the water is” (RH). “I think it was about 1948. We were up on Cherry (Mingus Mountain) where we would go to get acorn, you had to camp up there. The rangers (Forest Service) asked us ‘What are you doing?’ We told them, 'picking acorn.' They said 'you can't do that anymore, you'll have to move on.' *So we didn't go back up there*" (ER). "After the War a lot more of the country became inaccessible. Then you had to get a permit. Some of the Apaches made a big stink so the permit was free, but you still needed one. Needing permission to collect on our own land was an insult even if it cost nothing" (VR). And as the traditional resource areas dwindled "there was more competition from O'odham and San Carlos at the good places. Even the Mexicans were picking it" (RH).

The Cattle

And then there are the cattle. The Western Apache Coalition has mapped over 1,000 traditional place names on the Arizona landscape. Several of these locations are named for Emory oak groves such as, *chi ch'il sikad* (oak tree flats) near Payson. Yvonne Bonser has visited and evaluated several locations regarding the health of the oak trees and native plants. She has observed that wherever cattle are present, small diameter trees are rare or nonexistent. Her research indicates that cattle make it impossible for trees to get started, and in places where seedlings make it through the first year they are all trampled or grazed off by the second. In marginal areas where trees have survived into the 10-50 year range they are multi-stemmed bush-like plants, not mature single stemmed trees that produce a crop useable by Apache people. Where under story plants still exist in a grazed area they are dominated by non-native grasses (*Bromus* sp.) and invasive noxious weeds (e.g., *Tribulus terrestris*; Yvonne Bonser, unpublished data 2003). Numerous studies associate the success of these and other non-native species as indicative of improper grazing practices at the expense of oak woodlands and native grasses. This double-edged sword of drought and cattle goes hand in hand with an observation made by Elizabeth Smith-Rocha regarding gathering acorn after the War. "It was all drying up, no more water, no more little trees. They were pumping it to who knows where for the cows."

The Bull

On the first day of August, 1930, Tom Smith loaded up the pick-up with his pregnant wife, Lilly; his sister, Virginia; and several younger children and set off. He drove east out of Camp Verde through Fossil Creek to a big cluster of oaks north of Payson. It was a hot day. Tom unloaded the provisions and headed back to work, planning to return for his family within the week.

For many years this expansive grove had been summer pasture for several bulls. One of these monsters was put out by the unexpected company and began to charge the large alligator juniper under which they had set up camp. Virginia got all of the children and herself up into the tree, but for Lilly climbing was not an option. The bull charged several times, coming close, but pulling up short on each occasion. After a while he stopped and went away. Within the hour Lilly gave birth to a little girl, Rebekah (RS, VS, ER, ES, VN). More than six decades later we drove by this place and Rebekah (who passed away in 1999) pointed out the spot under the big juniper where she was brought forth by the bull.

These bulls are ever-vigilant allies of the modern forests. Like the rangers on Mingus Mountain, they apparently have no tolerance for the acorn pickers and have no intention of letting any new trees get a start. Amongst the ancient oak of Rebekah's grove there are no healthy trees less than 50 to 80 years old. So while the cattle flourish despite a significant drought, traditional Apaches have become an endangered cultural entity.

Conclusion

There is growing concern among land managers about the health of our Southwestern landscapes. Due to the thoughtful efforts of several employees of the Tonto National Forest that organization is by their action showing respect for Dilzhe'e history and traditions. We encourage this trend. Any steps taken to restore health to the landscape will require input from Western Apaches to be effective. We are concerned, however, that the national agenda of the Forest Service will trump regional vision and could ultimately stifle the creative policies instituted by local forest officials.

Epilogue

Vincent Randall took his mother picking for the last time in 1989. She was in her nineties and passed away the following spring. It was her mother who snuck off from San Carlos in the previous age to gather chi ch'il by moonlight. Virginia Newton, who placed the Smith children in the old juniper tree 74 years ago, is the mother of Adam Newton. She is almost 90 (she passed away the month after the conference).

In the old days, Apache ladies could discern which groves acorns came from by taste. They often named individual trees, Old Man or the Twisted One*,* expressing their own sense of stewardship. (KB, EW, VR, personal communication). They were sustained by their unsurpassable ability to make due. Modern resource management often means squeezing every molecule and droplet from the Earth, sooner rather than later as if a storm was fast approaching. This can only go on for so long. A lot of Apaches believe someday after the storm has passed they will need the old skills again.

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The Western Apache Home: Landscape Management and Failing Ecosystems

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Abstract—*The traditional Western Apache home lies largely within the Madrean Archipelago. The natural resources of the region make up the basis of the Apache home and culture. Profound landscape changes in the region have occurred over the past 150 years. A survey of traditional Western Apache place names documents many of these changes. An analysis of the history and Apache places in the Wheatfields area in southeastern Arizona illustrates the loss of Apache natural resources. Traditional Apache elders attribute the loss of these resources to disrespectful land management practices, resulting in direct harm to Apache communities.*

Introduction

For the past thirteen years the authors have worked extensively with Apache elders from the San Carlos Apache Tribe, the White Mountain Apache Tribe, the Tonto Apache Tribe, and the Yavapai-Apache Nation. Much of this work has centered on gathering traditional Apache information about the natural world, including field work documenting traditional place names and plant uses. The Apache information included in this paper comes from Apache elders interviewed during the course of this work.

The traditional Western Apache home encompasses a large area of central and eastern Arizona (see figure 1). Trade, warfare, and ceremonial practices required occasional trips to the Rio Grande and east, Mexico, the Gulf of California, the coast of southern California, and the Grand Canyon northward. Apaches have lived in this region for centuries, and traditional knowledge of this region is profound in its depth and specificity. Many Apache songs and stories describe specific natural elements and processes in this region from the time before humans existed. Prior to the establishment of the reservations, Apaches depended totally on the natural resources of this region for their livelihood.

Native Americans have lived in this region for thousands of years, exploiting resources to survive. Apaches did not live in a pristine landscape, unaltered by human hands. However, Apaches consciously limited their impact on the land in pre-reservation times, attempting to live within traditional parameters governing their own population size, harvesting of wild resources, and agricultural techniques. Apaches traditionally understood the negative consequences of living beyond these traditional parameters, and misusing natural resources.

The ecosystems of the Western Apache homeland have suffered profound changes since Inah (Europeans or Euro-Americans) arrived in the 1820s to trap beaver (Dobyns 1981), and especially after 1870 as Inah agricultural and mining practices altered the natural world in a very short period of time. Numerous authors have described the environmental impacts of this period including Dobyns (1981), Bahre (1991, 1995, among others), and Pyne (1982). Apache elders describe this change as a series of speedy and violent transformations: commons changing into restricted lands, wetlands changing to drylands, water sources diminishing or disappearing altogether, the loss of topsoil in general, transformation of grasslands into woodlands or shrublands, transformation of open forests to choked forests, non-native plants and humans displacing natives, and natural places transformed into industrial or urban sites. Elders see this change in terms of lost access to cultural resources, as the pre-Inah ecosystems have all but collapsed.

The ongoing Western Apache Place Names Project has to date identified over one thousand Apache place names within central and eastern Arizona (see figure 1). These names reflect a wealth of knowledge of the region, including descriptions of the land prior to Inah activities and settlement. Over 50 places have been documented so far whose traditional names no longer aptly describe the land due to significant alteration or destruction by Inah activities. For example, Chichíl Bi[dagoteel ("Emory Oak Flat"), an important traditional acorn-gathering area, is now the site of the intersection of Highways 87 and 260, shopping centers, and fast-food in Payson, Arizona. Tee[Hach77 ("Row of Red Cattails") was a wetlands with a dense of growth of traditional plants on the eastern boundary of the San Carlos Reservation, and has now been pumped dry by off-Reservation farmers and urban users. T][ichíog7 ("Yellow Water Spring") is a spring that feeds Pinto Creek north of Superior, Arizona, next to a traditional Danceground, and will soon be in the middle of the Carlota Copper Company's planned open-pit mine.

The land-altering activities of the last 130 years, and their effects on Apache resources, are easily visible in the region of Wheatfields, along Pinal Creek just west of Globe, Arizona

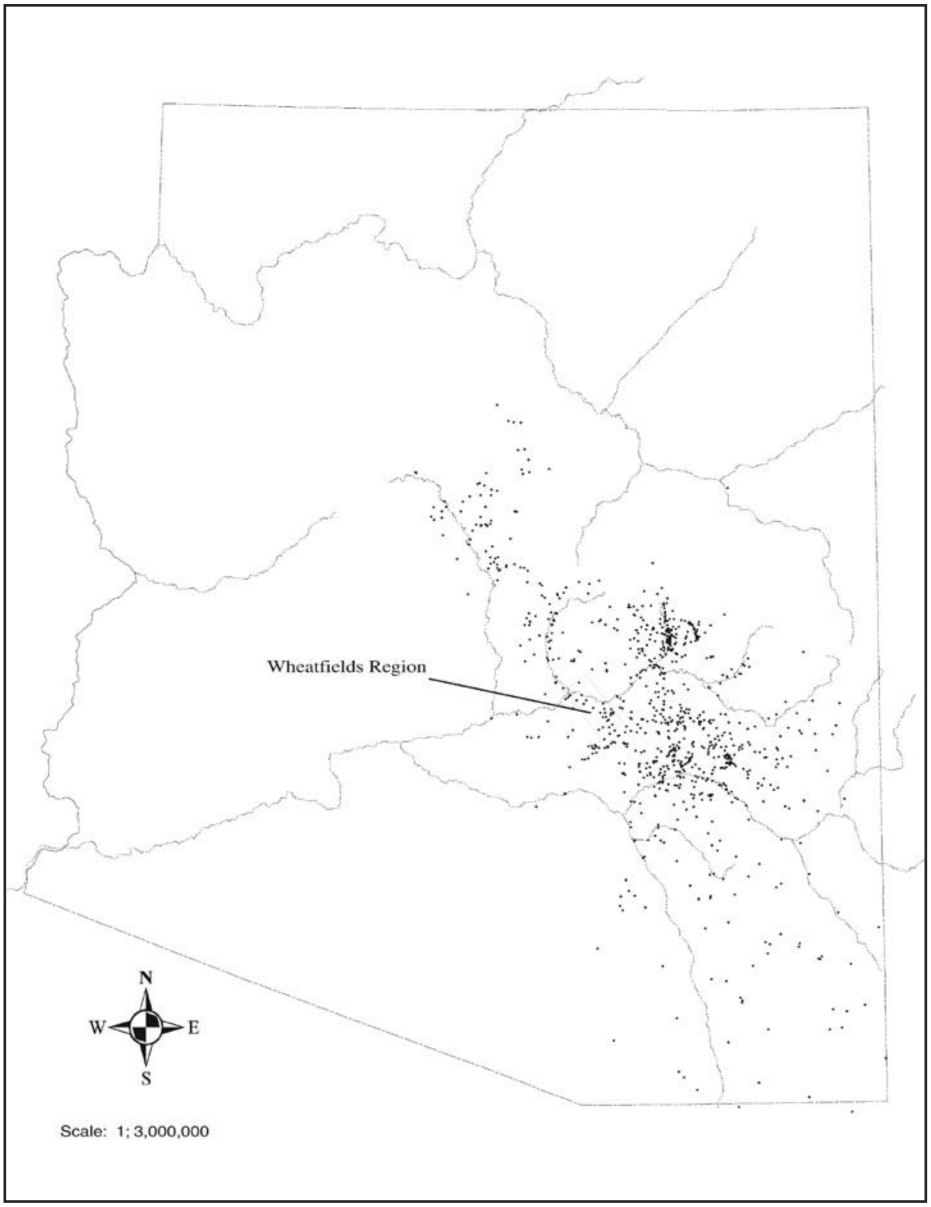

Figure 1—Western Apache Place Names in Arizona.

(see figure 2). This region, known as Tíis Tseba ("Gray Cottonwood Growths"), is a traditional homeland, permanent camp, and farming area for the Kís Chínt7í4dn ("Alders Jutting out People"), Ts8 Ts4h4skidn ("Trees on a Hilltop People"), Dzi[Likesilan ("Mountains in a Row People"), Tsebinasti4 ("Rock Encircled People"), and the Hak2iy4 ("Inah Upwards") clans in Tíis Tseban (the Pinal Band) country. Apaches lived in Tíis Tseba in significant numbers well into the 1930s, even though most Apaches had been moved onto the Reservation by then.

Situated at about 3,100 feet, the riparian area still consists of some cottonwood, willow, elderberry. The immediate surrounding flats are thick with mesquite and catclaw, or cleared farmland, home sites, or industrial sites. The uplands, reaching 5,000 feet in elevation, range from upper Sonoran scrub, to desert grasslands, and juniper, pinyon, oak woodlands, and chaparral.

According to Apache elders from the 1930s, the Tíis Tseba of centuries ago was "…vacant and never before occupied by Apache. Place so beautiful that [the Hak2iy4] clan moved there in entirety…(Goodwin, 1942)" Within the last ten years, elders in their eighties and nineties have remembered the Tíis Tseba of their youth and of their elder's memories, describing the pre-settlement landscape in some detail. Pinal Creek flowed year round, with a relatively narrow and deep channel. The banks were covered with grass, and the crowns of tall cottonwoods and willows on both sides of the creek connected to form a closed canopy.

The flats on either side of the creek were generally open and grassy with some mesquites, cottonwoods, burro brush, graythorn, and other shrubs. The lower slopes on either side of Pinto Creek were composed of Sonoran scrub species, but quite open with almost all of the surface covered with grass. The woodlands were open and covered with grass, with occasional pinyon, junipers, and oaks.

Most prominent in elder's memories is the former abundance of water. Not only was Pinal Creek perennial, but so were numerous springs in the region. Most of these springs ran strong, and supported luxuriant growth at their sources, and along the creeks that ran from them.

The Tíiis Tseba region was rich and varied in Apache resources, due to its abundance of water and varied ecosystems. The flats along Pinal Creek supported farms where Apaches grew traditional crops of corn and squash. The surrounding country supported numerous wild plants that provided traditional food, and all the elements of material culture. The many water sources supported plentiful wild game. One elder estimated that the Tíiis Tseba region traditionally supported an Apache community of a few hundred (Elder X, 2004). This same elder referred to the region of that time as "an Apache paradise." Although popular Inah writing has made much of Apaches as warriors and raiders, most of their traditional subsistence was owed to agriculture and wild food harvesting. Buskirk (1986) estimated that the traditional diet of many Western Apache groups was comprised of up to 90-100 % wild and agricultural foods, with only the smallest portion made up of products obtained in raids.

In the mid-1860s wars with Inah began in earnest, and by the early 1870s most of the Western Apaches had been subdued by the U.S. Army and concentrated on reservations. The San Carlos Reservation was established in 1872, and Tíiis Tseba was originally included in the Reservation. As Inah found copper, gold, and silver ores, and good grazing lands, on and off the Reservation, large tracts of the Reservation, including Tíiis Tseba, were placed back into the public domain. A detailed history of the Apache wars, the establishment of the reservations, and the removal of lands from the Reservation, as they pertain to Tíiis Tseba, can be found in Newton (1999).

Extensive ranching and mining operations in the Tíiis Tseba and Globe/Miami regions began in the early 1870s. As an Apache elder from Tíiis Tseba told us, "Those ranchers, they already had it figured out with the Army. The Army would come in, and the ranchers would start up right away" (Elder X, 2004). To support the fast-growing population of the area, non-Apache farms were established in the flats throughout Tíiis Tseba. The combination of ranching, mining, and agriculture very quickly impacted Apache resources and access in the region, and in twenty years greatly altered the landscape.

Elders have told us that by the beginning of the Twentieth century Pinal Creek started to flood more frequently and erode more rapidly, greatly widening the creek's course. By the 1910s or 1920s, Pinal Creek flowed only with the rains. By this time cattle had cleared much of top layer of vegetation and topsoil over most of the hills, and there was less grass to be found. Most importantly in the memories of elders was the loss of many of the springs by the 1910s. As they recall, the copper mines established a water delivery system for the mines that effectively dried up the major springs in the area, and further diminished the flow in Pinal Creek. Other springs had been dynamited in an attempt to increase flow, but had resulted in killing the springs.

An examination of Apache places in the Tíiis Tseba region (see figure 2) clearly illustrates the change of the landscape as well as the loss of Apache resources. Nalee[iDanakaiy4 ("Ducks Waddle Around") was, in the early part of the last century, a wetland next to Pinal Creek with standing water year-round. A favorite spot to cool off and swim, it was known as a watering hole for animals and a source for important traditional plants. It was pumped dry by the mines in the teens, and the wetlands disappeared. Today a sewage treatment facility stands on this site. Similarly Ts4 L1tah T[("Water on Top of the Rock") was a spring that had a strong flow of cool water year-round, was a source of water for wildlife, plants, and Apaches and their farms. The area around this spring was traditionally one of the most heavily inhabited with a great number of farms. The spring site is now situated in a rock quarry and, even though the spring is gone, the place remains well known among elders throughout Western Apache country.

T]Yadnlin ("Water Flowing Down") is a wash that used to run year-round before the mines came, but now runs only occasionally with heavy rains. Elders told us that the springs near the head of this wash used to support an Inah rancher's fruit orchard, but the springs' flow is now greatly reduced and often dry. The cottonwoods, willows, and walnuts that used to be abundant along the wash are now only sporadic. Large desert-willows (*Chilopsis linearis*), hackberries, mesquites, turbinella oak, and a few walnuts are now the dominant trees. Nagonelt in ("*Yerba Mansa*") is the name of a spring and wash that was a traditional campsite for groups from Tíiis Tseba going out to gather acorns at the nearby Chichilda[kizh ("Spotted with Emory Oaks"). This spring has since been developed, with a windmill feeding several pipelines. Today the spring supports cottonwoods, willows, and reed, but there are encroaching non-natives such as Ailanthus trees, spearmint, red brome, and horehound; and none of the *yerba mansa* plants for which the spring was named. Once plentiful and highly valued in healthy wetlands, *yerba mansa* is increasingly hard to find in Apache country.

Today Pinal Creek and its immediately adjacent lands, Nalee[iDanakaiy4, Ts4 L1tah T], and the spring at Nagonelt in are all private holdings, surrounded by U.S. Forest Service lands. Often signs are posted on private property boundaries warning trespassers to keep out. Apaches are used to being legally separated from their traditional, off-Reservation places and the traditional resources that are found there. Often Apaches must sneak under fences to harvest traditional plants, and the authors have seen elders hide behind bushes or in ditches so that no one will see them gathering important resources, even when perfectly legal, accustomed as they are to harassment by law enforcement personnel or local citizens.

Several years ago the authors spoke to an accomplished Izee Dighin (a traditional herbalist), who was then in his mid-nineties, about the state of the natural world. He told us that "..the world is drying up. The water and the springs are going down, and the medicine plants are pulling back away from us….. We are disrespecting the land and the plants, that's why…." (personal communication, Richard Galson 1992). Traditional Apaches recognize that every element of the natural world has power, and that maintaining a good relationship with each of these elements is crucial to one's ability to use these powers for sustenance and health. Hurting any of these relationships by disrespect or ignorance can harm oneself, one's loved ones, or the community. To traditional Apaches, the home consists of all those with whom one strives to maintain good

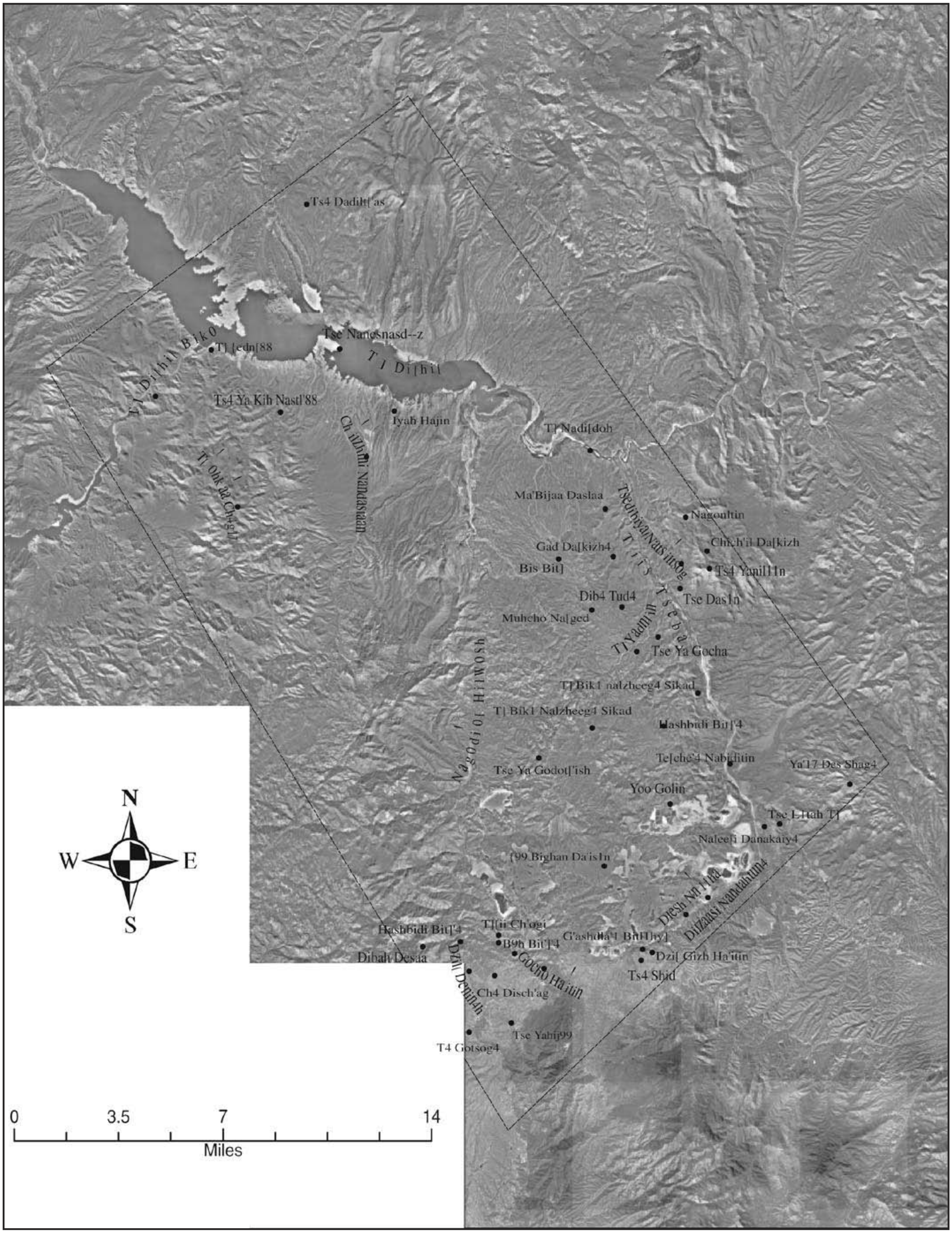

Figure 2—The Wheatfields Region.

relationships—the relatives, friends, places, species, and natural elements that one depends on to be healthy and happy.

Elders consider activities that harm the natural world, such as large-scale mining and irresponsible ranching, inherently disrespectful and dangerous. Apache elders acknowledge the necessity of exploiting natural resources to survive, but are critical of destructive exploitation. Harming the natural world not only destroys habitats for natural resources, thereby removing access to resources, but it breaks the foundation of one's home, exposing people and communities to the harmful side-effects of broken relationships. Because traditional people still have and maintain these relationships, the destruction of habitats hurts them deeply and profoundly, as if a family member has been harmed or killed. The authors were present when a medicine man from Cibecue tearfully told Forest Service and mining representatives that their proposed copper mine would "…tear open the veins of Mother Earth." (Elder Y, 1997) This reflects a conservative and traditional Apache view of copper ore. The authors have often witnessed elders in tears when they have seen a denigrated part of their home.

Apache elders believe that forced separation from traditional places, the destruction of traditional places, and the destruction of natural resources profoundly harms all of us, and that this harm manifests itself in a variety of individual and social ills, which encourage disrespectful behavior. Elders point out that Agency and private land management practices, and the individuals responsible for carrying out these activities, have directly harmed Apaches and their resources. Apache elders want land managers to understand that what they do on the land directly affects the health and well-being of the entire Apache community. Apache elders want all of us to manage the land to resemble as close as possible pre-Inah settlement conditions.

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Varmint Control in Cochise County Over the Years

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Abstract—*Varmint control has a long history in the area, going back at least to the 18th century. More than 125 years of systematic varmint control in Cochise County has had mixed success. Two large predators, the grizzly bear and the Mexican wolf, were eliminated from the area. Coyotes have maintained their numbers despite hundreds killed annually. While organized government efforts have played a major role, individual efforts by hunters, farmers, homeowners, and others have been far more significant.*

Introduction

In March 2004 Tucsonans argued, sometimes vehemently, about what to do about mountain lions that seemed not to fear people in and around Sabino Canyon. A lion was caught live and sent to a rehabilitation center, a result that many thought unsatisfactory for various reasons. This was just the latest in a long series of attempts to reduce conflicts between predators and humans. Many people were probably not aware that this lion fit into the context of some 385 mountain lions killed in Arizona in 2001, of which 34 were disposed of under governmental predator control programs.

The Spanish Period

From the earliest days of European occupation, settlers worked to eliminate species they deemed undesirable. Native people dealt with nuisance animals, especially those that ate their crops, but when Spaniards introduced livestock, predator control became important.

Ignaz Pfefferkorn (1989) described customs in mid-18th century Mexico south of the Sky Islands: "I have told above how skillfully Indians kill tigers with arrows… Deep pits are dug and covered over with brush and a small amount of earth so that the animal does not notice the deception. A lamb or calf is tied at a spot, which the animal cannot reach without stepping on the trap. When he ventures onto them, the weak boughs break and the thief lies in the hole where he is stoned or shot to death."

Another missionary said: "Stock raising in Sonora and in Spanish America in general suffers about as much from the coyote or coyotl as from the aforementioned animals. … When hunger plagues him [the coyote] and no smaller prey presents itself, he does not hesitate to attack a grown calf or colt" (Treutlein 1965: 110-11).

Pfefferkorn found bats "nasty" (1989: 119) and said, "In my room I killed and chased away ten or twelve, and more, and in my church I sometimes killed two to three hundred with the help of some Indians…"

The American Period

Reasons for Varmint Control

The major incentives for varmint control (whether justified or not) are: livestock predation, attacks on humans, crop destruction, elimination of nuisances, and rabies. Once livestock had arrived in the area, predators viewed these animals as just another food source, not unlike deer. Ranchers, on the other hand, viewed livestock as private property. This dichotomy was often resolved in favor of the rancher.

Fear of attacks on humans was fed by widely circulated stories such as one from 1858: "They are a large brown species [of bear] and the hunters say they are as fierce as the grizzly. They will generally attack a man whenever they meet him without waiting to be provoked. I felt more afraid of them than I did of the Indians … They are very hard to kill, and a dangerous enemy" (Way 1960: 283).

The rare attack on a human was sometimes viewed as a reason to try to eliminate the species. A 1991 study of cougar attacks on humans, however, shows that fear of attack was much greater than the number of attacks would justify (Beier 1991: 404-406). Mech (1970: 289-293) found little evidence that wolves ever attacked humans unprovoked. Table 1 shows General Accounting Office estimates. Some 19th century settlers at Tres Alamos (north of Benson) and St. David complained that beaver dams spoiled their irrigation projects so farmers destroyed dams as they were built. By 1890 only the occasional beaver lived along the upper San Pedro, although they continued in the lower river. Farmers constantly battled rodents and some kinds of birds.

One major reason for control was rabies. The first documented case of rabies in North America is from the East Coast in 1785 (Jackson and Wunner 2002; Kiple 2002). A description of what appears to be rabies comes from the Tubac area in 1858. "The wolves are numerous here and in July and August they sometimes go mad and in that condition they will enter a town or even a house if the door is left open and bite everything in their course. At this season the Mexicans … sleep on top of their houses out of reach of this danger" (Way 1960: 291).

Table 1—Estimated annual human fatalities and injuries in the United States by animals (General Accounting Office 2001).

Animal	Injuries	Fatalities
Rodents	22,000	Unknown
Various snakes	8,000	15
Skunk	750	0
Fox	500	0
Bear	30	1
Coyote	2	0
Cougar	2	0.4

After three confirmed cases of rabies in Cochise County in 1961, the government imposed a quarantine and pet leash law. Seventy-three man-days of hunting resulted in killing 164 skunks, 118 feral cats, 33 raccoons, 10 coyotes, and 11 miscellaneous critters in Santa Cruz and Cochise Counties (ADC 1961).

Governmental Programs

The first American travelers and settlers took care of varmints themselves. "Yesterday 2 of our men … had an encounter with a large cinnamon [grizzly] bear. They were cutting timber at the foot of a mountain close by, when they saw a bear on the side of the mountain feeding upon acorns. They crept up slightly within a hundred yards of him without being seen. When Mr. Randall raised his rifle, took deliberate aim and fired, the monster dropped on his knees, roared with pain, but recovered himself in an instant and discovered his enemies and darted like lightning down the mountain. They saw him coming and knew their danger. McCoy sprang into the fork of a low mesquite tree and he had hardly done this before the bear was at the foot of the tree with his mouth wide open, ready to drag him down." (Way in 1858 published 1960: 355-356). After more adventures, they shot the bear.

Cochise County paid bounties ranging from $1 for skunks to $10 for lions. A pregnant female merited bounties for herself and each of the "unborn." The Federal government gradually entered the picture. The Bureau of Biological Survey (BBS), founded in 1885, initially conducted biological surveys and did scientific work. The law emphasized "economic agriculture" and stressed bird and rodent-caused agricultural damage. Gradually "practical" work became a larger part of its mission and problem wildlife a focus. By 1917 the Bureau had a full-blown predator and rodent control program (PARC) and issued its first annual report for Arizona. Detailed records by bounty hunter and county exist for the early years, with kills recorded by home town of the bounty hunter. In 1931, for example, E. E. Anderson of Tombstone killed and collected bounties on 111 coyotes, 27 bobcats, and 6 foxes (table 2).

The program evolved from a bounty system to salaried hunters. It has continued under several names, first in the Department of Agriculture, then in the Department of the Interior and finally back to Agriculture in 1987. In the 1960s, questions about the value of the program, especially use of poisons, led to a 1963 official report by A. S. Leopold that was critical of the goals and method. Another by S. A. Cain followed in 1971. Both resulted in changes in methodology and control methods.

The program, under its current name, Wildlife Services, includes a variety of control and research activities, including reducing wildlife damage to aviation, invasive species, reducing human exposure to rabies and plague, preventing beaver damage, and reducing damage to livestock and wildlife.

Cooperators

The Arizona Game and Fish Department (AGFD) has long been a cooperator in Federal programs and has primary legal responsibility for the State's wildlife. It is responsible for problem game animals such as bears that can be legally hunted under a permit system.

Cochise County has also been a cooperator. In 1996-1997, for example, Cochise County contributed about $17,000 to the predator control program, about half the total cost of the program there. Table 3 indicates the number of animals destroyed

Table 2—Animals killed by bounty hunters in Cochise County in selected years (PARC and USDA Division of Wildlife Services annual reports).

Year	Coyotes	Wolves	Bobcats	Mountain Lions
1917[a]	67	11	5	0
1927	2	0	0	0
1931[a]	110	1	27	6
1936[a]	388	1	39	0
1939	282	0	43	4
1940	383	0	78	0
1943	515	2	130	2
1945	504	1	22	1
1950	325	0	42	10
1956	287	0	27	
1958	467	0	1	
1960	329	0	8	
1962	520	0	33	
1965	522	0	19	

[a] Incomplete report for the year.

Table 3—Animals destroyed in Cochise County under the Animal Damage Control program and reported domestic animals damaged by predators during FY 1996-1997 (ADC records).

Animals destroyed		Animals claimed damaged		Suspected culprit
Feral dogs	106	Sheep	22	Coyotes
Feral pigs	379	Emus	2	Feral dogs, coyotes
Coyotes	722	Cattle	1	Coyote
Skunks	34	Chickens	4	Coyotes, feral dogs
Other	29	Other	3	Coyotes, feral dogs
Total	**1,241**	**Total**	**32**	

under the program and claimed damages. Other cooperators included ranchers, and the Arizona Departments of Agriculture and Health Services.

The role of individuals

Although government programs have for years played significant roles in varmint control, individuals actually eliminate many more animals. Cochise County had some locally famous hunters. Ila Healy, for example, who ranched in the Huachuca Mountains during the first half of the 20th century, was described as "our resident lion hunter." The Arizona Republic (August 6, 1979) added, "that's a bit like calling Johnny Cash merely a guitar player. It simply doesn't define the subject," and said that Ila had been in on more than 200 lion kills in the Huachucas.

The 1999 Finding of No Significant Impact for the Federal program on non-Federal lands in Arizona states that only some seven percent of all coyote kills in Arizona are done under the cooperative program—the remainder by individuals. The 1998 Environmental Assessment for the program on Federal lands make similar claims. Table 4 shows 2001 Arizona estimated figures.

Brief Summaries of Species

*Wolves (*Canis lupus*)*

Wolves were pursued relentlessly. By 1920 few remained. The 1922 PARC report stated: "I believe the most striking piece of work accomplished this year was the wolf work along the Mexican border where we destroyed thirty wolves, not allowing a wolf to drift more than twenty five miles into the United States and, with the possible exception of one wolf, we did not allow a wolf to get back into Mexico…. There are five passes where wolves cross from Mexico in the State of Arizona … One of these places is the Huachuca Mountains… Men are kept continually on these ranges."

Table 4—Animals killed in Arizona in 2001 under the Federal Predator Control program (source: Wildlife Services Annual Report).

Animal	Number killed under program	Total estimated killed all sources
Bear	8	179
Birds[a]	1,200+	
Feral cat	64	
Coyote	821	42,526
Feral dog	118	
Cougar	43	385
Jackrabbit	34	
Skunk	110	
Others[b]		

[a] Pigeons, grackles, English sparrows, ravens.
[b] Badgers, beaver, bobcat, fox, raccoon.

The 1926 PARC report declared: "The fiscal year 1926 has been our banner year for real success in control and extermination of predatory animals in the State of Arizona. This year marks the end of the lobo wolf for there are no wolves left inside the border of our state."

By the 1930s the number of wolves killed had dropped to zero most years, although some did make it across the border from time to time. The 1940 report said: "Wolves frequently visited the State from Mexico and were unusually troublesome in the border country northwest of Nogales.… As a general rule, wolves would appear, make a kill or two, and if not trapped, they would immediately return to Mexico.… A trapper employed by the New Mexico district took a pack of wolves depredating on cattle in the extreme southeastern corner of the State of Arizona and southwestern New Mexico."

In 1945 hunters took the last breeding wolves in Arizona at Fort Huachuca. The program had apparently succeeded in its goal of eliminating the species in Arizona. According to PARC, reports from Sonora indicated that the "wolf problem" had been solved there too.

The 1951 report concluded: "It took eight years for a few Biological Survey [employees] working under a well planned program, to completely eliminate resident wolf populations in Arizona. In doing so they virtually did away with a problem that had plagued stockmen ever since livestock were first brought into the State. The elimination of resident wolves is believed to have been the first conservation program ever completed in Arizona…."

In 1954, however, Hoffmeister said: "Wolves are present rather frequently in the Huachucas, principally, if not exclusively, at the present time on the western side" (Hoffmeister and Goodpaster 1954).

In 1957 two wolves were taken with "coyote-getters" near Elgin and Redington. "It may well be that wolves enter the State more frequently than is supposed and are taken by coyote getters or other methods and are never found (PARC 1957). David Brown said, "More than fifty years of constant effort finally destroyed the wolf. That it took that long is a fitting testimonial to his tenacity" (1984: 175).

*Coyotes (*Canis latrans*)*

Coyotes, too, were targeted from early territorial days, but their fate was quite different from that of the wolf. Coyote kills under the program in Cochise County ranged from 67 in 1917 to 552 in 1965. The 1918 PARC report said: "Coyotes, on account of their queer habits and nature, create a rather puzzling problem. Although vast numbers are killed annually … yet, with a lapse of a short period of time, the ranks of the missing have been filled. … we realize that the straight trapping of coyotes is an uncertain method of reducing the great supply. .... Coyotes appear to keep a close check on suitable range and when the number are reduced migratory movements soon adjust the distribution to about normal, considering local food conditions. The taking of 8,000 to 10,000 of the animals in a year seems only to encourage the remainder to breed more freely and to re-establish their numbers."

In 1927 PARC reported: "Great inroads were made into the population of these animals during the past fiscal year, with the result that losses in lambs on the lower desert ranges were very slight." Over the years, as can be seen from table 1, coyote kills fluctuated but remained relatively steady.

Ranchers generally liked coyote control, but some farmers did not. One farmer said, "Now that you have killed off the coyotes what are you going to do about rabbits and rodents? I would just as soon have the coyotes on my range" (PARC 1956).

Connolly and Longhurst's 1975 study helped explain coyote tenacity. The authors concluded that the primary effect of killing coyotes is to reduce population density, thereby stimulating changes in birth and mortality rates. If 75 percent of the population is killed each year, it would take more than 50 years to reach extermination, assuming no influx of coyotes from nearby areas.

Currently, some 13,000 hunters take an average of between 30,000 and 40,000 coyotes a year in Arizona, (AGFD estimates). Trappers used to take a high percentage of the coyotes, but this has declined to only a little more than 1,000 a year (AGFD 2004), partly in response to citizen-initiated legislation passed in 1994 restricting the use of leghold traps, and partly due to decline in fur demand.

Mountain Lions, Bobcats, and Jaguars

Mountain lions (*Felix concolor*) have been a target for many years. In 1859, Kennerly wrote: "The Mexicans, who call it Leon, wage against it an unceasing warfare, on account of the ravages which it commits among the cattle. .... The most effective means used for their destruction, in the hands of the Sonorians, is strychnine. They poison with this substance the carcasses of the animals that have been slain, and not only often succeed in thus killing the Leones, but a great number of wolves also."

The territorial legislature declared mountain lions predatory and placed a bounty on them. In 1970 the mountain lion legally became a "big game" animal, subject to hunting regulation. The most killed in one year in Cochise County under the bounty program was 10 in 1951. The annual Arizona take now ranges between 250 and 350, about 15 percent of which is under governmental programs.

The number of bobcats (*Lynx rufus*) killed in Cochise County under the program rose until it peaked at 130 in 1943 and then declined. Arizona sport hunters report taking between 1,200 and 1,300 bobcats a year currently. As with other species, trapping has declined dramatically. In 1987, more than 6,500 were killed, and more than 5,000 export tags were issued to trappers and fur dealers wanting to ship bobcat pelts out of State. Less than 500 bobcats have been trapped each year since 1994 (AGFD 2004).

Jaguars (*Felis onca*) were seldom encountered, although in the 1850s Kennerly reported them as "very common" near the Santa Cruz River in Mexico. Lange (1960) collected records of 45 reported jaguar kills in Arizona from 1885-1959. The majority were within 90 miles of the border. These were nearly all kills by individuals or scientists, not by bounty hunters or government officials. Brown and Gonzales (2001) documented the decline of the jaguar in Mexico and Arizona.

Bears

The early settlers had conflicts with bears as described above. Carmony and Brown (1991: 182-83) concluded from historic reports that grizzly bears were rather common in southeast Arizona. Brown (1985) documented the grizzly's demise through hunting, some of it under the bounty program.

Early travelers reported few black bears along the San Pedro, but this may have been because people did not travel in the mountains where bears are most common. Encounters were more frequent along the Santa Cruz River.

The 1918 PARC annual report stated: "As the wolves and lions are killed out in certain districts, much light is thrown on the case against bears as predatory animals. Guilt is now being placed on them, where in years gone by it was generally supposed that bears did little killing of domestic stock. They are becoming more destructive to cattle in recent years. The dry seasons have probably added to their killing, since the shortage of food has created a demand for range everywhere, even in the highest and most heavily forested regions—the home of big bears—has thrown the helpless stock into the very haunts of the animals."

AGFD classified bears as game animals in the 1960s and developed hunting regulations. In 2004, Game and Fish allocated 75 permits for the spring male bear hunt in Game Management Unit 29 that includes eastern Cochise County. Few female bears may be killed legally.

Badgers, Foxes, and Rodents

Badger trapping was common into the 1980s when more than 1,000 per year were taken Statewide. Very few badgers are taken today. Currently about 3,500 foxes are killed annually Statewide, mostly gray foxes. Previously, trappers took far more foxes than did hunters, but trapping has almost disappeared in Arizona.

Rats, mice, ground squirrels, rabbits, and many other rodent species were targets of this program. Ranchers considered prairie dog (*Cynomys ludoviciana*) detrimental. For example, "up to this time one of the greatest drawbacks to farming and the stock business [in the Sulphur Springs Valley] has been the prairie dog pest" (U.S. Biological Survey 1956). A 1917 bulletin claimed that there are "many sections of prairie dog-infested land in the San Pedro Valley near Hereford and westward to the Huachuca Mountains" and said the grass was rapidly being destroyed (Paschall 1917: 331). In the 1890s ranchers praised bisulfide of carbon which they said was "great stuff" to kill all burrowing animals. In the early 20th century PARC had great hopes of controlling rodents by introducing fatal epidemics, but experiments led to "nothing but disappointment" for the agency (Cameron 1929). Prairie dogs were nearly extirpated by the 1930s, although a small colony persisted near Fort Huachuca until 1938 (Hoffmeister 1986).

Closing Observations

Government programs played a role in supporting extirpation of some species and reduction of others, although in most cases the number of animals killed under the program was only a fraction of the total kill. The programs had varying success rates depending on the nature of the target species. Changing public attitudes influenced the direction of the programs, especially reduced use of poisons. Citizen-initiated restrictions on trapping and changing economics led to many fewer animals trapped. More attention is given today to the role that predators play in the balance of nature. Beaver have been reintroduced in Cochise County and wolves and prairie dogs elsewhere. Major problems remain however, in handling continuing human-wildlife conflicts as human populations continue to expand into wildlife habitat.

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Invasive Species

Changes in the Pinacate Reserve Ecosystems: Invasion of Non-Native Plants

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Abstract—*Over the years, humans have modified the Sonoran Desert by introducing invasive plants that prosper in disturbed and non-disturbed habitats. These invaders modify the dynamics and structure of populations and the composition of communities, which in turn can result in radical changes in wildlife habitat. The natural landscape of the Sonoran Desert is characterized by extensive valleys with parallel and discontinuous arrangements of narrow ranges (Shreve and Wiggins, 1964). Within this ecosystem is the heart of the Sonoran Desert called the Pinacate Reserve (Reserva de la Biosfera El Pinacate y Gran Desierto de Altar). The Pinacate Reserve registers 97 invasive plant species, of which 18 are altering the natural ecosystems.*

In 2002 the Sonora Conservation Data Center (CDC) started a project to identify and map invasive species in Sonora and implemented a pilot program in the Pinacate Reserve. This project found a total of 97 invasive species in the Reserve, 18 of which represent the greatest threat to the natural habitat of the area (table 1). Salt cedar (*Tamarix ramosissima*), buffelgrass (*Pennisetum ciliaris*), and Sahara mustard (*Brassica tournefortii*) have been considered the primary concerns for the Reserve area (CDC, 2002). The CDC analysis also identified sites with the greatest proportion of invasive species within the Pinacate Reserve in order to establish Management Areas for Invasive Species (MAIS). One of these sites that represents a very clear example of significant changes to the natural system is in the Río Sonoyta, located just south of the U.S.-Mexico border and adjacent to Organ Pipe Cactus National Monument. This location in the Río Sonoyta is the site of an abundant invasion of salt cedar that has eliminated native plants such as cottonwood (*Populus fremontii*), willow *(Salix gooddingii),* and mesquite *(Prosopis velutina).* The river is also habitat for endemic species like desert pupfish (*Cyprinodon eremus*), Sonoyta mud turtle (*Kinosternon sonoriensis longifemorale*), and longfin dace (*Agosia chrysogaster*).

Another example of important changes in the ecosystem involves the recent widening of the Mexican highways 2 and 8 that mark the northern and southern limits of the Reserve, respectively. These construction activities resulted in environmental impacts that were difficult to avoid (Búrquez and Castillo, 1993) and that later gave place to the establishment of invasive species like Sahara mustard (*Brassica tournefortii*) and buffelgrass (*Pennisetum ciliaris*), which compete with native species (CDC, 2002). Observations and surveys along the main dirt road that connects the Reserve's biological station with highway 2 have detected Sahara mustard at moderate levels. However, this exotic species has begun to invade adjacent areas as well. A very dense stand of Sahara mustard is located on the west side of the Ladrilleros hills, east of Sierra Suvuk, on the southeastern corner of the Reserve (CDC, 2004). In this area, the Reserve personnel, students, and social workers have made some first attempts to control the Sahara mustard by mechanical and manual efforts. The results have not yet been impressive since it is a task that will require a long-term commitment.

Exotic plants invade both the low parts of the Reserve and the core zone known as Sierra Pinacate, where there are records of some invasive species already established, like red brome (*Bromus rubens*), filaree (*Erodium cicutarium*), Lehmann lovegrass (*Eragrostis lehmanniana*), and barley (*Hordeum murinum).* These species could present a risk for displacing natives like *Senecio pinacatensis,* which is endemic to the high parts of the Sierra Pinacate.

For the purpose of eradicating invasive species to support the conservation of natural landscapes, we designated a MAIS within the Pinacate Reserve. The management area allows us to unify efforts in the development of programs targeting noxious species. These programs include prevention, inventory, monitoring, mapping, and methods of integration for managing invasive plants, as well as public participation. The ultimate goal of the MAIS is to facilitate cooperation between Reserve administrators and local landowners in order to solve the shared problem of invasive species within a common area. An objective is to prevent the reproduction and dispersal of the invasive species within the management area (Bureau of Land Management et al., 2000).

Within the management area, we identified zones where the infestation of invasive species is most evident. These zones are found within areas of high-priority conservation for the Reserve. Such subdivisions of the MAIS will facilitate the implementation of an Invasive Species Management Plan that will both diminish the presence of these undesirable species and avoid their dispersal (Paredes, 2003). Through mapping and inventories we will have the basic tools to implement the specific actions in the management areas, since these techniques will help us identify and delimit the exact locations of areas with populations of invasive or noxious species (Paredes, 2003).

Table 1—Invasive plants of interest in the Pinacate Reserve.

Family	Scientific Name	Synonyms	Common Name	Distribution/ Characteristic
AIZOACEAE	*Mesembryanthemum crystallinum*	*Cryophytum crystallinum*	Cristal IcePlants, hielitos	Wildland invasive
AIZOACEAE	*Mesembryanthemum nodiflorum*		Slender-leaf iceplant, Hielitos	Wildland invasive
ASTERACEAE	*Centaurea melitensis L.*		Malta starthistle	Sonoyta farm fields and impacted sites (roadsides); wildland invasive
BRASSICACEAE	*Brassica tournefortii*		Sahara mustard, Mostaza	Widespread wildland weed; density greatest on sandy soils
CYPERACEAE	*Cyperus esculentus var esculentus*		Yellow nutgrass, yellow nut sedge, Coquillo amarillo, cebollin, coquille.	Temporary or permanent wet habitats; invasive
GERANIACEAE	*Erodium cicutarium*	*Geranium cicutarium*	Filaree, storksbill Alfilerillo	Widespread and naturalized in disturbed and undisturbed wildlands
MOLLUGINACEAE	*Mollugo cerviana*	*Pharnaceum cerviana*	Thread-stem carpetweed, indian chickweed	Common in wildlands
POACEAE	*Bromus rubens*	*B. madritensis* ssp. *rubens*	Red brome, Bromo rojo	Invasive in disturbed & undisturbed habitats; limited by low rainfall
POACEAE	*Cynodon dactylon*		Bermuda grass , Zacate bermuda, zacate ingles.	Invasive in wetland habitats, common along roadsides and major arroyos
POACEAE	*Panicum antidotale*		Blue panic grass	Wildland invasive
POACEAE	*Pennisetum ciliare*	*Cenchrus ciliare*	Zacate buffel	Wildland invasive
POACEAE	*Pennisetum setaceum*			Wildland invasive
POACEAE	*Polypogon monspeliensis*			Wetlands
POACEAE	*Schismus arabicus*	*S. barbatus* ssp. *arabicus*	Zacate árabe	Widespread & abundant
POACEAE	*Schismus barbatus*	*Festuca barbata*	Zacate común del mediterráneo	Widespread & abundant
POACEAE	*Sorghum halepense*	*Holcus halepensis*	Zacate Johnson	Irrigation ditches and roadsides; potential invasive in wetlands
TAMARIACACEAE	*Tamarix ramosissima*		Pino salado, salado	Riparian systems, wetlands and ditches; invasive
ZYGOPHYLLACEAE	*Tribulus terrestris*		Torito, toboso	Farm fields and occasional along roads; not in wildlands

Invasive species control in Mexico is new, and it is just as new in Sonora where such species of plants are still used in some regions for cattle forage. Thus, we are in the first stages of the programs to implement controls for invasive plant species with the support and collaboration of American organizations and agencies with more experience in the control of undesirable species.

During this initial phase, we participated in international meetings, conferences, and workshops with the objective of determining preliminary status of invasive plants in the Pinacate biosphere reserve and surrounding areas. These gatherings helped identify priority actions for control and management through advice from expert organizations that have stated their interest in supporting this type of project in the Reserve (Paredes 2002). Sister reserves of the Pinacate and Organ Pipe Cactus National Monument conducted a workshop in March of 2002 that identified needs of both external participants (municipal officials, landowners, and interested groups) and personnel from the parks. This workshop included presentation by researchers with experience in this topic, visits to the areas with problem invasive plants in the Pinacate Reserve, and the forming of teams to discuss the basic aspects of control and management of these species.

In closing, we would like to acknowledge and state our special gratitude to the Arizona Department of Transportation and the Sonoran Desert Invasive Species Council. We appreciate the help of all the agencies and organizations who have assisted us.

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Monitoring Invasive Plants Using Hand-Held GIS Technology

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Abstract—*Successful control of invasive species requires a clear picture of the spatial extent of infestations. The latest mapping technology involves coupling global position systems and hand-held computers running geographic information systems software in the field. A series of workshops applying this technology to mapping weeds was developed and presented to Weed Management Areas across Arizona. Workshops were designed to be robust, flexible, and inexpensive. Participants were strategically selected to enhance material retention and to foster networking outside of formal instruction. Workshop success was due, in large part, to the continued commitment of the participants, especially members of the Tonto Weed Management Area.*

Introduction

Invasions of invasive species can have drastic consequences for ecosystem functional (Vitousek and Walker 1989; Le Maitre et al. 1996) and structural attributes, including decreased biodiversity of native plants and animals (Wilcove et al. 1998), altered fire regimes (Mack and D'Antonio 1998), and in some cases, extinctions of native species (Pimm et al. 1995). Invasion by exotic species is a major threat to global biodiversity, second only to habitat loss. It has been estimated that invasive plant species cost the United States $34.7 billion annually in economic damages and control costs (Pimentel et al. 1999). This figure does not account for environmental and health costs, which could force the number to be much greater.

Weed Management Areas (WMAs) are local organizations that bring together landowners and managers (private, city, county, State, and Federal) in a geographical area to coordinate efforts and expertise against common invasive weed species. "The purpose of...a WMA is to facilitate cooperation among all land managers and owners to manage a common weed problem in a common area....WMAs have similar characteristics such as geography, weed problems, climate, common interest, or funding support" (USDA and USDI 2000). The individuals comprising WMAs are often dedicated, hard-working individuals, volunteering their free time in an effort to eradicate a particular noxious plant.

Weed Management Areas typically have strictly limited budgets and time. As such, control efforts must be carefully planned to maximize efficacy and efficiency. Weed control efforts have been likened to fighting wildfire—a clear understanding of the size, rate of spread, and direction of spread of a fire or a weed invasion is necessary to enhance efforts (Dewey 1995). A clear picture of the extent, spread, level of infestation, and other ancillary information can inform management decisions and assist in planning.

One method for increasing weed management efficiency is the implementation of monitoring using digital mapping systems. The tradeoffs for the investment in equipment purchase and education are many. Mapping weeds digitally rather than on paper by hand is much faster and more accurate, eliminates the transfer of data from various paper sheets, enhances sharing of information between agencies, allows for easy updates, and can help users to set management priorities. In addition, digital mapping facilitates information sharing and the transfer of locally relevant files to regional databases such as the U.S. Geological Survey's Southwest Exotics Mapping Program (SWEMP, USGS 2004).

Currently in Arizona, ten active WMAs exist, targeting over thirty noxious plant species (Sonoran Institute and The Nature Conservancy 2001). Because WMA members often come from a wide variety of backgrounds, they commonly do not have expertise or even experience with geospatial tools. To address this need, a program entitled "GIS/GPS for Weeds Mapping" was developed through a University of Arizona/NASA Space Grant Graduate Fellowship. This program, which introduces geospatial technologies to individuals with little or no prior experience, has been developed around the need for weeds monitoring and mapping.

Theoretical Approach

Our objective of facilitating invasive species management through geospatial technology presented three primary challenges. The most apparent was finding a technological solution to the challenge faced by those currently collecting data on the location and characteristics of invasive species infestations. Next, it was clear that "a good idea" alone was insufficient to encourage the adoption of the technological solutions. And finally, the majority of the potential users were previously unexposed to geospatial technology, and in many cases apprehensive of the perceived steep learning curve it might represent. Social scientists, marketing researchers, and non-formal education practitioners have studied these latter two challenges extensively. We have addressed each from a theoretical framework appropriate to the problem at hand: managing invasive species through the support of volunteers working under the organizational structure of Weed Management Areas.

Technology Adoption and the Diffusion of Innovation

Futurist John Naisbitt (1982, 1999) demonstrated powerful insight when he suggested, "whenever new technology is introduced into society, there must be a counterbalancing human response—that is, high touch—or the technology is lost. The more high tech, the more high touch." In our approach, we apply translational science (Birmingham 2002) and technology transfer (Lionberger and Gwin 1991), facilitating interaction between technology sponsors (workshop leaders) and users resulting in actual innovation and the adoption of a new product or procedure.

Translational research and technology transfer are personal acts, requiring advocates with keen observational power and insight. Critical to this process are intermediaries between the source of information and the ultimate user, encouraging and supporting the adoption of new technology or innovations to and from his or her clients. Diffusion, or the spread of an idea, method, practice, or product throughout a social system (Rogers 2003), occurs gradually as some users wait to see how it has worked for others before they are willing to adopt a new method. Early adopters, our initial target in this approach, tend to be respected and visible in their community; they provide practical evidence that an innovation actually works, which is important to later adopters. When we reach and equip intermediaries, a much broader audience can be reached by creating an underlying network. By bringing handheld computers and GPS units to groups composed of both early adopters and those less likely to outright use the technology, we applied this theory in the field.

Technology for Education Versus Educational Technology

The theoretical basis for our educational approach is based on "idea" technologies that de-emphasize hardware and emphasize Earth science ideas, particularly those surrounding invasive species, through a geospatial perspective. The traditional focus on technology for education begins with familiarization and utilization, but generally stops at integration of the technology into application. An alternative approach we have implemented pursues a contemporary perspective of educational technology that focuses on a learner's active construction of the knowledge. This approach allows for evolution of both the student and the learning materials with technological change (Hooper and Rieber 1995). Technology alone will not ensure learning, but it can improve learning if students are engaged and challenged by the task. In this way our workshop participants learn about GPS and GIS through their desire to address a specific need—the management of invasive species.

Methods

Institutional Infrastructure: Weed Management Areas

The approach we have taken with the "GIS/GPS for Weeds Mapping" program has been to apply technology to an identified need through an existing infrastructure, Weed Management Areas, and an established natural resource education framework, Cooperative Extension. In Arizona it is common for Extension agents responsible for natural resource educational programming to be members of local WMAs. By working with established WMAs, we introduced technology into an existing infrastructure and support group. The link to Extension helped ensure that the educational support necessary for the adoption of this technology could be obtained immediately, and that it could be adjusted in the future to address evolving needs.

Field Mapping System

The field system selected for these workshops consisted of a Garmin V WAAS-enabled GPS unit and a Compaq iPAQ 3950 pocket PC running the StarPal HGIS Plus GIS software package. This combination was selected from the wide variety of possibilities due to its relative ease of use for inexperienced users, its low cost (approximately $1,200 in 2003), and field practicality. Of all packages investigated, the iPAQs were the easiest to see outdoors in bright sunlight. Additionally, after attachment to a clipboard, the system can easily be carried and manipulated in the field. However, workshop success was not dependent on the hardware selected. Because this program was developed with flexibility in mind, the content could easily be adapted to work with other comparable packages.

Workshop Design

An introductory workshop, covering basics of global positioning systems (GPS) technology, geographic information systems (GIS) technology, mapping standards, and field data collection, was developed and performed for several groups across Arizona. These initial workshops involved participants from a variety of local, State, and Federal agencies, non-profit groups, volunteers, and academia.

Workshops were tailored to meet participants' needs and skill levels. Workshops were designed to meet individual WMA's needs, employing a mix of lecture and hands-on fieldwork. To accommodate different skill levels and learning styles, modules were adapted during the workshops. By including additional instructors and encouraging the participation of local experts, we were able to assists individuals past their intimidation or fear of technology. Field exercises, instructional materials, and fact sheets were developed in support of the workshops (Mau-Crimmins and Orr 2003; Mau-Crimmins et al. 2003). At the conclusion of each workshop, we met with the participants and asked which program elements were appropriate and which needed modification. In addition, we had all participants fill out evaluation questionnaires providing comments and suggestions. Finally, as new workshops were scheduled, we looked to the participants to dictate what they felt was needed, both in terms of content and support. In this way we adapted our training materials and emphasis as we learned more about the needs of WMA volunteers—our target audience.

Localized "Learning Networks"

Successful implementation of geospatial technology is largely dependent on cooperation between data users, technical experts, and developers. The greater the number of individuals sharing data or technical support across institutional lines, the more likely adoption will occur and the more likely geospatial technology will be viewed as having a positive impact (ARSC 2001). Localized, informal "learning communities" have been particularly important among rural users, where physical distances can impose barriers that are difficult for formal education programs to overcome (Seelan et al. 2003). Recognizing the importance of these localized learning networks, we have made special efforts to help Extension agents and members of WMAs involve as much local expertise as possible in our workshops. In all workshops we have encouraged the WMAs to invite any local GPS or GIS experts with an interest in invasive species management, thereby helping establish the contacts necessary for local data sharing and technical support.

Advanced Workshops

One component of the workshops that seemed to foster success of the program was our willingness to invest in addressing operational challenges that could have been barriers. By working with participants outside of the structured workshops, we demonstrated our commitment to the group, strengthening the feeling of a support network. To better understand both the utility of this technological solution to invasive species mapping as well as potential barriers to adoption, we decided to work more closely with the WMA that showed the strongest desire to implement the technolology. The Tonto Weed Management Area, based out of Young, Arizona, demonstrated strong commitment to the technology despite very little funding, a poor Internet connection, and a dependence on volunteerism to accomplish the mapping. We established a working relationship with the Tonto WMA and performed several successive workshops covering more detailed hands-on work with the GPS and iPAQ units, downloading collected data into GIS software on desktop PCs, analysis and manipulation of data within a GIS environment, and aerial photo acquisition from the internet.

Our continued investment in the Tonto WMA resulted in diffusion of the technology well beyond our area of influence. We were showered with requests for workshops beyond our initial area of interest; in addition, spontaneous application of the technology to other uses including mapping of water wells and shooting range siting occurred. By fostering connectivity among workshop participants, we observed their desire for the technology expand beyond mere curiosity into management in real applications.

Results

The demand for geospatial data capture system among Weed Management Areas in Arizona has proven quite high. Though we have not advertised the program, we have conducted 11 invasive species mapping workshops involving 312 participants since fall 2002. The requests for follow-up trainings and introductory trainings from groups in Nevada, Colorado, and New Mexico have exceeded the capacity of the program in its current form. Organized programs outside the invasive species realm have also taken interest, including the Cooperative Extension's Master Watershed Steward Program and the Navajo Watershed Research Project. Most recently, a team of 4-H and Youth Development Extension professionals began exploring ways to integrate this technology into their programming.

In addition to the very evident demand for a digital, geospatial alternative to current data capture methods employed by WMA, we have observed three fundamental impacts. First, where local support networks can be fostered, this technological solution can address more than the capture of data. A number of the WMAs expressed the desire to integrate this technology into regular mapping activities with the goal of building a spatial database that can be both used locally and shared with the regional data integration centers such as SWEMP. Second, efforts by groups like SWEMP together with WMAs to streamline the process between data logging, sharing, and ultimately returning derived products from the regional database to the WMAs would benefit from adding the spatial dimension to data logging efforts. Finally, groups addressing other natural resource needs (e.g., watershed, wildfire) either already use or are considering using this kind of field data capture methods. Clearly there is a need for both training and post-training support through local networks.

Future Directions

Our workshops were timely for the Tonto WMA, providing the means they sought for more effective weed management. Outside of our work with them, members of the Tonto WMA obtained grant funds and purchased three Garmin/iPAQ/HGIS combinations. Their level of commitment prompted the continued development of geospatial support. Currently, we are exploring ways to provide WMAs with aerial photographs of their study area in the appropriate format and size for the iPAQs to handle. In addition, project-specific GIS datasets are being assembled for the WMAs, keeping in mind that desktop GIS packages and the iPAQs demand different datasets. Finally, workshop participants are being encouraged to use a web-based bulletin board to ask questions and share findings. Continued information sharing among users with greatly enhances the experience of all involved.

We are working with the Tonto WMA and other weed mapping groups to encourage adoption of common data standards and attributes collected. The Tonto WMA is currently collecting attributes common with the Tonto National Forest to facilitate data sharing. We are encouraging the Tonto WMA and other groups to aim to share data with regional databases such as the Southwest Exotic Plant Mapping Project (SWEMP).

The great success of this program suggests that groups with little or no experience can adopt geospatial technology when it is applied to a specific problem. The benefits of this program are that the elements were robust, flexible, and inexpensive, allowing it to be applied to a wide variety of groups and adapted easily. Our program met with success because the participants were ready for the technology and we maintained a core group of committed individuals throughout the consecutive workshops. We are excited by the program's success to date and look forward to expanding the application of geospatial tools to weed mapping into the future.

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Tamarisk and River Restoration Along the San Pedro and Gila Rivers

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Abstract—*The abundance of tamarisk (*Tamarix ramosissima *and related species) along the San Pedro and Gila River flood plains varies with differences in stream flow regimes. Tamarisk abundance, relative to Fremont cottonwood and Goodding willow, is greater at sites with more intermittent stream flows and deeper and more fluctuating ground-water levels. Tamarisk abundance is further increased below Coolidge Dam, where both flood and low flow patterns have been altered. Shifts from cottonwood-willow to tamarisk parallel other changes in the riparian community: as rivers are dewatered and flood regimes altered, species diversity and landscape heterogeneity decline. Tamarisk dominance can be seen as an indicator, rather than a cause, of riparian degradation, reflecting changes in the physical processes that shape riparian plant communities. Restoration strategies should focus on identifying and alleviating these underlying environmental stressors to produce long-lasting results.*

Introduction

The biota and physical environment of an ecosystem undergo continuous change. There has been a particularly high rate of influx of new species into riverine habitats, partly due to their intensive use as agriculture lands, urban areas, and transportation routes, and partly due to their intrinsic nature as high-disturbance, linear corridors, whose community composition is largely driven by immigration processes (Brown and Peet 2003). The millions of neotropical migrant birds flying north and south along the San Pedro riparian corridor, for example, transport plant seeds. At the same time, frequent flooding provides for nearly constant flux in resource availability and thus provides frequent opportunities for species replacement (Davis et al. 2000). Thus, many immigrant plant species have become integrated into riparian landscapes (McLaughlin 2004).

Tamarisk (*Tamarix chinensis* and *T. ramosissima*) was introduced to the United States from Asia in the 1800s for soil erosion control and landscaping purposes. Tamarisk now forms a minor component of the riparian landscape mosaic on some western rivers, but on others it has become the dominant vegetation type. Contemporaneous with tamarisk increase has been decline of Fremont cottonwood-Goodding willow (*Populus fremontii-Salix gooddingii*) associations on some (but certainly not all; Robert Webb, unpublished data) rivers of the Southwest. Given perceptions of tamarisk's high water use and role in altering ecosystems, there are considerable efforts to control its spread and dominance in western riparian ecosystems. Methods such as burning, herbicide application, mechanical removal, and biologic control via insect herbivores are frequently employed (Quimby et al. 2003).

Correlations observed between tamarisk abundance, low biodiversity, and low abundance of cottonwoods-willows have fostered this species-removal approach to river restoration. However, it can be difficult to distinguish between alterations to an ecosystem caused by a new species (autogenic effects) and those caused by changes to physical processes that facilitated the shift in species composition (allogenic effects) (Stromberg and Chew 2002). A plant species may be a cause of change or it may be a symptom of change; distinguishing between the two is critical for designing restoration plans.

Hydrology and geomorphology are key drivers of vegetation dynamics in riparian ecosystems, and as these physical factors change, so does the biota (Poff et al. 1997). Shifts in hydrologic regimes can alter competitive hierarchies and cause shifts in species composition (Tickner et al. 2001). Thus, consideration of hydrologic regimes and fluvial processes is essential for river restoration projects. Our objectives in this paper are to discuss (1) relationships between hydrologic factors and cottonwood, willow, and tamarisk distribution along the San Pedro River and middle Gila River; (2) ecosystem changes associated with shifts from cottonwood-willow to tamarisk, and (3) relationships between tamarisk management and riparian ecosystem restoration.

Stream Flow Regimes

The flood flow regime of the undammed San Pedro River reflects the climatic signal. Floods occur mainly in winter, late summer, and fall; peak flows of >10,000 cfs occur fairly frequently. The low flow regime ranges from perennial to intermittent to ephemeral. The location of perennial reaches varies depending on proximity to major tributaries, sub-surface geology, and the extent of ground water pumpage. In perennial reaches, surface flows remain in the channel even during dry seasons, sustained by ground-water inflow from the stream alluvium and regional aquifers. In intermittent areas, surface flow ceases during the months (e.g., May, June; October, November) between rainy seasons. The depth to ground water (averaged across the flood plain) at the intermittent sites can be more than five meters with inter-annual fluctuation of more than one meter. At the driest sites, flow is present only for a few days each year following run-off events. Intermittent-flow reaches are prevalent in the Lower Basin downstream from areas of ground-water pumping for agricultural and copper mining uses, and also occur in the Upper Basin, such as below the St. David diversion structure.

Flows in the middle Gila River (San Carlos Lake—Ashurst/Hayden Diversion Dam) are influenced by the operation of Coolidge Dam. In the below-dam reach, river flow is maintained during most years by scheduled releases for downstream agriculture users. Steady releases for irrigation can cause alterations in channel morphology (Graf et al. 2002), and the Gila River through this reach appears to have narrowed and deepened to carry higher spring and summer base flows (Paradzick unpubl. data). Inflow from the Lower San Pedro River, about 25 km downstream of the dam, contributes some water. However, when water levels in the San Carlos reservoir are low, due to drought and high levels of diversion and pumping by upstream water users, flow releases from Coolidge Dam can cease. The flood regime also has been greatly altered. Prior to dam closure in 1928, annual flood peaks frequently exceeded 10,000 cfs and sometimes exceeded 100,000 cfs. Since that time, other than a large release in 1993 (29,300 cfs), peak flows have been small (typically <1,000 cfs) immediately downstream of the dam. The disturbance affects of flood flows entering from the San Pedro River apparently have been damped (i.e., reduced flood-plain scouring and inundation) by channel adjustments described above (Paradzick unpublished data).

Abundance Patterns of Tamarisk, Cottonwood, and Willow

Tamarisk distribution and abundance should be considered within the context of the underlying physical and biological processes that shape the ecosystem. The abundance of tamarisk varies over the length of the San Pedro River in tandem with site hydrology, with the species on this river essentially serving as an indicator of low water availability. As well, its abundance differs between the free-flowing San Pedro and flow-regulated Gila River. Differing patterns of abundance of tamarisk, cottonwood, and willow along these rivers reflect the varying responses of these species to environmental influences, at life stages from seedlings through adults.

Tamarisk, Fremont cottonwood, and Goodding willow all are pioneer species that establish in open areas. A typical pattern on Southwestern North American free-flooding rivers is for large winter floods to scour and redeposit flood-plain sediments, creating a patchwork of potential seed beds for plants to establish without competition from an existing overstory. Receding flows in spring moisten the bare sediments during the brief window when viable seed of the cottonwoods and willows are present. Continued flow recession during late spring and summer creates opportunities for the later-seeding tamarisk to establish. However, where cottonwood and willow seedlings are present, they can reduce the growth rate of intermixed tamarisk seedlings. Field and pot studies have shown that as a seedling, tamarisk, a stress-tolerant species, is not a strong competitor against co-establishing cottonwoods (Sher and Marshall 2003). Often, a negative relationship exists between the ability of plants to tolerate abiotic stress and the ability to compete (Grime 1979).

Cottonwood and willow are the dominant tree species in the flood plains of perennial and wet-intermittent reaches of the San Pedro River, given the presence of suitable hydrologic conditions for their establishment and survival (Lite and Stromberg, in press). In these wet reaches, rates of flood water recession and water table decline during recruitment years remain within tolerance ranges (Shafroth et al. 1998). Over time, the flood-plain surfaces vegetated by cottonwood and willow aggrade during depositional flood events. Depth-to-ground water under the mature forests typically remains less than about three meters, with less than one meter inter-annual fluctuation, which prevents mortality from drought in these drought-sensitive species (Horton et al. 2001). At these perennial river sites, tamarisk occurs as a slow-growing understory component of the cottonwood-willow forests (and see Lesica and Miles 2001). It also forms discrete patches in the flood plain, typically on surfaces that have slightly deeper ground water than those supporting cottonwoods and willows.

As flows become increasingly intermittent and ground water deepens, conditions become less suitable for cottonwoods and willows and more suitable for tamarisk. Lite and Stromberg (in press) have defined hydrologic thresholds at which dominance shifts from cottonwood-willow to tamarisk along the San Pedro River. Cottonwood and willow were dominant at sites where surface flow was present more than 74% of the time, inter-annual ground-water fluctuation was less than 0.5 m, and average maximum depth to ground water was less than 2.7 m, during a two-year period of hydrology data collection. Tamarisk was dominant, with cottonwood and willow absent or sparse, where flow permanence was less than 46%. The three species were co-dominant at the intermediate range of hydrologic conditions. This compositional shift largely reflects interspecific differences in tolerance ranges. Compared to Fremont cottonwood and Goodding willow, tamarisk is deeper rooted and more drought tolerant, and less susceptible to canopy dieback from declining water tables. Along a gradient of dependency on ground water, willow is considered to be an obligate phreatophyte and tamarisk to be a facultative phreatophyte, with cottonwood falling in between. Thus, tamarisk can dominate at dry sites that exceed the environmental tolerance ranges of cottonwood and willow (Busch and Smith 1995).

Changes in the flow regime below dams also influence the relative abundance of tamarisk, cottonwood, and willow, as evidenced by patterns on the Gila River. Tamarisk was first observed along the Gila River in 1916 (on a denuded flood plain after a large flood; Robinson 1965) and became abundant by the 1940s and 1950s. From there, it may have spread up the San Pedro River, where it became abundant in the 1950s. Today, tamarisk is more abundant on the flow-regulated Gila River than on the Lower San Pedro, likely due to hydrologic differences between the rivers. Paradzick (unpublished data), in a study of a 38 km reach below Coolidge Dam, found that tamarisk was the dominant patch type in the flood plain, with cottonwoods and willows sparse (figure 1). This likely reflects the combination of altered flood regimes, high-base flow and concomitant channel morphological changes, and fluctuating ground-water levels.

Reduced flood magnitude, suppression of spring flooding, and rapid decline of flood waters have contributed to reduced rates of recruitment of cottonwood and willow along some dammed rivers throughout Western North America (Rood and Mahoney 1990), although on some river reaches populations have remained stable or undergone short-term population increases. Tamarisk, in contrast, often increases below dams, partly because of its opportunistic reproductive strategy. Because it disperses seeds over a longer period, it can thrive in human-altered landscapes where the flood pattern differs from the climatic norm. For example, below-dam increases in tamarisk have been observed on the Verde River, apparently associated with high summer flows for delivery to downstream water users (Beauchamp and Stromberg, unpublished data). With reduction in the intensity and frequency of scouring floods, the cover of tamarisk, and overall density and coverage of woody riparian vegetation across the flood plain, can increase (Shafroth et al. 2002).

Tamarisk abundance patterns along these rivers also may be influenced by land use factors. For example, even when considering only wet sites, tamarisk patches are more abundant in the Lower Basin than Upper Basin of the San Pedro River. This may reflect basin differences in land use history. Past decades of intense livestock grazing may have contributed to high tamarisk abundance in the Lower Basin. When livestock are grazing in riparian seedling beds, they clip the stems of the cottonwoods and willows, which can cause them to lose their height and growth rate advantage to the less palatable tamarisk. Or, wet reaches in the Lower Basin may have been drier in past decades, contributing to high tamarisk abundance in older age classes (Stromberg 1998a).

Forest composition also is influenced by the rate of forest turnover. Flood intensities (measured as total stream power of various return-interval floods) increase with distance downstream along the San Pedro River as watershed size increases but then peak in the upper end of the Lower Basin as stream gradients decline (Lite 2003). This has allowed for greater flood-related turnover of the pioneer forests in the Lower Basin, where the cottonwood, willows and tamarisk populations all are relatively young. In the Upper San Pedro, there is an abundance of old cottonwoods (which pre-date the oldest tamarisk), thus contributing to high relative abundance of cottonwood-willow relative to tamarisk. Tamarisk has not yet reached its maximum life-span on the San Pedro (Stromberg 1998a).

Landscape Heterogeneity, Biomass Structure, and Species Diversity

From a landscape perspective, river flood plains can be viewed as mosaics of patches, each supporting a different vegetation type reflective of particular hydro-geomorphic characteristics. Studies on the San Pedro indicate that patch heterogeneity increases both as a function of flood intensity and stream and ground-water availability (Bagstad et al., unpublished data). As floods of high velocity and shear stress exceed the thresholds for vegetation removal, certain vegetation patches are destroyed, followed by development of new patches that have a different species composition or age structure. With declines in water availability along the San Pedro, the patch diversity declines, despite the active flood regime. Patches maintained by shallow ground water, such as seep-willow (*Baccharis salicifiolia*) shrublands and cottonwood-willow forests, "drop out," leaving only patches dominated by deep-rooted or drought-tolerant species such as mesquite (*Prosopis* spp.), burrobrush (*Hymenoclea* spp.), and tamarisk (figure 1). The trend toward homogeneity is more evident on the Gila River, where periodic drought, flood

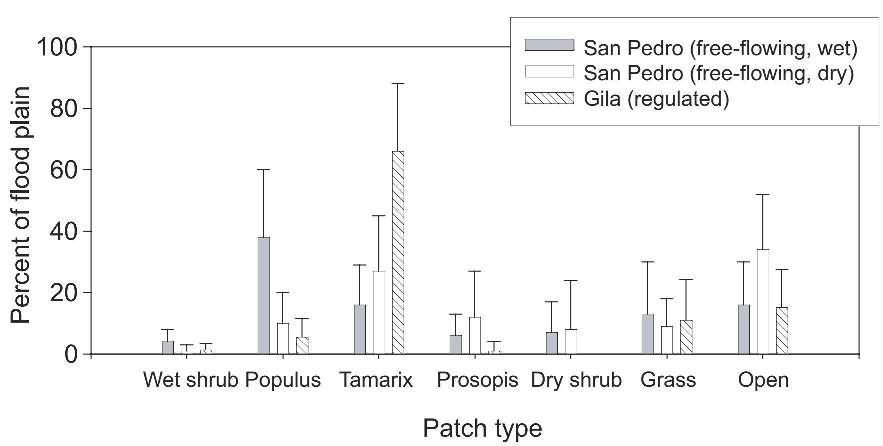

Figure 1—Relative abundance of patch types within the flood plain of the free-flowing San Pedro River (Lower Basin) and the flow-regulated Gila River. Patch types are wet shrublands (*Baccharis salifolia*, *Salix exigua*), *Populus-Salix* patches, *Tamarix* shrublands, *Prosopis* patches, dry shrublands (*Hymenoclea monogyra*), grass-forblands, and open patches (those with <25% cover in ground, mid-story, and canopy strata). The San Pedro sites were classified into wet (>70% flow permanence) and dry (<70% flow permanence) categories, based on data collected over a two-year period. Values shown are means (and standard error) of 6 to 10 sites per river type.

reduction, and geomorphic changes associated with river damming have created a more homogenous landscape (figure 1). The patch structure is simplified compared to that of the Lower San Pedro River, its major tributary.

There also are changes in vertical biomass structure at dry sites. As composition shifts from cottonwood-willow to tamarisk across spatial gradients of water availability, structure of the riparian forest changes accordingly, reflecting the different growth forms of the species. Along the San Pedro River, average canopy height declined from 23 meters to 13 meters, vegetation volume in upper (above eight meters) canopy layer declined, and woodlands gave way to the shrubland structure type, from perennial to dry-intermittent sites (Lite and Stromberg, in press). These structural changes, together with reduced patch diversity, can reduce wildlife habitat. Tamarisk dominance is not the ultimate cause of the altered wildlife habitat, rather, it is the proximate manifestation of a shift towards a more xerophytic growth form resulting from declines in the resource base. On dynamic, wet river reaches, the complexity of structural types, inclusive of tamarisk patches, creates a habitat-rich area. Many bird species, including the southwestern willow flycatcher, utilize tamarisk patches for nesting and feeding (Paradzick and Woodward 2003; Yard 2003).

The combination of ample water and active flood regimes results in high plant species richness in riparian ecosystems. As flows become more intermittent and ground-water tables decline, there is loss of obligate and facultative wetland herbs and woody hydrophytes (Lite et al., unpublished data). Plant species richness also can be altered by dams. Below-dam richness can increase in some contexts, but also can decline in response to reduced flood disturbance (and reduced temporal and spatial heterogeneity) or to reduced resource availability (e.g., reduced water and nutrient holding capacity of silt-poor soils). Several reviews have reported low biodiversity in tamarisk patches or ascribed other community changes to tamarisk (e.g., Di Tomaso 1998). However, these findings are largely based on studies conducted on dammed and flow-regulated rivers, where species effects are confounded by effects due to changes in the physical processes that regulate species diversity.

Few studies have compared biodiversity levels between vegetation patches on free-flowing rivers. On the San Pedro River, an interesting pattern emerged wherein herbaceous species richness was higher in tamarisk than in cottonwood patches, while woody species richness was higher in cottonwood-willow patches (Bagstad et al., unpublished data; Stromberg 1998b). As well, the understory of the tamarisk had a lower percentage of introduced species than did cottonwood patches. Although this latter pattern is consistent with the lower (and wetter) fluvial surfaces of the cottonwood patches, one also would expect the lower lying cottonwood patches to have higher richness of understory species. However, many factors influence species diversity. The dense canopy (and dense litter layer) of the cottonwood forests may preclude establishment of small-seeded species, and produce a depauperate herbaceous understory, while favoring survivorship of the often larger seeded tree species. Differences in soil mycorrhizae populations between Fremont cottonwood and tamarisk patches, a topic that warrants further study, also may come into play.

Riparian Ecosystem Change and River Restoration

Various conceptual models exist to explain recent changes in Souwthestern riparian communities (figure 2). One model places tamarisk as the main driver of biotic changes, by modifying the resource base and disturbance regime. However, the supporting evidence for such changes (including river salinization and dewatering), when one traces the citation trail, is very sparse, or is not substantiated by recent research. Recent reviews (Glenn et al., unpublished data), for example, demonstrate how measured rates of tamarisk evapotranspiration have declined over time as methodologies have improved; rates of tamarisk evapotranspiration now are viewed as being on par with many Sonoran riparian species, with a water use of about 1 m per year. With respect to salinization of flood plains, unsubstantiated and perhaps erroneous conclusions have been drawn (e.g., Walker and Smith 1997) by confounding the *correlation* between halophytic tamarisk and saline habitats with *causation.* On one free-flowing river, differences in soil salinity between cottonwood-willow and tamarisk patches were not evident (Bagstad et al., unpublished data; Stromberg 1998b). On regulated Southwestern river systems, salt accumulation on the soil surface could be a combined effect of tamarisk exudation and lack of flushing flood flows, as some have speculated (Shafroth et al. 1995), but this has not been rigorously investigated.

An alternative model places humans as the primary cause of the vegetational shifts from cottonwoods-willows to tamarisk, by altering flood patterns, water quantities, and water quality (figure 2). Certainly, all plants modify their environments; the presence of tamarisk as a competitor likely restricts cottonwoods and willows from areas of marginal habitat. However, there is considerable evidence that tamarisk dominance is part and parcel of a suite of changes associated with river flow management: dewatering causes declines in species biodiversity and landscape heterogeneity and drives compositional shifts toward drought tolerant species, while dam operation further contributes to reduced heterogeneity and diversity. Thus, the dominance of tamarisk can be viewed as an indicator, rather than a prime cause, of degradation, that reflects alterations to the biophysical factors and processes that control riparian ecosystem structure.

If one fails to address the root causes of riparian vegetation change, the desired end product likely will not be attained, and adverse effects could result from ecosystem manipulations. On diverted or regulated streams, where there is a clear decline in the fundamental resource base or disturbance regime, restoration of flow regimes is warranted. Many restoration efforts, however, simply involve "weeding" tamarisk from flood plains. By clearing tamarisk from such reaches, without increasing water resources or modifying disturbance regimes, one may further reduce the quality of the habitat depending on what plant species are available to replace the tamarisk patches.

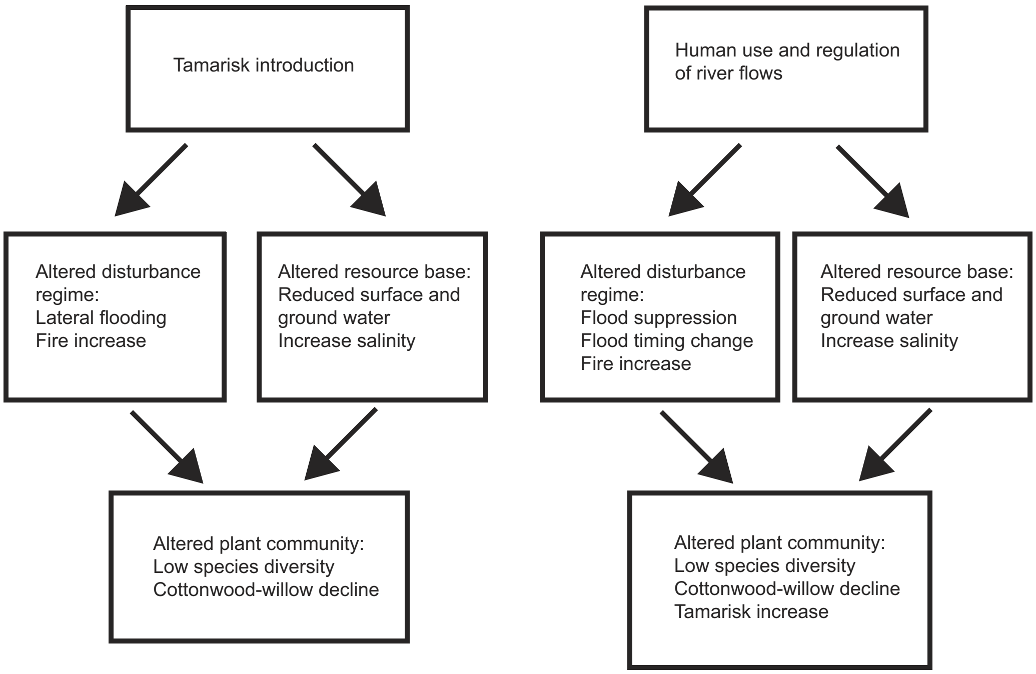

Figure 2—Alternate conceptual models of the primary factors driving changes in riparian plant communities of Southwestern river flood plains.

On free-flowing, perennial, ungrazed rivers, restorative efforts (including tamarisk weeding) likely are not needed. When an introduced species such as tamarisk is simply one of a mixture of species in a diverse riparian plant community, there does not appear to be any compelling reason, other than aesthetic, to engage in tamarisk removal efforts.

It is fundamentally more difficult to restore river flows or "re-wild" rivers than it is to rally efforts around removing an unwelcome species. There are a few notable cases where rivers are being re-watered for restoration purposes. Among these is the San Pedro, which has become a mitigation site for regional riparian degradation, resulting in local reductions in rates of ground water pumping from the stream aquifer. Monitoring of changes in species diversity, landscape heterogeneity, and cottonwood, willow, and tamarisk abundance, in response to river re-watering, will provide an interesting test of our knowledge of riparian plant-environment relationships.

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Hydrology and Biodiversity

The Lower San Pedro River—Hydrology and Flow Restoration for Biodiversity Conservation

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***Abstract**—The lower San Pedro River, downstream from Benson, is a nearly unfragmented habitat containing perennial flow reaches that support riparian vegetation that serve as "stepping stones" for migratory species. The Nature Conservancy has purchased farm properties and retired agricultural pumping along the lower river, based largely on results from hydrologic analyses indicating that increased water availability for riparian vegetation will result from retiring agricultural pumping at key locations. A long-term commitment to hydrologic and ecological monitoring provides data that the Conservancy uses to inform property management, guide habitat restoration, and measure success of the agricultural retirement strategy.*

Introduction

The San Pedro River originates in the Sky Islands and desert grasslands of southeastern Arizona and northern Sonora, Mexico, and extends approximately 140 miles north to join the Gila River at Winkelman, Arizona. The San Pedro River watershed has been divided into two hydrologic cataloging units in the United States—the upper San Pedro and the lower San Pedro (Seaber et al. 1987). The Lower San Pedro, comprising an area of about 1,980 square-miles and containing about 76 miles of river, begins at "The Narrows," which consists of a bedrock constriction in the valley 12 miles north from Benson. The lower San Pedro River basin is shown in figure 1.

The San Pedro River is a migratory corridor of international importance for neotropical birds, bats, and insect pollinators (Kreuper 1996) and is considered one of the best remaining occurrences of Sonoran cottonwood-willow riparian forest, one of the rarest woodland types in North America (Noss et al. 1995; Stromberg et al. 1996). Compared to the upper San Pedro, the lower San Pedro basin is considerably less populated and has received less research attention; however, the lower San Pedro is an equally important terrain, with numerous reaches of high quality, cottonwood-willow riparian habitat that serve as "stepping stones" for migratory bird species (Skagen et al. 1998). The lower San Pedro River and its tributaries serve as important corridors linking the Rincon-Catalina Mountain complex to the west with the Galiuro Mountains to the east, as well as serving as a north-south corridor linking these mountain ranges with ranges to the north and south.

San Pedro River Hydrology

The lower San Pedro River flows north in the San Pedro trough, an elongated structural depression bounded on the southwest by the Catalina core complex and associated uplands lying farther north and bounded on the northeast by the faulted range fronts of the relatively undeformed Galiuro and Dripping Spring Mountains (Dickinson 1991). The San Pedro trough contains basin-fill deposits (Quiburis Formation) that overlie a complexly corrugated paleotopography of internal tilt blocks forming the substratum of the trough floor (Dickinson 2003). Inset into the basin-fill deposits along the San Pedro River is the recent floodplain alluvium, comprised of unconsolidated, chiefly course-grained sediments that immediately underlie and adjoin, and are in direct hydraulic communication with, the stream.

The San Pedro River was formerly perennial or nearly perennial throughout much of its length (Brown et al 1981; Tellman et al. 1997). Current and formerly perennial reaches are shown in figure 1. In the lower San Pedro River, at least 50 miles of perennial flow has been lost (digital analysis of Brown et al. 1981), chiefly as a result of human activities that have changed the river in numerous ways. Lost perennial flow has eliminated riparian habitat in many areas; reduced perennial flow has degraded riparian habitat, resulting in an increase in the population of non-native species, such as tamarisk, at the expense of cottonwood-willow riparian forest.

Locations of perennial flow reaches in the San Pedro River are controlled chiefly by the underlying paleotopography. Where tilted fault blocks have produced low-permeability bedrock at shallow depths below the river, the overlying higher-permeability basin-fill deposits are thinned; these bedrock constrictions force groundwater in the alluvial aquifer to discharge to the river. The presence of fine-grained facies in the basin-fill deposits may also control locations of perennial flow. Fine-grained layers act as a confining unit, restricting the connection between the deeper regional aquifer (basin-fill deposits aquifer) and the shallow aquifer/river system. Vertical upward groundwater flow may occur through sand and gravel deposits at the edge of the fine-grained layers, allowing discharge from alluvial aquifers to the river and forming perennial reaches.

Mining and agriculture are the chief water uses in the lower San Pedro River basin; water use in 1990 totaled about 40,000 acre-feet. Groundwater pumping from the recent alluvium aquifer most directly diminishes streamflow. Pumping from the basin-fill deposits aquifer may indirectly diminish streamflow

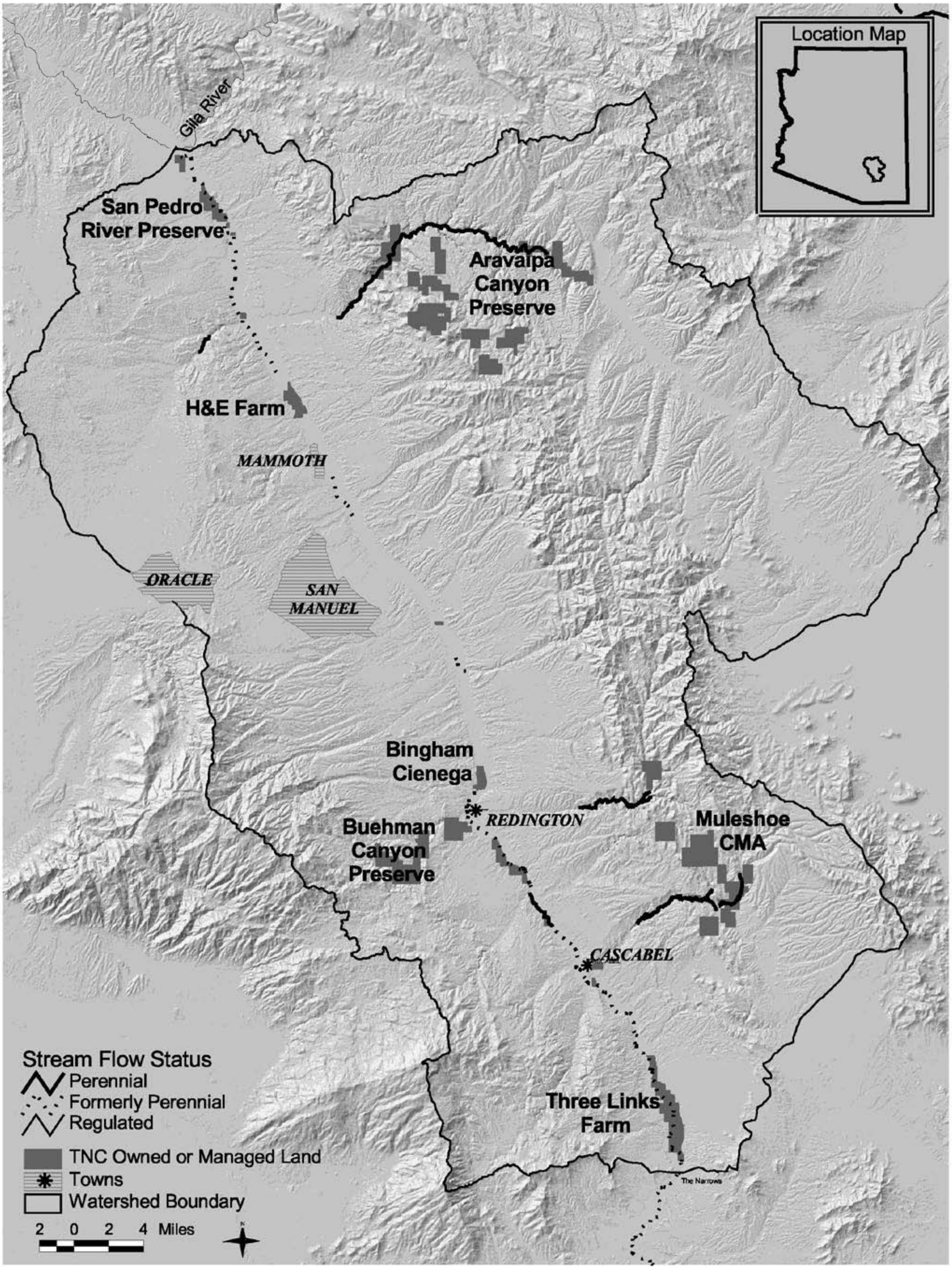

Figure 1—The Lower San Pedro River Basin.

through interception of groundwater that would have otherwise discharged to the recent alluvium and hence to the stream. Groundwater pumping leads to groundwater level decline and decreased perennial flow, which cause degradation of riparian and aquatic ecosystems. Recent research shows major reduction of streamside emergents as streams are converted from perennial to intermittent; even small increases in the degree of streamflow intermittency cause reductions in plant species richness and shift species composition from wetland species to more drought tolerant species such as bermuda grass (Julie Stromberg, Arizona State University, personal communication, April 14, 2004).

The Nature Conservancy's Flow Management Approach

The Nature Conservancy actively promotes biodiversity conservation throughout the San Pedro River basin by engaging agency and community partners in effective working relationships that foster conservation. As part of the overall conservation toolbox, the Conservancy may purchase land in key areas to meet conservation goals in that area. For the lower San Pedro River, a major conservation goal is increased water supply for riparian vegetation and a corresponding improvement in extent and quality of riparian habitat. To this end, the Conservancy has purchased three major farms totaling 3,545 acres along the lower San Pedro River; more than 8,000 acre-feet per year of agricultural groundwater pumping has been retired on these three farms.

The flow management approach can be described in four broad steps: (1) conduct hydrologic analyses, including groundwater-surface water modeling, to simulate impact to groundwater levels and surface water flow from various agricultural pumping retirement scenarios; (2) based on results from hydrologic analyses, purchase property and retire agricultural pumping at key locations; (3) following property acquisition, conduct monitoring to provide data for delineating baseline conditions and trends in ecosystem parameters; and (4) utilize data from monitoring to refine management actions and, ultimately, to gage success of the property acquisition-agricultural pumping retirement strategy.

Existing models are used, where available, for conduct of hydrologic analyses. Because an appropriate-scale groundwater model did not exist for the San Pedro River downstream from Redington, the Conservancy provided partial funding to support a University of Arizona graduate student to develop a model for this area. The model is nearly complete and will be used to analyze hydrologic response to various water management scenarios on the lower San Pedro River.

Hydrologic Monitoring and Results

The Nature Conservancy conducts hydrologic monitoring at a number of locations in the lower San Pedro River basin, including sites along the river as well as sites in several tributaries. Results from monitoring at the three largest properties on the river—the San Pedro River Preserve, H&E Farm, and Three Links Farm—are summarized below.

San Pedro River Preserve

In 1996, the Conservancy obtained a grant from the U.S. Bureau of Reclamation to acquire the 820-acre San Pedro River Preserve on the San Pedro River near Duddleyville (figure 1). The property was formerly used for agriculture and aquaculture, with annual groundwater pumping of about 2,500 acre-feet per year (AFA), the majority of which was retired. The riparian corridor was fenced to exclude cattle and off-road vehicle (ORV) use. Hydrologic studies were conducted and a groundwater model was constructed to delineate impact to groundwater levels and river flows from various habitat restoration scenarios. Data indicated less impact to river flows from conversion of old ag fields to native grasses as compared to conversion to mesquite bosque. These data guided restoration design.

Preserve staff conduct monthly measurement of groundwater levels, surface water flow, and precipitation. Water levels from selected wells are shown in figure 2; data indicate that water in the stream and in the recent alluvium are in direct hydraulic communication, as witnessed by the rise in groundwater levels following the flood of October 2000. Groundwater levels fluctuate seasonally, reflecting climatic cycles and changes in riparian vegetation water use. Overall, groundwater levels have declined 1.5 to 2 feet since measurement began in August 1998 (figure 2), a period of severe drought. Despite drought-induced groundwater level and streamflow decline, riparian vegetation has thrived, based on field observations. Riparian-floodplain transects have been established and repeat surveys will provide data to document trends in riparian vegetation and channel geomorphologic condition.

H&E Farm

Groundwater level data, extent of surface flow, and geologic data available for the area from Mammoth to the Aravaipa Creek confluence were analyzed to predict results from various agricultural retirement scenarios. Results of analysis justified the purchase in 2001 of the 528-acre H&E Farm, with corresponding retirement of about 2,100 AFA of groundwater pumping. The riparian corridor was fenced to exclude cattle and ORV use. The expected benefit is extended perennial flow upstream from Aravaipa Crossing.

Preserve staff conduct monthly groundwater level measurements and measure precipitation; streamflow is currently ephemeral adjacent to H&E Farm and hence is not measured. Water levels from four shallow monitor wells installed in the floodplain are shown in figure 3, which also shows streamflow at the Redington gage. Data indicate that water level in the recent alluvium aquifer is responsive to river flows, with an immediate rise in water level following a flow event, followed by a decaying water level trend until the next flow event. Precipitation has been far below normal since property acquisition; few flow events have occurred and groundwater levels have overall declined. Riparian-floodplain transects

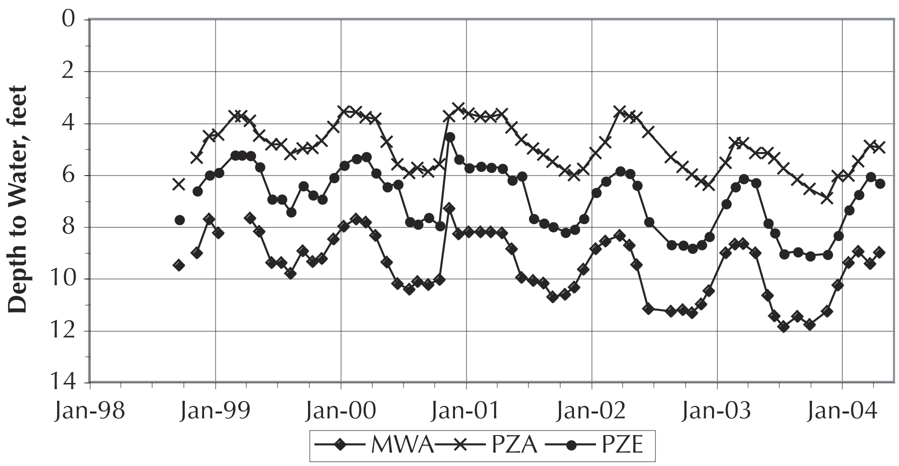

Figure 2—Depth to water in selected monitor wells at the San Pedro River Preserve.

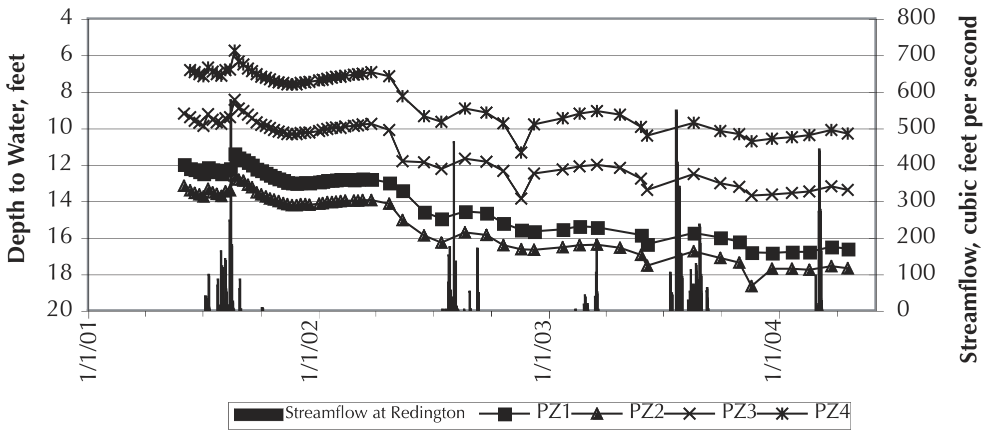

Figure 3—Depth to water in selected monitor wells at H&E Farm and streamflow at Redington.

have been established and repeat surveys will provide data to document trends in riparian vegetation and channel geomorphologic condition.

Three Links Farm

In 1998, The Nature Conservancy contracted a consulting hydrologist to resurrect an existing groundwater-surface water model (Jahnke 1994) for the purpose of analyzing hydrologic system response to specific agricultural retirement scenarios along the lower San Pedro River (Lombard 1998). The modeled domain extended from Fairbanks to Redington. Results of modeling justified the purchase, in 2003, of Three Links Farm, with corresponding retirement of nearly 3,500 AFA of groundwater pumping. The riparian corridor is being fenced to exclude cattle and ORV use. Based on model results, the expected benefit is increased extent of perennial flow in 14 miles of the San Pedro River, in the reach from Three Links to Cascabel.

Conservancy staff measure streamflow and depth to water in monitor wells quarterly; precipitation at the site is recorded. Results from groundwater and streamflow monitoring are shown in figure 4. Although the record is short, results indicate that water levels vary on a seasonal basis and water levels overall have remained fairly steady. The stream gains flow as it moves from Station 1 (most upstream) to Station 3, then loses flow to Station 4 (most downstream).

Hydrologic analysis at Three Links Farm indicates substantially more hydrologic connectivity through “The Narrows” than formerly documented, which has implications to management of properties downstream from The Narrows in view of the expected increase in municipal water use upstream from The Narrows.

Summary and Conclusions

The lower San Pedro River has received much less research and public attention than the upper San Pedro River. However, the lower San Pedro is an equally important terrain. The lower San Pedro basin is an institutionally less complex region than the upper and may offer more traction for biodiversity conservation. Hydrologic connection exists between the upper San Pedro basin and the lower San Pedro basin, both in terms of flood flows and in terms of groundwater underflow through The Narrows.

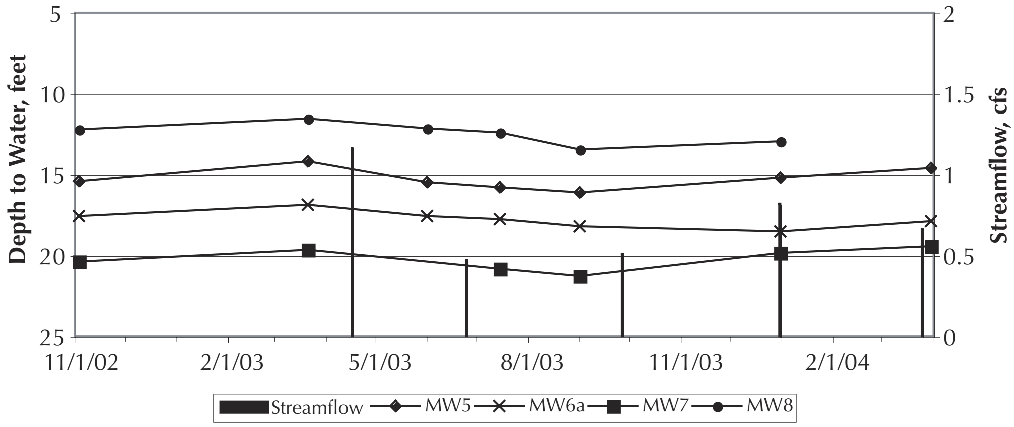

Figure 4—Depth to water in selected monitor wells and streamflow at Three Links Farm.

The Nature Conservancy employs a flow management approach to biodiversity conservation on the lower San Pedro River, with the goal of improving the water supply for riparian vegetation and returning flow to formerly perennial reaches of the river. Purchase of farms in the lower San Pedro River by the Conservancy has resulted in retirement of about 8,200 AFA of groundwater pumping. In addition, closure of the San Manuel mine has eliminated about 20,000 acre-feet of groundwater pumping. Therefore, more than half of the cultural groundwater use has been eliminated, with expected benefits for the river and riparian system.

Hydrologic monitoring and analysis of hydrologic data, both published and unpublished, contributes to: (1) selecting properties for acquisition; (2) restoration design and implementation; (3) delineating trends in ecosystem parameters; (4) documenting and reducing threats to conservation targets; (5) measuring success of a selected strategy; and (6) refining management actions accordingly.

Hydrologic components are key to restoration in riparian and wetland systems. Results from hydrologic monitoring at properties on the lower San Pedro River reflect the severe drought that has been occurring. Data from San Pedro River Preserve and Three Links Farm indicate that where hydrologic conditions support near-surface water, removal of stresses such a pumping for agricultural irrigation and cattle grazing in the riparian corridor provide system resilience for buffering against drought.

Groundwater systems respond slowly to human actions and response is often over-printed by natural climatic variation. Understanding the intricate interactions between surface water, groundwater, and riparian-aquatic systems is integral to appropriately managing these complex systems. Such understanding comes from a long-term commitment to hydrologic and ecological monitoring—collection of high quality data at consistent time intervals for an adequate length of time—prior to judging the success of a selected conservation or restoration strategy.

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Hydrology, Ecology, and Management of Riparian Areas in the Madrean Archipelago

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Abstract—*Riparian areas in the Madrean Archipelago have historically provided water necessary for people, livestock, and agricultural crops. European settlers were attracted to these areas in the 1880s, where they enjoyed shade and forage for themselves and their livestock and existed on the readily available wildlife and fish. Trees growing along stream banks were harvested for fuel, poles, and building materials. Demands for water dominated management of riparian corridors as human populations increased after World War II. Many of these fragile ecosystems were altered by attempts to salvage water. Only within the last 25 to 30 years have people once again begun to recognize the value of the diverse benefits associated with riparian areas. The changing management emphasis of riparian areas in the Madrean Archipelago is a focus of this paper. Research and management issues continue to concern the flows of water and sediments, the impacts of livestock and other human activities, and the sustaining of wildlife and fish habitats, vegetative structure, and patterns of plant succession.*

Introduction

Riparian areas in the Madrean Archipelago occupy less than two percent of the total land area. Nevertheless, these ecosystems are the most productive and valuable of all of the lands in the region. They are found in a range of climatic, hydrologic, and ecological environments from high-elevation montane forests through intermediate-elevation woodlands to low-elevation shrublands and desert grasslands. They are located along the banks of rivers and streams and around the edges of lakes, ponds, and meadows and they are delineated largely by soil characteristics and vegetative communities that require free or unbound water. However, the abruptness and extent of the transitions between the terrestrial and aquatic interfaces that define these riparian areas are mostly site-specific.

Much has been learned about the hydrology, ecology, and management of riparian areas in the Madrean Archipelago and, more broadly, the Southwestern United States in recent years (DeBano and Baker 1999; Baker and others 1999; Cartron and others 2000). Many of the inherent relationships between these areas and their surrounding watersheds are known as a result of earlier and ongoing management experiences and research efforts. The general nature of these relationships, the historical and current riparian resource use, and the changing emphasis of riparian management in the region are presented in this paper. More comprehensive treatments of these topics are found in a recently published book by Baker and others (2004) on the hydrology, ecology, and management of riparian areas in the region.

Hydrologic Relationships

Flows of water, sediments, and other pollutants through riparian corridors are controlled by vegetation, physiography, and geologic formations within a closely linked system. Most of the stream systems originating in the Madrean Archipelago are either intermittent or ephemeral. Flowing water is observed in response to large frontal rain storms and (occasionally) to snowmelt-runoff events in the winter and spring and to monsoonal thunderstorms in the summer (DeBano and others 1996; Baker and others 2004). Although streamflow is often discontinuous, communities of riparian vegetation occupy adjacent flood plains where the water table is near the surface most of the year. Annual precipitation at higher elevation is generally sufficient to sustain longer periods of streamflow through the higher elevation riparian corridors.

The health of riparian areas in terms of the efficiency of their hydrologic and ecological functioning is dependent largely on the movement and storage of sediments through the channel systems. Sediments entrained in overland flow from surrounding hillslopes are deposited into the channels. These sediments then move to sites downstream in flowing water, where they accumulate until "flushed" to still further downstream sites with larger volumes of streamflow. Therefore, the transport of sediments into and through riparian corridors is episodic because the prime mover of eroded soil materials is the infrequent large storm (Baker and others 1998; DeBano and Baker 1999). However, the intermittent storage and movement of sediments through the channel systems in response to a disturbance is a complex process. A disturbance factor of significance is the loss of plant cover associated with "improper" or "unwise" management practices or with severe wildfire events, producing large amounts of overland flow and consequent streamflow that move sediment deposits that were previously stored in the channel system.

Buffer strips of trees, shrubs, and herbaceous plants adjacent to channel systems act to reduce the velocity of overland flow that carries sediments and other pollutants from hillslopes toward the channel systems. Many of these pollutants are also trapped in accumulations of litter and duff within the buffer strips before entering the channels (DeBano and Baker 1999; Baker and others 2004). Shade cast by stream-side vegetation also helps to reduce thermal pollution of shallow low-volume streams. Other benefits of these buffer strips include maintaining streambank stability and channel integrity; and furnishing shelter and food for livestock, wildlife and fish species, and other aquatic organisms.

Land-use activities can change riparian-watershed relationships by disrupting the proper functioning of hydrologic processes within the riparian corridors and their surrounding hillslopes. Included among these activities are livestock grazing, tree cutting, and mining practices that affect the regulating effects of vegetation on soils, streamflow, and water quality. Recreational endeavors leading to the loss of riparian vegetation or soil compaction, and construction and continuing maintenance of roads and trails are also problems. The spreading urbanization and rural housing developments that are common throughout the Madrean Archipelago are other land-use activities of concern, largely because of the increasing groundwater extractions and water withdrawals accompanying these activities. Natural disturbances most likely to affect the hydrologic functioning of riparian areas are flooding events following large intense rainfall events and the loss of protective vegetation and damage to soil resources caused by wide-spread wildfire. People have little control over these latter events other than to maintain the best possible riparian-watershed conditions so that the affected systems can withstand the disturbances.

Ecological Relationships

Riparian corridors are sites where the soil moisture generally exceeds that otherwise available due to water flowing into and through the stream channels or subsurface seepage (DeBano and Baker 1999). Excess water in these systems facilitates establishment of soil-vegetation habitats that reflect the influence of the extra soil moisture. The variable soils of riparian ecosystems are largely reflective of the nature of the parent materials, topographic setting, and stream morphology and gradient. Soils at higher elevations consist of consolidated or unconsolidated alluvial sediments that are derived from a wide range of granitic, metamorphic, and sedimentary bedrock materials that form the surrounding uplands. Soils on flood plains are more recent depositions, tend to be uniform within horizontal strata, and exhibit little structural development. The alluvial soils of most riparian areas are subject to frequent flooding and, as a result, are characterized by a range of textures. Riparian ecosystems are found in widely different geomorphologic environments that vary from narrow, deep, steep-walled canyon bottoms, to intermediately exposed sites with one or more terraces or benches, to exposed, wide valleys with meandering streams.

Riparian vegetation at higher elevations occurs as mosaics of dynamic successional stages in relatively narrow bands along steep and narrow stream systems, while broad floodplains support more extensive plant communities (Cartron and others 2000; Snyder and others 2002; Baker and others 2004). Many riparian trees and shrubs require periodic flooding events to disperse their seeds and create sediment bars for their germination (Brock 1994). The distribution and structure of stands of these trees and shrubs are determined largely by flooding as a consequence. The frequency of flooding in some riparian ecosystems is such that the riparian vegetation remains in a state of early succession.

Compositions of plant cover are largely determined by elevation. Much of this "elevational stratification" is attributed to the availability of water for plant establishment and growth. Precipitation at higher elevations provides a more reliable source of water for the survival of plants than is found at lower elevations where local rainfall alone is often insufficient. Plants in riparian ecosystems at lower elevations require access to flowing water or a groundwater aquifer for their development. The rooting systems of riparian trees and shrubs bind the soil together, promote high infiltration rates, and provide streambank stability. A variety of grasses and grass-like plants, forbs, and half-shrubs help in armoring streambanks against large, channel-forming flood flows.

The mammals, avifauna, and herpetofauna found in the Madrean Archipelago are closely related to and largely dependent on the nature of the habitat conditions encountered within riparian corridors. Foraging habits, protective cover, and breeding areas and nesting sites are all related to the composition, structure, and spatial arrangements of the required habitat components of food, cover, and water (Baker and others 2004). Life cycles of some wildlife species include time spent in the riparian corridors of mostly one ecosystem, while other species seasonally migrate between and among riparian ecosystems and the surrounding watersheds. As a consequence, species that are identified as inhabiting particular ecosystems frequently overlap.

Many of the riparian-stream systems have historically supported the aquatic habitats critical to the survival of native fishes. However, the availability of suitable habitats and native fishes in these areas has declined markedly in the past 75 years (Baker and others 2004). Aquatic habitats have been modified or lost through the construction of dams, water diversions, and groundwater withdrawals. Biological alterations have also occurred in the form of introductions of nonnative fishes, crayfish, and frogs. Several native species are extinct and local extirpations are common as a result. While the rate of these hydrologic and biological changes has slowed in recent years, the effects of previous alterations can persist in many instances.

Resource Use

Livestock grazing in the Madrean Archipelago began in the 1600s, when the Spanish established missions along (mostly) permanent streams and their livestock concentrated along these streams for shade, forage, and water. Some riparian corridors continue to be grazed by livestock. However, resource managers and the general public are becoming increasingly concerned about the need to balance the use of riparian areas for livestock grazing with other often non-consumptive uses of the ecosystems (Chaney and others 1990; Jemison and Raish 2000; Baker and others 2004). Livestock grazing in riparian corridors has been curtailed in recent years because of this concern. Unfortunately, earlier overgrazing has deteriorated many riparian ecosystems to the extent that they have ceased to function properly in a sustainable manner and, therefore, restoration efforts have become necessary.

Early settlers in the Madrean Archipelago also cleared riparian trees on floodplains so that the soils of alluvial bottoms could be used for agricultural crop production and livestock grazing purposes. These people did not always view the trees in riparian forests as a valuable resource to sustain (DeBano and Baker 1999; Baker and others 2004). Riparian trees were "mined" rather than "managed" as a consequence, a practice that continued off-and-on into the early 1970s. Clearing of riparian trees has been limited in more recent years because of environmental concerns, and, as a result, only dead and downed wood is occasionally gathered by campers for firewood.

Wildlife species associated with riparian ecosystems have historically had value in hunting for sport, viewing and photography, and in ecosystem functioning such as nutrient cycling and changing physical and chemical properties of the soil resources. Required food, cover, and water for these wildlife species are often found in these relatively cool and shaded streamside environments. Nearly 80% of all vertebrates found in the Arizona and New Mexico spend at least one-half of their life in riparian corridors and more than a half of these species are totally dependent on these sites for their well being (Chaney and others 1990). Many of these species are classified as threatened or endangered on Federal or State listings.

Many of the fish species in the rivers and streams flowing through the riparian corridors are also threatened, endangered, or being considered for listings in one of these categories. A judicious implementation of instream flow rights is necessary in providing adequate streamflow to maintain viable fish populations (Rinne and Minckley 1991; Rinne 1994) and, therefore, is a main focus of fishery management in the region. An instream flow right is a legal entitlement to the non-consumptive use of surface water within a specified area of a stream channel for fish, wildlife, recreational use, and the sustainability of streamside vegetation.

Recreational use of riparian areas has always been disproportionate to the small area that they occupy. Recreational activities that are common in these fragile ecosystems include hunting and fishing, picnicking, camping, and off-road vehicular use. Canoeing and tubing opportunities occur on some of the larger waterways. These streamside environments also provide a shady place for people to walk, look at birds, or simply enjoy a pleasant quiet time. Riparian ecosystems have long been recognized for their scenic beauty.

Water continues to be the most important natural resource in this water-limited region. The main use for this intermittently available but crucial resource has historically been related to the agricultural sector (DeBano and Baker 1999; Baker and others 2004). However, the increasing water demands associated with urban sprawl and other developments continue to impact on the sustainability of many riparian ecosystems because of the water withdrawals necessary for continuing development. As groundwater pumping technology improved, it has become possible to extract more water from ever-increasing depths. A consequence of the increased pumping has been a lowering of water tables in some basins to the point where sustainability of many of the waterways and adjacent riparian ecosystems is threatened. Nevertheless, viable sources of high-quality water remain necessary to support growing human needs, compounding the water-scarcity problems in the region.

Changing Emphasis of Riparian Management

Conversion of riparian plant communities along stream channels and on adjacent floodplains to other vegetative types that transpire less water and, in doing so, provide more water for downstream users was a main theme of watershed management in the Southwestern United States from the late 1940s through early 1970s. Possibilities for water yield improvement by converting the high water-using riparian vegetation to low water-using plants were considered to be potentially significant for a number of reasons. The high transpiration rates of plants growing in the region's riparian corridors, with their roots extending into the vicinity of the water table or capillary fringe, was a main reason for the original optimism that these conversions might increase downstream water supplies (Baker and others 1999). Removals of phreatophytes such as the saltcedar (*Tamarix* spp.) created particular interest. Managers believed at the time that phreatophytes were relatively low in their economic value and, importantly, were high water-wasters.

Early watershed experiments were conducted to ascertain the potentials for water yield improvement by removing saltcedar, other phreatophytes, and other riparian vegetation (DeBano and Baker 1999; Baker and others 2004). While the results from these experiments were largely inconclusive in terms of water yield improvement, eradication programs continued into the early 1970s. However, continual pressure exerted by environmental groups and the general public to preserve or develop riparian areas for wildlife habitats, recreational opportunities, and aesthetic values resulted in a changing emphasis in riparian ecosystem management by the middle of the 1970s (Baker and others 1999). People's interest in the health and sustainability of riparian ecosystems had increased greatly by this time. No longer was water yield improvement a primary focus of watershed management and, therefore, the eradication of riparian vegetation for this purpose largely ceased. But, impacts on native plant communities by exotic species like saltcedar will continue to be a major concern.

Concern for the declining health of riparian areas, expressed initially by the scientific community, is shared today by a much broader spectrum of interest groups including land and water resource managers, legislators and litigators, educators, and environmentalists. All of these interested stakeholders are seeking more information and a better understanding of the dynamics, functions, uses, and the restoration of degraded riparian areas. This holistic form of management for riparian areas has proven timely and is, it has been concluded, an appropriate land-use strategy for the Madrean Archipelago because of the urgent need to sustain the integrity of these ecosystems.

Conclusions

Ramifications of increasing populations of people will influence how riparian areas in the Madrean Archipelago will be used and the nature of their management into the future. The effectiveness of people's stewardship of these fragile ecosystems must improve to accommodate the growing needs for conservation and the sustainable use of riparian lands, water, and other natural resources in the region. A better balance between environmental benefits that are associated with land, water, and other natural resources management practices and the products, services, and amenities obtained in riparian ecosystems and demanded by society will be necessary.

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Comparing Ecosystem Water and Carbon Exchange Across a Riparian Mesquite Invasion Gradient

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Abstract—*Ecosystem water and carbon fluxes were monitored over a riparian grassland, mesquite-invaded grassland, and mesquite woodland to understand the consequences of woody plant encroachment. Water use and carbon gain were largest at the woodland site. Results suggest that the deep roots of mesquite will lead to a decoupling of ecosystem water sources as the invading mesquites mature in former grasslands. The ability of mesquite to rely on stable groundwater sources rather than precipitation enhanced net carbon uptake in the dry periods and net carbon loss in rainy periods. These results highlight the important role that water sources and ecosystem morphology play on controlling water and carbon balances in semiarid areas.*

Introduction

How vegetation and climate interact to affect terrestrial carbon, water, and soil nutrient cycles is not well understood. Between 50 and 90% of North America's biomes may see significant shifts in vegetation composition and land cover in the near future (Neilson 1993), which may become the most ubiquitous form of global change. Additionally, the timing and magnitude of precipitation inputs into North American ecosystems have been forecasted to change (Houghton et al. 1996). With these shifts in climate and land cover, understanding potential linkages between ecosystem structure, function, and climate variability is warranted.

In the Southwest, precipitation is often the dominant control on biological activity (Noy-Meir 1973). Altered depth-duration frequency distributions of precipitation events, combined with shifts in vegetation (through woody-plant encroachment of grasslands, non-native species invasions, riparian encroachment by phreatophytes, etc.) may alter biological activity across a landscape in quite unpredictable ways. The historic increase of woody plants within the grasslands and savannas worldwide is an aspect of land cover change with large-scale ramifications (Archer 1994; McPherson 1997). Woody plant encroachment can decouple primary productivity from summer rains in the Southwest; deeply rooted woody plants access water sources unavailable to grassland species (Scott et al. 2004). However, increases in primary productivity may be offset by larger respiratory fluxes from soil microbial communities that are still highly responsive to summer precipitation and fueled by high quality litter inputs from the woody vegetation.

In this paper, we briefly investigate the consequences of mesquite encroachment on water and carbon exchange in a Southwestern riparian area. Encroachment by mesquite (*Prosopis* spp.) is arguably the most pervasive and temporally dynamic land-cover change in the Southwestern United States. Our goal is to predict how on-going woody plant encroachment affects ecosystem water and carbon cycling by understanding the abiotic and biotic controls on these fluxes. Fulfillment of this goal will provide important information about the role of riparian vegetation in basin water balances and how woody plant encroachment changes the carbon cycling and carbon sequestration potential of semiarid lands. Our approach is to make multiyear observations of carbon and water fluxes from a grassland, a grassland that has been encroached by mesquite (a shrubland), and a mesquite woodland, assuming that the space for time substitution adequately represents the ecosystem dynamics throughout the encroachment process.

Methods

Three study sites representing a grassland, a grassland that has been encroached by mesquite (a shrubland), and a mesquite woodland were established along the San Pedro River in southeastern Arizona. The Charleston Mesquite (CM) study site is located on the east side of the San Pedro River at an elevation of 1,200 m, approximately 16 km northeast of Sierra Vista, Arizona. The site is a woodland dominated by velvet mesquite (*Prosopis velutina*). The understory is primarily sacaton grass (*Sporobolus wrightii*) with scattered greythorn shrubs (*Zizyphus obtusifolia*) and various summer active annual herbaceous species. The average canopy cover is ~70%. The measured Leaf Area Index (LAI) ranges from an average (n = 40) of ~1.0 prior to leaf-out to ~1.6 during most of the growing season. The mean canopy height is approximately 7 m and the maximum canopy height ~10 m. Depth to groundwater is ~ 10 m.

The Lewis Springs Sacaton (LSS) and Lewis Springs Mesquite (LSM) study sites are located in close proximity to each other on the east side of the San Pedro River at an elevation of 1,230 m, approximately 12 km east of Sierra Vista, Arizona. The micrometeorological tower at the Lewis Springs Sacaton Site (LSS) lies in the center of a low alluvial terrace bordering the river. The tower is surrounded by a lush growth of sacaton grass roughly 200 m east/west and 800-1,000 m north/south. The canopy height is about 1 m, and average canopy density is ~ 70%. The mean depth to groundwater in a co-located piezometer is ~2.8 m. LAI ranges from an average (n = 40) of ~1.0, prior to the initiation of the growing season, ~1.5 during the pre-monsoon season, and ~2.5 during and after the monsoon season. The flux tower at LSM lies immediately to the northeast of LSS in a moderately dense shrubland of velvet mesquite, roughly 500 m east/west by 500 m north/south. The mesquite canopy density is estimated to be 60% with an average tree height of 3-4 m. The depth to groundwater is ~7 m, and the LAI ranges from about 0.3 (prior to leaf production by the mesquite shrubs) to a peak of 0.6 during the height of the summer monsoon.

Evapotranspiration (ET) and carbon dioxide (CO_2) fluxes were measured using the eddy covariance technique throughout most of the active growing season from 2001 till present at CM and from mid-2002 till present at LSS and LSM. Basic meteorological, soil moisture, and groundwater height data were also collected. A three-dimensional sonic anemometer and an open path infrared gas analyzer mounted at approximately 2 to 3 m above the height of the canopy measured the three components of the wind velocity vector, sonic temperature, and the densities of water vapor and CO_2. These were sampled at 10 Hz by a datalogger, which also calculated their 30-minute covariances using block Reynolds averaging. Surface fluxes were later calculated off-line, after performing a two-dimensional coordinate rotation and accounting for density fluctuations (Webb et al. 1980). The sonic temperature was used to calculate sensible heat flux using the method suggested by Paw U et al. (2000). Fluxes measured when the wind was coming from a direction that was within 20° of behind the anemometer were ignored due to possible interference from the anemometer support and the IRGA mounted behind the anemometer.

Results and Discussion

We discuss the measurements made in 2003, as this was the first year in which comparable measurements were available across all sites. Detailed results from the water and carbon exchange studies conducted during 2001 and 2002 at the CM woodland site have been published by Scott et al. 2003, Yepez et al. 2003, and Scott et al. 2004.

Surprisingly, total annual precipitation was nearly identical at all three sites (figure 1). The annual total precipitation was 232 mm at CM and 234 mm at LSS and LSM, much less than the 30-year average of 343 mm at nearby Tombstone, AZ. Air and dew point temperatures at LSS and LSM (not shown) were very similar to those found at CM (figure 1). The difference between the daily maximum and minimum temperatures often exceeded 20 ºC for most of the year and was around 15 ºC during the monsoon. In the San Pedro Valley, the 2003 monsoon began on DOY 194 and ended on DOY 255 (using the standard of greater than/less than 12.8 ºC dew point temperature for three consecutive days), though there were several large rain events between the end of the monsoon and the end of growing season. Spring nighttime freezing ended on DOY 131 and several nights of hard freezes began on DOY 308 in the fall. Scott et al. (2004) reported that the minimum temperatures inside the riparian corridor are as much as 10 ºC cooler than on the valley floor due to nocturnal cold air drainage.

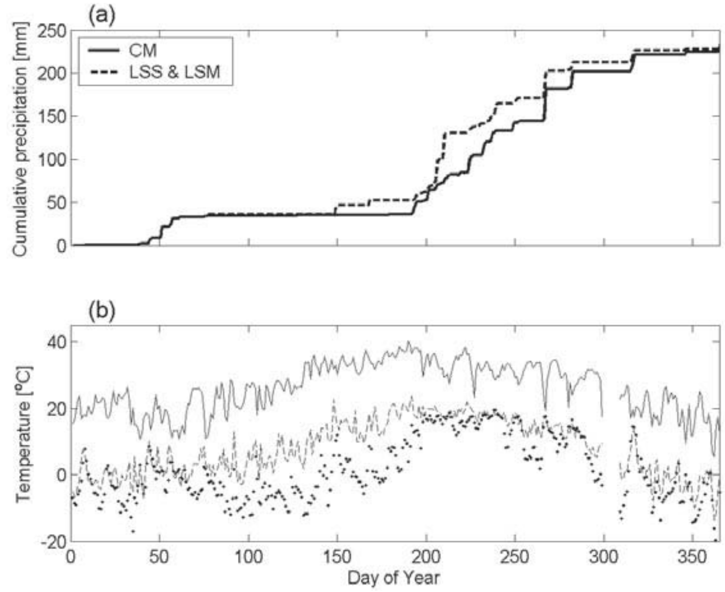

Figure 1—(a) 2003 cumulative precipitation at the Charleston Mesquite Site (CM) and the Lewis Springs Sites (LSS and LSM). Since LSS and LSM are adjacent to each other, their precipitation is nearly identical. (b) Daily maximum (solid line), minimum (dashed line), mean dew point (dots) air temperatures at CM. Temperatures at LSS and LSM were very similar.

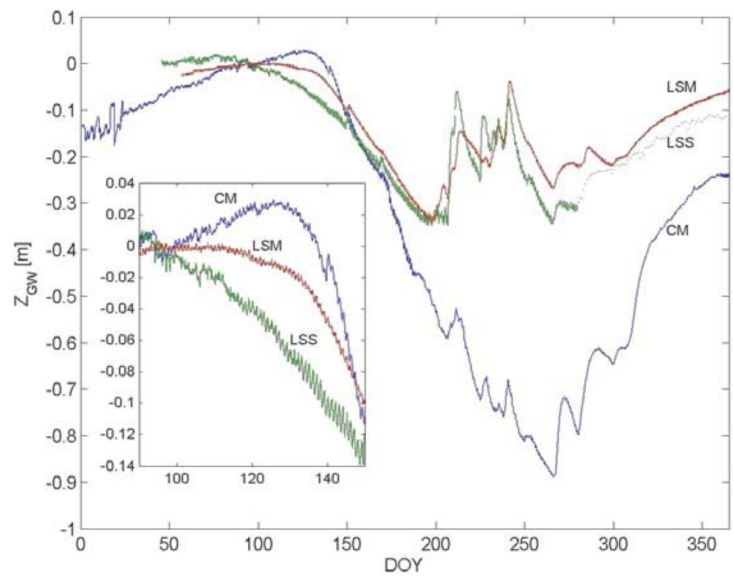

Figure 2—2003 relative ground water depths, Z_{GW}, for all three sites. Z_{GW} was computed by adding the water table depths from DOY 90 (CM = 9.51 m, LSS = 2.44 m, LSM = 5.28 m) to all values. Inset expanded figure shows the water table changes during the spring green up that initiated water table drawdowns and regular diurnal fluctuations due to ground water extraction by the plants.

Mean depths to groundwater for piezometers at all three sites were 2.6 m, 5.4 m, and 9.8 m at LSS, LSM, and CM, respectively. The annual changes in water levels were about 0.9 m at CM and 0.4 m at both LSM and LSS (figure 2). Groundwater levels generally declined from the time of new leaf production until the beginning of the monsoon. During the monsoon, the water levels record the complex effects of passing floods in the river channel that recharge the alluvial aquifer. The effects of these propagating flood waves in the aquifer were more dampened going from LSS to LSM to CM, corresponding to the increasing distance of each site's piezometers to the nearest stream channel. The presence of regular diurnal fluctuations at all sites following leaf flush indicates that all ecosystems used groundwater. These regular diurnal fluctuations (with a minimum depth to groundwater in the early morning and a maximum around sundown) began around DOY 120 at LSS, about 10 days earlier than LSM and 20 days earlier than CM. This agrees well with visual observations that indicated an earlier green up for the grass at LSS and the mesquite at LSM. Before these fluctuations began at LSS, water levels had already begun to decline. Since the sacaton piezometer was closer to the stream and cottonwood gallery, this general decline was likely due to the activity of nearby cottonwood trees, which greened up around DOY 90. CM is located along a losing reach and has a greater density of trees, which possibly is the reason why once the mesquites at CM began using groundwater, the rates of water level decline were much greater than the other two sites. While water table heights began to recover around DOY 270, regular fluctuations at both LSM and CM did not cease until DOY 307 when a hard freeze forced mesquite senescence (diurnal measurements were unavailable at LSS after DOY 275).

The seasonal water uses of the adjacent shrubland (LSM) and grassland (LSS) sites followed a very similar pattern to that seen at the woodland (CM) site (figure 3). The grassland initiated photosynthetic activity and began to transpire earlier in the year, whereas the frost sensitive mesquite were more conservative. However, after mesquite leaf flush, ET rates at LSM rapidly caught up to, and then began to exceed, those of the grassland, perhaps due to an enhanced ability of the deeper rooted trees to acquire groundwater more effectively. During the growing season, ET at CM always exceeded the other two sites. ET increased at LSM and LSS during the monsoon period, whereas it stayed the same at CM perhaps indicating that the grassland and shrubland are not as coupled to the groundwater source, ephemerally utilizing summer precipitation events. From the end of the monsoon until the end of the growing season, LSM and LSS had similar rates of ecosystem water loss to the atmosphere.

The water use pattern of the LSS site differed considerably from a similar site across the river that was monitored in 1997-1998 using the Bowen ratio technique (Scott et al. 2000). The earlier sacaton site was shown to have a tight coupling between precipitation and ET from which Scott et al. (2000) concluded that it used little groundwater. The cumulative water use at LSS indicates that ET was significantly in excess of precipitation—implying groundwater use by the grassland. Regular diurnal fluctuations during the growing season in a

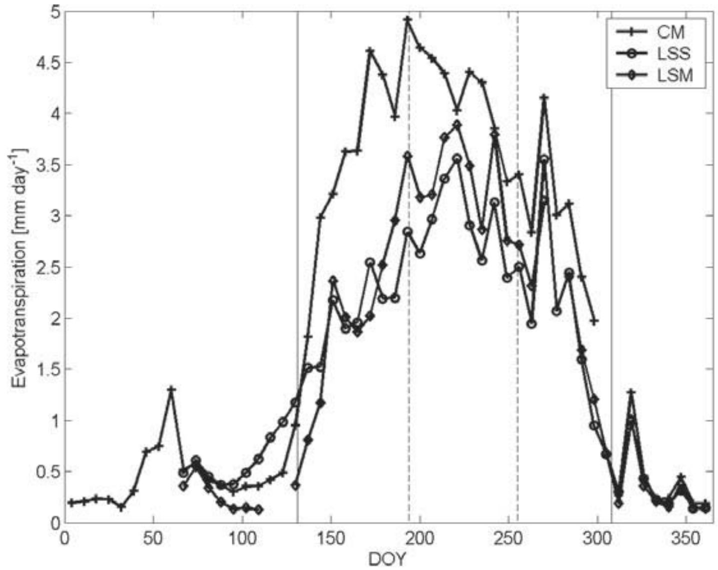

Figure 3—2003 weekly average ET. The days of the last freeze of spring and first freeze of fall (solid line) and monsoon period (between the dashed lines) are also indicated.

piezometer at the site confirmed this (figure 2). The likely explanation for this disparity between the two grassland sites is that the earlier sacaton grassland site had a depth to groundwater of >3.5 m, whereas at LSS it was often less than 3 m. Thus, sacaton appears to not acquire groundwater from sites where the groundwater depths are greater than ~3 m. This conclusion is supported by a study using stable isotopes that identified a water table depth threshold of ~3 m for sacaton groundwater use (J. Stromberg, Arizona State University, personal communication).

Net ecosystem exchange of CO_2 (NEE) reflected the competing influences of plant carbon acquisition and both autotrophic and heterotrophic respiratory processes (figure 4). In general, most plants at all the sites were dormant during the winter, and respiration losses were evident. Groundwater, available to deeply-rooted plants but not to shallow soil heterotrophs, fueled net carbon gain during the pre-monsoon summer period. High temperatures and shallow soil wetting associated with monsoon rains correlated with strong respiration responses, offsetting net uptake of carbon. Strong respiration responses to precipitation inputs were seen in all seasons (compare figure 1a and figure 4). The greater respiratory efflux following precipitation events at LSS and CM was probably a result of the greater availability of labile carbon in the surface soils at these sites as evident by the copious amounts of plant litter and debris found at them. Also, respiration at LSS was likely more responsive than LSM because of the finer textured soils and greater amount of ground cover that sustained higher levels of soil moisture for longer time periods (data not shown).

To better quantify the differences in carbon exchange between the three sites we computed seasonal average NEE for three separate periods in 2003: (1) Dormant—the wintertime period when most plants were dormant, (2) Dry Growing—the pre-monsoon growing season with typically very little rainfall, and (3) Rainy Growing—the monsoon and post-monsoon

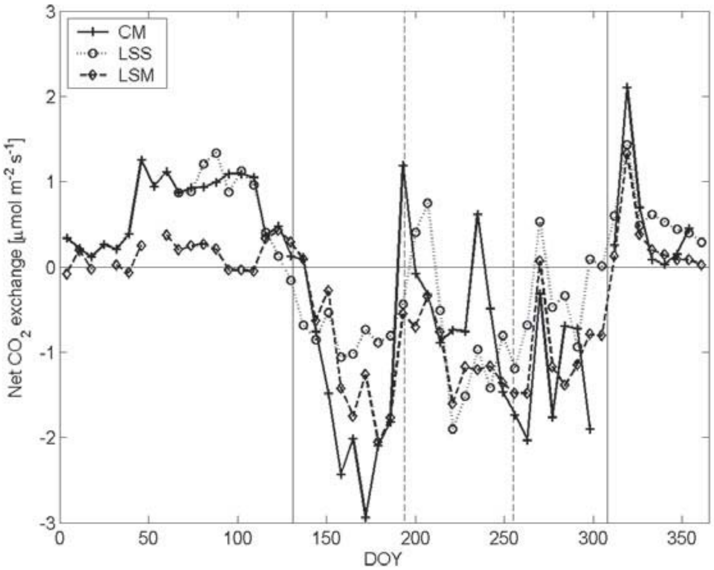

Figure 4—2003 weekly average net ecosystem exchange (NEE) of carbon dioxide. Negative NEE indicates net atmospheric loss and a net uptake of carbon by the ecosystem. The days of the last freeze of spring and first freeze of fall (solid line) and monsoon period (between the dashed lines) are also indicated.

growing season when the majority of the rain fell (table 1). During the dormant period, the seasonal averages of NEE indicate that both CM and LSS were sources of atmospheric CO_2. During the pre-monsoon growing season, carbon sequestration increased with woody plant density. NEE at all sites actually decreased during the rainy season indicating that soil respiration losses outweighed the increase in plant carbon uptake. The reduction in ecosystem carbon gain from the dry to the rainy season increased with mesquite encroachment, possibly indicating that the grassland productivity was more closely tied and responsive to the increases in near-surface moisture.

Summary

These initial 2003 results are summarized as follows:

- All ecosystems used groundwater. The grassland groundwater use was due to the shallow groundwater availability at the site, which is not the case for many grasslands within the riparian area of the San Pedro. Groundwater use was highest at the woodland site.
- Decoupling of ET from precipitation was most evident at the woodland site, though all sites showed some degree of decoupling due to the ability of the dominant vegetation to access groundwater.
- All sites had high respiration losses of carbon following precipitation events. The response was stronger and longer lasting at the grassland and woodland sites. The decreased response at the shrubland site relative to the grassland site was likely due to the coarser soil texture and lower amount of plant debris found there.
- All ecosystems had a lower net gain in carbon during the rainy growing season, relative to the dry part of the growing season. This decreased gain in carbon was magnified by woody plant density.

Table 1—2003 average net ecosystem exchange of carbon dioxide [μmol m^{-2} s^{-1}] for the pre-monsoon growing season and the monsoon through post-monsoon growing season.

Period	(Day of Year)	LSS	LSM	CM
Dormant	65-105 & 309-365	0.79	0.23	0.75
Growing, dry	148-196	-0.78	-1.30	-1.66
Growing, rainy	197-301	-0.60	-1.05	-0.88

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Conservation Practice

Citizens' Council Protecting Sky Island Wildlife Corridor

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Introduction

In 1999-2000, stakeholders involved with efforts to create Las Cienegas National Conservation Area identified lands north of the designated National Conservation Area and Acquisition Planning District boundaries as important to protect as well. These lands, formerly known as the Missing Link and now known as the Cienega Corridor, represent over 50,000 acres of important wildlife habitat and corridors, open space, cultural and economic resources, and watershed for recharge of Tucson's groundwater. The area is under imminent threat of development, however, because it lies just a few miles east of the City of Tucson.

Pima County's growth rate is more than double the national average: an increase of more than 34 percent since 1990. The population is projected to top 1.2 million residents in less than 20 years, while vital resources such as clean water, air, and open space are dwindling. Because of critical habitat designations for endangered species in northwest Tucson, it is expected that much of the future growth will occur in the southeast sector—the Cienega Corridor, which is highly desirable for development because it is adjacent to existing large-scale development on the burgeoning Houghton Road corridor and on Old Spanish Trail. It also offers many amenities including stunning views of and access to protected natural areas such as Saguaro National Park, Coronado National Forest's Rincon Wilderness, and Cienega Creek Natural Preserve.

Additionally, the majority of the lands in the Cienega Corridor are Arizona State Trust Lands, most of which are currently leased for cattle grazing. The Arizona State Constitution mandates that State Trust Lands produce the maximum economic benefit for the beneficiaries of the Trust, most of which are school districts. One of the primary ways in which the State Land Department raises funds is to auction its Trust Lands for commercial or residential development.

If not protected soon, the important cultural and natural values—including the most important wildlife corridor linking Saguaro National Park and Las Cienegas National Conservation Area—will be lost.

Background

In December 2000, President Clinton signed into law the Las Cienegas National Conservation Area Establishment Act (HR 2941). The Act created a 47,000-acre National Conservation Area, including 5,000 acres of State Trust Lands, within a 143,000-acre Sonoita Valley Acquisition Planning District in southeastern Arizona, five miles from the eastern edge of Tucson. The Sonoita Valley Planning Partnership, an ad-hoc volunteer group of local residents and environmental, ranching, and recreational interests, worked together with the Bureau of Land Management, the Sonoran Institute, and Congressman Jim Kolbe to achieve passage of the legislation. To move the legislation through the House and Senate in 2000, several changes were made. Approximately 50,000 acres at the north end of the watershed were left out of the initial Federal designation. Although these lands link the National Conservation Area to National Park and Forest lands in the Rincon Mountains east of Tucson (hence the name "Missing Link"), they comprise a mix of State, county, and private lands, which raised concerns in Congress and the Arizona State Land Department about how they would be acquired and managed.

However, the National Conservation Area legislation did require that the Secretary of the Interior submit a report to Congress within two years that describes "the most effective measures to protect the lands north of the [Sonoita Valley Acquisition Planning District and National Conservation Area] within the Rincon Valley, Colossal Cave area and Agua Verde Creek corridor north of Interstate 10 to provide an ecological link to Saguaro National Park and the Rincon Mountains" (Section 8.a.).

The Bureau of Land Management contracted with the Sonoran Institute to take the lead on gathering and compiling the resource information and public input necessary to prepare the report required by the National Conservation Area legislation. With additional support from Saguaro National Park, the Sonoran Institute conducted a series of workshops and public open houses designed to:

- Generate as much information as possible about the significant natural and cultural resources—including ecological linkages—found in the Cienega Corridor (i.e., the Rincon Valley, Colossal Cave area, and Agua Verde Creek corridor).
- Solicit feedback from resource experts and the lay public on alternative protection options and management strategies.
- Compile and analyze this information, and provide recommendations about which protection measures would be most effective.

Findings

Results indicated there is broad consensus among stakeholders and science experts that the Cienega Corridor is an important and valuable area, and that some form of protection is necessary, and urgently needed, for its varied cultural and natural resources. These include endangered and/or rare wildlife and plant species, open spaces, and recreational opportunities.

Highlights of findings include:

1. The area is biologically and geologically significant:

- The Cienega Corridor provides habitat for four Federally endangered plant and animal species, and ten species of special concern.
- According to data gathered in field studies conducted by the Sky Island Alliance, the Cienega Corridor lands are important movement corridors for “Sky Island” mountain mammals, especially black bears, mountain lions, coatis, and mule deer.
- Resource specialists, including biologists working with Pima County on its Sonoran Desert Conservation Plan, place the land in the Cienega Corridor at the highest-level priority for protection because of its habitat for endangered and threatened species, as well as its value as a wildlife corridor in an area classified as “biological core” by the Sonoran Desert Conservation Plan.
- The watershed, including Las Cienegas National Conservation Area, provides the City of Tucson with up to 20% of its groundwater recharge system, according to data from the Arizona Department of Water Resources (an average of 16,000 acre-feet per year, out of an estimated 50-60,000 acre-feet total).
- The area contains some 21 distinct and rare soil types, as well as numerous unique and rare limestone caves such as Colossal, Arkenstone, and Carter Caves. These caves are important because they provide habitat for the endangered lesser long-nosed bat and the Mexican long-tongued bat, as well as for several species of rare invertebrates.

2. The area is culturally and economically important:

- Numerous archaeological sites dating to 8000 B.C. and many historical sites, including Butterfield Stage stop and working ranches, are scattered throughout the Cienega Corridor on unprotected lands.
- The open space in the Cienega Corridor provides multiple recreation opportunities for the rapidly growing Tucson population: hiking, birdwatching, biking, horseback riding, scenic drives, photography, hunting, camping, cave exploration, and picnicking.
- Meeting recreation needs within the Corridor will help alleviate overcrowding of current protected lands adjacent to city limits, including Tucson Mountain Park and Saguaro National Park.
- The historical regional identity of the Rincon Valley is strongly based on Western rural lifestyle values, which include ranching and love of wildlife, open space, and outdoor recreation.

3. There is strong local support for protection of the resource:

- Strong support for protecting open space and ecological linkages already exists in the Rincon Valley region, through the work of the Bureau of Land Management, community collaborators in the Sonoita Valley Planning Partnership, the Sonoran Institute, and others to establish the Las Cienegas National Conservation Area in 2000.
- A poll conducted in spring of 2002 indicates that of 400 high-propensity voters surveyed, 63% consider preservation of wildlife habitat to be extremely/very important.
- A local non-profit conservation and community stewardship organization—the 15-year-old Rincon Institute—is well-established in the region, providing local conservation leadership. The Rincon Institute has established community-rallying points such as its highly successful Rincon Valley Farmers’ Market.
- Local land agencies and managers are currently working well together and are favorably inclined toward protection of the Cienega Corridor.

4. Of thirteen alternative protection measures considered for the area, “establish a community-based, nonprofit, non-governmental organization whose mission is to protect resources in the Missing Link” was chosen as the final recommendation for resource protection.

- Other alternatives included: “expand Las Cienegas National Conservation Area” (by far the public’s top choice), “expand Saguaro National Park,” “expand County Parks” (these were essentially tied for second), “expand Coronado National Forest” (the only other alternative to receive significant community support), “establish a National Wildlife Refuge,” “establish a State Park or Preserve system,” and “incorporate the area into a new municipality that could acquire the lands for creating a city refuge or other form of land preservation.”
- Of these, none were deemed feasible upon investigation by natural resource experts and the public at a series of workshops.
- Particular concern was expressed regarding the three alternatives that involved expanding the boundaries of Federal lands because: (1) they would have required an act of Congress; and (2) some members of the public might have viewed such an expansion as a Federal “land grab.”

Final Recommendation

The final recommendation, therefore, was to support local partners in launching a community-based, non-governmental, nonprofit organization that would take a collaborative management approach to protecting the Missing Link lands. This would include creation of an ad hoc organization with a governing board comprising land managers, landowners, and local stakeholders including ranchers, recreationists, and other land users. The approach would have the effect of moving ahead with locally driven, on-the-ground protection and management of the landscape.

Cienega Corridor Conservation Council

In response to this need, the Sonoran Institute facilitated formation of the *Cienega Corridor Conservation Council* in early 2003. The *Council*’s mission is to protect and enhance the biological and cultural resources of the Cienega Corridor through two major strategies: cultivation of an organized voice for conservation and development of a cooperative management agreement.

To grow the local voice and increase awareness about the Cienega Corridor, the *Cienega Corridor Conservation Council* co-sponsored a first-annual spring outreach event with the Sonoran Institute, Colossal Cave Mountain Park, and Rincon Institute on March 27, 2004. "Cienega Corridor Pioneer Day" resulted in one conservation easement donation underway and one easement under discussion, drawing about 1,000 visitors and 100 volunteers.

In addition, the *Cienega Corridor Conservation Council* was asked in August 2003 to prepare a report for the Pima County Conservation Bond Advisory Committee detailing land protection priorities for the May 2004 bond planning committee. Based in part on the *Council* recommendations, $44 million in priority was prioritized for open space protection in the Cienega Corridor. *Council* participants also spoke at two public hearings to support Pima County's solicitation for an Arizona State Transportation grant. The grant was awarded to help the County acquire and protect critical riparian parcels along Davidson Canyon wash—an important tributary to Cienega Creek.

The second approach for resource protection is to develop a cooperative management agreement among diverse partners. A cooperative management agreement is a voluntary memorandum of understanding that articulates how *Cienega Corridor Conservation Council* partners will work together to protect the natural and cultural resources. The agreement will link to a strategic plan outlining specific roles and responsibilities for signatories, who range from local landowners and citizens to government agencies. Some elements of the strategic plan include: collaboration on protection strategies and policies, data sharing, and communications.

The strategic plan will also include governance, monitoring, and adaptive management models to illustrate how partners will sustain and monitor progress toward resource objectives. The cooperative management agreement and strategic plan establish a framework through which citizens can engage in local resource protection and build relationships with key partners and decision makers. It may also link to a cooperative agreement between partners collaborating on resource management of Las Cienegas National Conservation Area. Once a cooperative management agreement is completed, the focus will shift to implementation of "pilot projects" outlined in the strategic plan. A draft cooperative management agreement is expected by early 2005.

Herpetology of the American Madrean Archipelago and Adjacent Valleys

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Abstract—*Approximately 110 species of amphibians (18 frogs and toads, and 1 salamander) and reptiles (47 snakes, 39 lizards, and 5 turtles) are known from the American Madrean Archipelago and adjacent valleys. The high diversity of the herpetofauna comes from a variety of factors, including a convergence of biotic communities representing deserts, grasslands, and mountains. Other environmental and ecological factors weigh heavily into the equation, making this one of the nation's richest herpetofaunas. Certain taxa are particularly speciose, including whiptails, rattlesnakes, and spiny lizards. Seventeen species are Mexican forms that barely enter the United States.*

Introduction

The American Madrean Archipelago (Sky Islands) and associated lowlands and foothills of southeastern Arizona and southwestern New Mexico (herein referred to as the Northern Sky Islands Realm, NSIR) is comprised of a series of mountains and valleys spanning over 7,000 vertical feet, from desertscrub to subalpine forests. This elevational range accounts for large differences in local climatic conditions, as well as supporting numerous biotic communities and a biologically diverse flora and fauna. This paper is a brief synthesis of the current knowledge of the NSIR's herpetofauna, with some discussion of the primary ecological and evolutionary factors accounting for such a high biodiversity. This paper also helps form a foundation for herpetological management on the Coronado National Forest (Jones and Painter, this volume).

Biological Diversity

The NSIR has long been known to harbor a diverse flora and fauna, and several papers addressed the topic in the first Madrean Archipelago symposium (DeBano and others 1995). The number of taxa from the NSIR includes about 2,100 species of plants (McLaughlin 1995), 466 species of birds (Davis and Russell 1991), 110 species of mammals (Bowers and others 2004), over 240 species of butterflies (southeastern Arizona, Bailowitz and Brock 1991), and most of the >176 species of mollusks reported by Bequaert and Miller (1973), plus many new species described after these accounts were published.

Amphibians and reptiles are also well-represented. Using the taxonomy of Crother and others (2000, 2003) and range maps of Stebbins (2003), primarily, we estimate the NSIR to have about 110 native species of reptiles and amphibians, as follows: 18 frogs and toads, 1 salamander, 47 snakes, 39 lizards, and 5 turtles and tortoises. Thus, the area has amongst the highest herpetofaunal diversity in the United States.

Biogeographic Origins of the Species

Lowe (1964) discussed the dizzying array of names and categories of various biogeographic units in Arizona, and due to space constraints, we will not delve into those discussions. Rather, we feel the most appropriate term for a functional biogeographical unit for our purposes is Herpetofaunal Assemblage (HA), which is analogous to *Faunal Area* of Gloyd (1937). HA designations are based on geography, herpetofaunal distribution patterns, and vegetative communities. We did not use the NSIR area itself for HA species designations. We feel there are three basic biotic (vegetative) communities, each with two HAs; these are described in table 1. Biotic communities generally relate to elevational differences, with deserts being the lowest, grass- and shrublands intermediate, and montane communities the highest.

To demonstrate the NSIR's herpetofaunal contributions, we assigned each species to one or more of the HAs, based on their "typical pattern of distribution and/or presumed origin." While this was done subjectively, in most cases their patterns were clearly allied to one or more of the HAs. Relative contributions of each HA to the NSIR herpetofauna were computed by tallying occurrences on a spreadsheet. For each species (row), a 1 was scored in each HA (column), where the animal typically occurs. These were tallied and columns divided by the grand total. The relative contributions (rounded) are: Chihuahuan Desert (22%), Sonoran Desert (21%), Great Plains (14%), Semidesert Grass- and Shrublands (22%), Madrean (17%), and Petran (5%). Clearly, all HAs contribute to the biodiversity, but the greatest contributions come from the southern and low- to mid-elevation HAs, while there is less contribution from montane and northern communities.

Table 1—Herpetofaunal assemblages recognized in this paper.

Biotic community	Herpetofaunal assemblage	Description
Desertscrub	Sonoran Desert	Primarily the Arizona Upland subdivision, to the west of our area.
	Chihuahuan Desert	Desertscrub lying southeast of our area
Grass- and Shrublands	Semidesert Grasslands	This includes the semi-desert grasslands, mesquite bosques, and other shrublands, and elements of subtropical thornscrub. This accounts for the mid-elevation grass- and shrublands of foothills and valleys at the desert and montane interface, primarily south of our area.
	Great Plains	A vast area of grasslands lying northeast of our area.
Montane	Petran	Oak/juniper woodlands to coniferous forests lying to the north of our area, allied to the Rocky Mountains.
	Madrean	Oak/juniper woodlands to coniferous forests to the south of our area allied to the Sierra Madre Occidental.

Other Mechanisms of Biodiversity

In addition to the biogeographic considerations discussed above, there are other environmental, ecological, and evolutionary factors contributing to biodiversity. There is a long growing season and many lowland species are surface-active much of the year. There is also a dual rainy season, with a spring peak of activity following the green-up produced by winter rains, then a larger peak during the summer monsoon season. In addition, special habitat features within biotic communities augment biodiversity by increasing habitat diversification. Riparian areas, meadows, talus slopes, and lentic and lotic habitats are examples of special features that can be found among different biotic communities.

On the evolutionary front, there are species or subspecies coming into contact in the NSIR, which has contributed to biodiversity. The whiptails are the premier example and have undergone an incredibly rapid speciation (Cole and Dessauer 1995). On the sub-species level, there are numerous examples of intergradation. Isolationism is another well-known factor, especially for montane forms. However, genetic diversity has not yet manifested itself on the species level. Animals living at high elevations in the Sky Islands are often genetically distinct from their nearby relatives, since gene flow has not occurred for thousands of years.

Representative and Noteworthy Taxa

Certain taxa are particularly well represented in our area, with several closely related species belonging to one or two genera. These include: whiptails (12 species), rattlesnakes (11 species), spiny lizards (8 species), true frogs (5 species), true toads (5 species), horned lizards (4 species), black-headed snakes (4 species), and gartersnakes (4 species). Often these species are known to co-occur in such small areas by partitioning resources, especially along elevational gradients, or because the NSIR is a mergence zone between HAs.

Whiptail lizards, genus *Aspidoscelis* (formerly *Cnemidophorus*), are particularly speciose in our area (Cole and Dessauer 1995). In addition, there are likely additional cryptic species that have yet to be described. *Aspidoscelis* is an interesting genus because many of the species are unisexual (all female), reproducing by parthenogenesis, resulting from the hybridization of two or more parental stocks (Cole and Dessauer 1995). *Aspidoscelis* are primarily denizens of grass- and shrub-land communities.

Rattlesnakes are represented by 11 species (2 genera) in our area, including about one-third of all known species and 79% of the species known from the United States. Five of the species are mountain dwellers, including 3 Madrean, 1 Petran, and 1 generalist species. The others are valley and/or foothill species. The Twin-spotted rattlesnake, a Madrean species, has been found as high as 10,500 ft. in the Pinaleño Mountains, a seemingly harsh environment for an ectotherm.

There are 8 species of spiny lizards (genus *Sceloporus*) in the NSIR, a genus that is also well represented south of our area (where there are about 77 total species). Along an elevational gradient from desert to subalpine forests, the large spiny lizards are partitioned as such: *S. magister* < *S. clarkii* or *S. poinsettia* < *S. jarrovii*. The smaller species are also habitat-partitioned.

Native ranid frogs include *Rana tarahumarae*, a Madrean endemic, and 4 species of leopard frogs. *Rana chiricahuensis* is a southern grassland to Cordilleran form, while the similar *R. yavapaiensis* is found at lower elevations. *Rana blairi* is a Great Plains species, while *R. subaquavocalis* is a Sky Island endemic.

Biologists have long recognized that our area was biologically important because numerous taxa are primarily Mexican species that barely enter the United States in the vicinity of the Sky Islands. There are currently 17 species of reptiles and amphibians that fall into this category (Stebbins 2003), including the Tarahumara frog, the only species that has been extirpated from our area. Two subtropical thornscrub species (*Oxybelis aeneus* and *Gyalopion quadrangulare*) have extremely limited ranges in southern Arizona, the only place they are found in the United States.

The fact that 19 species of amphibians can eek a living out of such a xeric environment is intriguing. While the mountains may receive fair amounts of rain and snowmelt, most of the species are valley-dwellers, and have developed mechanisms of adapting to xeric conditions, by using behavioral and physiological thermo-and hydro-regulation. Examples include explosive breeding (and rapid development) strategies, diel activity shifts, and seasonal activity shifts.

Discussion

Using terms such as "Appalachian" and "Madrean" to describe the herpetofaunal elements of the NSIR may be misleading, since only some species are allied to those mountains, and geographically, most species are lowland forms. Additionally, many species found in the cores of each of the HAs are often lacking in the NSIR. For example, there are numerous montane species found in the Sierra Madre Occidental of Mexico that are not known from the NSIR (McCranie and Wilson 1987). The same is true for all HAs. Herpetofaunal endemism on the species level is very low in the NSIR, and there is not a distinctive herpetofaunal assemblage of the NSIR and adjacent Mexican Sky Islands.

Thus, from a herpetological perspective, the NSIR is a mergence zone of HAs rather than a biogeographical province itself, or part of the Sierra Madre Occidental proper. This concept is similar to that of Morafka (1977) who termed the NSIR the "Cochise Filter." His designation was primarily directed to the relationship of the Chihuahuan and Sonoran herpetofaunas, whereas ours is extended to include middle and upper elevations. The concept of a filter is helpful, as some species occur up to the NSIR boundaries, while others pass through the boundary. However, we can further refine biogeographic tendencies across the various biotic communities by recognizing the following observed patterns (with examples in brackets): (1) some species do not occur beyond the boundary of an HA adjacent to NSIR (Trans-Pecos Rat Snake, of Chihuahuan Desert); (2) some species occur into the NSIR from an adjacent HA (but not beyond) by interdigitating into appropriate habitat (Sonoran Coral Snake); (3) some species "spill over" from an adjacent HA, occupying at least some atypical habitat in NSIR, but are not found in the opposite HA of the same biotic community (Gila monster, a Sonoran [and Mojave] Desert species); (4) some species are biotic community generalists, being found in both desert communities (glossy snake), both grass- and shrubland communities (Great Plains toad), or both montane communities (i.e., Cordilleran) (Sonoran mountain kingsnake); and (5) some species are habitat generalists, occurring among biotic communities and HAs (gopher snake).

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Herpetology of the Coronado National Forest: Managing Our Natural Heritage

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Abstract—*The Coronado National Forest (CNF) is the primary public land management agency for the United States' portion of the Madrean Archipelago. The region has a large diversity of amphibians and reptiles, with approximately 110 native species occurring on the CNF. Management of the CNF's herpetofauna is regulated primarily by environmental laws and policies. Sixteen taxa are variously listed as threatened, endangered, sensitive, and management indicators; potential effects to these taxa must be considered before habitat-disturbing projects can be implemented.*

Introduction

The United States' portion of the Madrean Archipelago is situated in southeastern Arizona and southwestern New Mexico, an area that overlaps much of the Coronado National Forest (CNF). Hence, the CNF is the primary public land management agency of the montane and foothill habitats of most of the U.S. Madrean Archipelago. The CNF manages all or part of 17 Madrean Sky Islands—all of the larger U.S. ranges except the Dos Cabesas, Baboquivari, Mule, and Animas Mountains.

The biodiversity of the region's herpetofauna has been discussed elsewhere, including this symposium (Gloyd 1937; Lowe 1964; Jones, this volume; Stitt and others, this volume; Swann and others, this volume). Currently, about 110 native species of amphibians and reptiles are recognized from the Northern Sky Island Realm (Jones, this volume). While it is unknown which species actually occur within the boundaries of the CNF, it seems likely that the great majority are represented. This is due to the spatial coverage and ecological heterogeneity of the CNF. Unlike many National Forests, parts of the CNF include some desert and grassland habitats. The CNF has a legal obligation to manage the public lands it administers, and maintaining the natural heritage is paramount to the success of that mission.

Environmental Laws and Policy

The National Forest System manages public lands using guidance from federal laws and policies, especially those addressing environmental issues. The Endangered Species Act (ESA) is of paramount importance, because it deals with taxa whose survival may be tenuous. Endangered "species" (which may include sub-specific taxa or distinct populations) are those that are or could become extirpated or extinct in the foreseeable future, while Threatened taxa are those that could become Endangered. The ESA carries the heaviest legal weight, and any actions proposed on National Forest lands must adequately address potential and cumulative effects to Threatened or Endangered (T&E) taxa. Recovery Plans and Critical Habitat designations may accompany ESA listing.

The National Environmental Policy Act (NEPA) and National Forest Management Act (NFMA) have additional language addressing conservation of habitats and populations of flora and fauna. These laws state that the National Forest must maintain viable populations of all species, well-distributed across their administered lands. These three laws, plus language from the Forest Service Handbook, Forest Service Manual, and other documents have been integrated into the Forest Plan. The Forest Plan, which is reviewed internally and externally, determines Forest management during the following 10 years or so.

To ensure compliance with the intent of environmental laws, the Forest Service compiles taxa lists with the aid of external experts. In addition to the USDI Fish and Wildlife Service (FWS) ESA list, the Forest Service maintains a Regional Forester's Sensitive Species list and a Management Indicator Species (MIS) list. The former includes taxa that have no federal ESA status, but these populations or habitats are considered uncommon and could be at risk. MIS include taxa in the following categories: state and federal T&E; having special habitat needs that may be influenced by management; commonly hunted or fished; nongame, of special interest; and indicators of changes due to management practices. Currently listed Threatened, Endangered, Sensitive, and Management Indicator amphibians and reptiles for the CNF are presented in table 1.

Taxa of Concern

The taxa listed in table 1 are considered to be taxa "of concern." Three of the species are listed as T&E: Sonoran tiger salamander (*Ambystoma tigrinum stebbinsi*, E), Chiricahua leopard frog (*Rana chiricahuensis*, T), and New Mexico ridge-nosed rattlesnake (*Crotalus willardi obscurus*, T). These species are legally elevated above all others and must be carefully considered when proposing any habitat-disturbing activities. However, management and mitigation for these species

Table 1—Amphibian and reptile taxa of concern, plus those with Conservation Agreements (completed or in progress), on or near the Coronado National Forest, with their distribution by Ranger District.

Common name	Scientific name	Status[2]	Ranger District[1] D1	D2	D3	D4	D5	Total by species
Sonora tiger salamander	*Ambystoma tigrinum stebbinsi*	E			X			1
Chiricahua leopard frog	*Rana chiricahuensis*	T	X	X	X	X		4
Lowland leopard frog	*R. yavapaiensis*	S		X	X	X	X	4
Ramsey Canyon leopard frog	*R. subaquavocalis*	C			X			1
Tarahumara frog[3]	*R. tarahumarae*	M		X[3]				1
Western barking frog	*Eleutherodactylus augusti cactorum*	S		X	X			2
Mountain treefrog	*Hyla wrightorum*	M			X			1
Desert tortoise (Sonoran Desert population)	*Gopherus agassizi*	C		X		X	X	3
Giant spotted whiptail	*Aspidoscelis stictogramma*	S	X	X	X	X	X	5
Gray checkered whiptail[4]	*A. dixoni*	S	X					1
Desert massasauga[4]	*Sistrurus catenatus edwardsi*	M	X		X[3]			2
Western black kingsnake	*Lampropeltis getula nigrita*	S	X	X	X			3
Northern Mexican gartersnake	*Thamnophis eques megalops*	S		X	X		X	3
New Mexico ridge-nosed rattlesnake	*Crotalus willardi obscurus*	T	X					1
Arizona ridge-nosed rattlesnake	*C. w. willardi*	S		X	X			2
Twin-spotted rattlesnake	*Crotalus pricei*	M	X	X	X	X		4
Total by District	-----		8	10	12	5	4	----

[1] Known or expected to occur within or near Forest boundary. D1 = Douglas District (Chiricahua, Dragoon, and southern Peloncillo Mountains); D2 = Nogales District (Pajarito, Atascosa, Tumacacori, and Santa Rita Mountains); D3 = Sierra Vista District (Huachuca, Whetstone, and Patagonia Mountains, Canelo Hills); D4 = Safford District (Pinaleño, Galiuro, Santa Teresa, and Winchester Mountains); D5 = Santa Catalina District (Santa Catalina and Rincon Mountains).
[2] E = endangered, T = threatened, S = Forest Service sensitive, M = Forest Service management indicator, C = conservation agreement.
[3] Extirpated in the United States, but plans involve reintroduction.
[4] Not recorded from within the CNF boundaries

can be beneficial to other species. Both *R. chiricahuensis* and *A. tigrinum stebbinsi* are aquatic obligates, as are five other species in table 1 (the other ranid frogs and *Thamnophis eques*). The aquatic obligates are the taxa of greatest concern to the CNF. Most species are declining, some at an alarming rate (Jones and Sredl, this volume). The Tarahumara frog (*R. tarahumarae*) has been extirpated from the United States and was previously known only from the CNF in the United States.

Similarly, *Crotalus willardi obscurus* and the three other rattlesnakes in table 1 have similar management concerns. The two ridge-nosed rattlesnake subspecies have indirect riparian associations but are not riparian obligates. The Sonoran population of the desert tortoise (*Gopherus agassizi*), found on the western edge of the CNF, has only recently been suggested as declining based on anecdotal data from monitoring plots. The gray checkered whiptail (*Aspidoscelis dixoni*), an all-female parthenogenic species, is only known from the vicinity of the Peloncillo Mountains of New Mexico (but has not been reported from within the boundaries of the CNF) and in a very small area of southwestern Texas.

The other taxa in table 1 have limited distributions and disjunct populations in the United States but are more widespread elsewhere (especially Mexico).

Management Issues

Potential management concerns can be categorized as aquatic or terrestrial issues. As mentioned above, taxa that are closely associated with an aquatic environment are the greatest concern for the CNF. Native tiger salamanders, ranid frogs, and Mexican gartersnakes, in particular, are in need of immediate conservation measures. Potential threats to these species include pumping and diversion of ground water, water pollution, mining, disease, competition and predation from native and non-native predators, habitat change, overgrazing, compromised meta-population dynamics, and climate change and drought.

Terrestrial ecosystem health has also declined since the appearance of European settlers into the American Southwest. Urbanization, recreation, altered fire regimes (including fire suppression), anthropogenic habitat shifts, and the introduction of invasive, non-native plants and animals have taken their toll on terrestrial environments. Some species, such as Madrean rattlesnakes (*C. willardi*, *C. lepidus*, and *C. pricei*) and gila monsters (*Heloderma suspectum*), are highly sought after by illegal collectors.

Cooperators, Partners, Authorities, and Jurisdictions

The CNF has the authority to manage habitats of amphibians and reptiles within the boundaries of their administered lands. The CNF also manages Special Use Permits, which are required for most activities (exclusive of hunting or fishing) occurring on National Forest lands. However, given the complexities of managing habitats and populations, the CNF relies on numerous cooperating agencies and non-governmental organizations (NGO's) to assist in amphibian and reptile conservation programs. The FWS oversees issues related to T&E species and their habitats and populations. The New Mexico Department of Game and Fish and the Arizona Game and Fish Department (NMDGF, AGFD) have jurisdiction over the non-federal T&E fauna, as well as game management and wildlife law enforcement. Some amphibians and reptiles are classified as fish and game species, respectively, in Arizona. In both states, there is protection from commercial take without a permit and protection for state T&E (New Mexico designation) and Wildlife Species of Concern in Arizona (Arizona designation). FWS, NMDGF, and AGFD also manage Scientific Collection permits for amphibians and reptiles within their authority. In most cases, these agencies may make decisions about managing populations without going through the NEPA process (but there is an internal NEPA-like checklist); however, proposals are usually reviewed by CNF biologists who can help determine if NEPA documentation is warranted.

Universities, NGOs, tribal governments, and other state and federal agencies play important roles in amphibian and reptile research and conservation. Besides inventory, research, and monitoring (IRM), which are discussed in the next section, these entities have many functions. The Nature Conservancy deals primarily with land exchanges and managing sensitive habitats. Examples on or near the CNF include Ramsey Canyon in the Huachucas and Muleshoe Ranch in the Galiuros; both places have amphibian and reptile species of concern. Environmental organizations such as the Sky Island Alliance, Centers for Biological Diversity, and National Audubon Society help ensure the interests of the environmental community are met by public land management agencies—a form of checks and balances. The Tucson Herpetological Society and Partners in Amphibian and Reptile Conservation address native herp conservation issues; the CNF works cooperatively with these NGOs.

Inventory, Research, and Monitoring

The National Forest System has authority to conduct inventory and monitoring of habitat and populations under the auspices of administrative studies, but research must be conducted by the research branch of the Forest Service, the Rocky Mountain Research Station (RMRS), or by other agencies or NGOs. The RMRS wildlife program has been involved mostly with studies of raptor ecology to date, although a comparison of the herpetofauna of several Sky Islands has been conducted by the Wildlife Program (W. Block, pers. comm.) and the Borderland Program has contracted studies on montane rattlesnakes. The University of Arizona (UA), Arizona State University (ASU), and Western New Mexico University (WNMU) have carried out most studies of the amphibians and reptiles on the CNF, but numerous other colleges and universities have also been involved. Table 2 summarizes some of the recent IRM activities. The entries in table 2 are not all-inclusive, but reflect responses to an email survey and known special use permits.

Table 2—Examples of some recent inventory, research, and monitoring (IRM) activities on the Coronado National Forest, from an email query sent to numerous herpetologists.

IRM categories	Taxa	Habitats and locations	Agencies, NGOs[1]
Taxa surveys	Ranids, Sonoran tiger salamanders, barking frogs, Mexican gartersnakes, bunch grass lizard, giant spotted whiptails, ornate box turtles, Sky Island rattlesnakes, exotics	Various, Forest-wide	FS, AGFD, NMDGF, ACA,
Road surveys	San Bernardino Valley, Stockton Pass Road, Portal Road, Haekel Rd, Marijilda Canyon	Chiricahuas, Pinaleños	FS, ACA
Genetic studies	Ranids, whiptails, night snakes, spiny lizards, horned lizards	Forest-wide	AGFD, FWS, ACA
Ecological studies	Fire and herps, drought and herps, habitat associations; mountain spiny lizards, Sky Island rattlesnakes, black-tailed rattlesnakes, ranid frogs, horned lizards, Gila monsters, Sonoran mud turtle	Chiricahuas, Pinaleños,	ACA, AGFD, NMDGF
Aquatic surveys	Ranids, Sonoran tiger salamanders, Mexican gartersnakes, explosive-breeding anurans, Sonoran mud turtles	Lotic, lentic, and riparian, Forest-wide	FS, AGFD, NMDGF, ACA,
Local, regional surveys	Whetstones, Pinaleños, Red Rock Canyon, Sky Island comparisons	Whetstones, Chiricahuas, Pinaleños, Huachucas, Santa Ritas, Santa Catalinas, Red Rock Canyon, Rock Creek, Peloncillos	RMRS, ACA

[1] ACA = various academic institutions; other acronyms in text

Managing the Herpetofauna on the CNF

The primary responsibility of CNF biologists is assessing and mitigating effects of proposed actions on flora and fauna, particularly species of concern (for amphibians and reptiles, those in table 1). When the biologist receives a proposal, he or she conducts surveys for species of concern in the proposed project area and does literature evaluations to determine the likely effects of the action on the taxa (and habitat) occurring in the area. This is done by preparing a specialist's report, Biological Assessment and Evaluation, and/or MIS Report. Mitigation is usually built into the documents and helps refine the proposed action. If there is a finding that the action may affect individuals, populations, or habitats of T&E taxa, the CNF must consult with the FWS. The FWS may or may not concur with the findings and may issue a Biological Opinion (BO). The BO may address terms and conditions, a "take" statement, and conservation recommendations for T&E taxa, and may include monitoring requirements. Due to space limitations this is an oversimplification of the NEPA process.

Habitat improvement projects by the CNF and its cooperators include aquatic and terrestrial site renovations. In aquatic habitats, sensitive riparian sites have been fenced or partially fenced to control overgrazing, tanks have been cleaned out, new ponds have been built, and harmful non-natives have been removed from select lentic systems. Fuel reduction projects (removal of excessive woody debris) via fuelwood sales, understory removal, prescribed burns, and forest and woodland restoration projects are becoming increasingly important terrestrial wildlife habitat management practices.

In addition to complying with the requirements of various documents, the CNF may be proactive. Some examples include the 2002 native ranid frog survey, which was done in anticipation of the listing of the Chiricahua leopard frog, and the follow-up 2003 surveys in the Galiuros Mountains (Jones and Sredl, this volume). The CNF has also been proactive by participating on interagency teams for recovery plans, conservation and strategic agreements, and re-introduction plans. These teams have helped set the pace for dynamic conservation plans (some in progress) for *A. tigrinum stebbinsi* (recovery plan), *R. chiricahuensis* (recovery plan), *R. yavapaiensis* (strategic plan), *R. blairi* (strategic plan), *R. subaquavocalis* (conservation agreement), *R. tarahumarae* (re-introduction), and Sonoran Desert population of *G. agassizi* (conservation agreement).

Suggestions for Improving Management of the Amphibians and Reptiles on the CNF

The CNF has room to improve management of their herpetofaunal resources. The current Regional Forester's Sensitive Species and MIS lists are inadequate (particularly the latter) for meeting our conservation objectives. Both lists are Forest Service-generated, so the Forest Service must be responsible for managing these taxa and ensuring monitoring needs are met. A useful MIS list should 1) be concise, 2) include only taxa that occur across the CNF, 3) have populations that can be logistically and statistically monitored (i.e., with adequate power to detect trends), and 4) be appropriate indicators of management practices across the major biotic communities. Hence, future lists must be more carefully scrutinized than previous iterations before becoming finalized.

One of our greatest challenges is to continue to be effective conservationists in a changing political arena. As an example, the Healthy Forest Restoration Act has led to an increased emphasis on terrestrial fuels reduction projects, while aquatic and riparian projects are currently considered "low priority." However, most of the threatened, endangered, and sensitive species are aquatic dependents. This means that we must be creative in finding additional resources and mechanisms to ensure survival of the aquatic herpetofauna. To that end, increased interagency cooperation and the pursuit of additional grant money may become a critical future direction.

While the CNF addresses the conservation needs of many species, activities are often more re-active than pro-active. Too much time is spent responding to B.O.'s and in litigation, instead of recognizing and addressing wildlife conservation needs up front. However, the CNF is increasingly more proactive with early interagency involvement with conservation and strategic plans. The CNF has a legal obligation to conserve our natural heritage, including its herpetofauna. The challenge lies in keeping focused on environmental laws and policies and conservation issues in a changing social and political environment.

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Coyote Abundance in Relation to Habitat Characteristics in Sierra San Luis, Sonora, México

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Abstract—*Coyotes have expanded their historical distribution range because of anthropogenic activities and habitat transformation, where forests have been considered marginal habitat. We tested the relationship between vegetation structure and coyote abundance in different habitat types. We expected to find a higher abundance in open lands than in thicker areas. We used scent station surveys and found that the shrub layer seems to be the factor determining coyote abundance, with a higher use of open areas. The structure of the vegetation represents an important factor in the distribution and conservation of large carnivores.*

Introduction

Coyotes (*Canis latrans*) are neartic canids that originally inhabited open country and grasslands but currently occupy diverse habitats, principally influenced by two factors: (1) food availability, (especially during winter), and (2) vegetation structure where grasslands, meadows, and shrub-meadows have larger coyote populations. This expansion has been attributed at least in part to human activities, such as those that later caused the extirpation of the gray wolf (*Canis lupus*). However, even where there are no wolves in the forests, these types of habitats are still considered marginal to coyotes (Crete et al. 2001, Bekoff 1977, Knowlton et al. 1999, Litvaitis 1995). In areas of dense vegetation (i.e., forest and the riparian areas), coyote populations are smaller and sometimes undernourished (Gese et al. 1996, Knowlton et al. 1999, Windberg et al. 1997). The purpose of this study was to determine the relationship between vegetation structure and coyote abundance in areas with different types of vegetation in the Sierra San Luis in Sonora, Mexico, where coyotes had not previously been studied. In an area containing grasslands and forests, we tested the hypothesis that areas with thick cover are marginal habitat for coyotes (Gese et al. 1996, Palomares 2001). We predicted that grasslands would have the highest abundance of coyotes with a reduced abundance in forests.

Study Area

The Sierra San Luis is located in northeastern Sonora, Mexico, between the 31º15'N latitude and the 108º 48'W longitude (figure 1). This area is the confluence of four biogeographical regions: the Sierra Madre Occidental, the Rocky Mountain region, and the Chihuahua and Sonora Deserts. This confluence creates topographic, geologic, and climatic variability producing an elevated ecosystem diversity. The primary land use in this area is livestock ranching. The annual weather pattern is characterized by a wet season extending from June to September and a dry season for the remainder of the year, with sporadic winter rains (Sayago Vazquez 2004).

We worked in three private ranches that have not had livestock for the past seven years. Two of the ranches, El Valle and Los Ojos, are adjacent to each other but act as independent units separated along elevation gradient. The third ranch, El Pinito, is separated from the others by 15 km (figure 1).

The first site, El Valle ranch, has native grassland typical of semiarid zones, with scattered shrubs and almost no trees. This grassland community consists mainly of blue grama (*Bouteloua gracilis*), cotton top (*Trichachne californica*), tobosa (*Hilaria mutica*), spidergrass (*Aristida ternipes*), and needlegrass (*Stipa eminens*, Orth and Lewis 1995, SEMARNAT 2001). This community also includes shrubs such as white-thorn acacia (*Acacia constricta*), wait-a-minute bush (*Mimosa biouncifera*), cholla (*Opuntia imbricata*) and Engelman's prickly pear (*O. phaeacantha*).

In the second site, Los Ojos, the main vegetation type is low open forest: short tree communities 5-10 m high with species such as Mexican blue oak (*Quercus oblongifolia*), shrub live oak (*Quercus turbinella*), one seed juniper (*Juniperus monosperma*), desert acacia (*Acacia ferneciana*), and thorn acacia (*A. constricta*). This community has a shrub layer with species such as bear grass (*Nolina microcarpa*), Parryi agave (*Agave parryi*), bitter condalia (*Condila globosa*), and sotol (*Dasiliryon wheelerei*). There is a well-defined grass layer. This community is commonly found as a transition between grasslands and coniferous forest, has a temperate sub-humid weather, and has a great variety of vegetation structure despite being considered a single vegetation type (Low open forest; SEMARNAT 2001).

Finally, the El Pinito ranch has a plant community composed of pine forests between 8-25 m in height and pine-oak forests 5-20 m tall. The climate is humid and sub-humid temperate weather with temperatures that can be temperate to semi-cold. The forest consists of Chihuahua pine (*Pinus leiophylla*), Apache pine (*Pinus engelmannii*), Arizona white oak (*Quercus arizonica*), silverleaf oak (*Quercus hypoleucoides*), Arizona cypress (*Cupressus arizonica*), alligator juniper (*Juniperus deppeana*), and pointleaf manzanita (*Arctostaphylos pungens*). There is also an important extension of chaparral: dense and

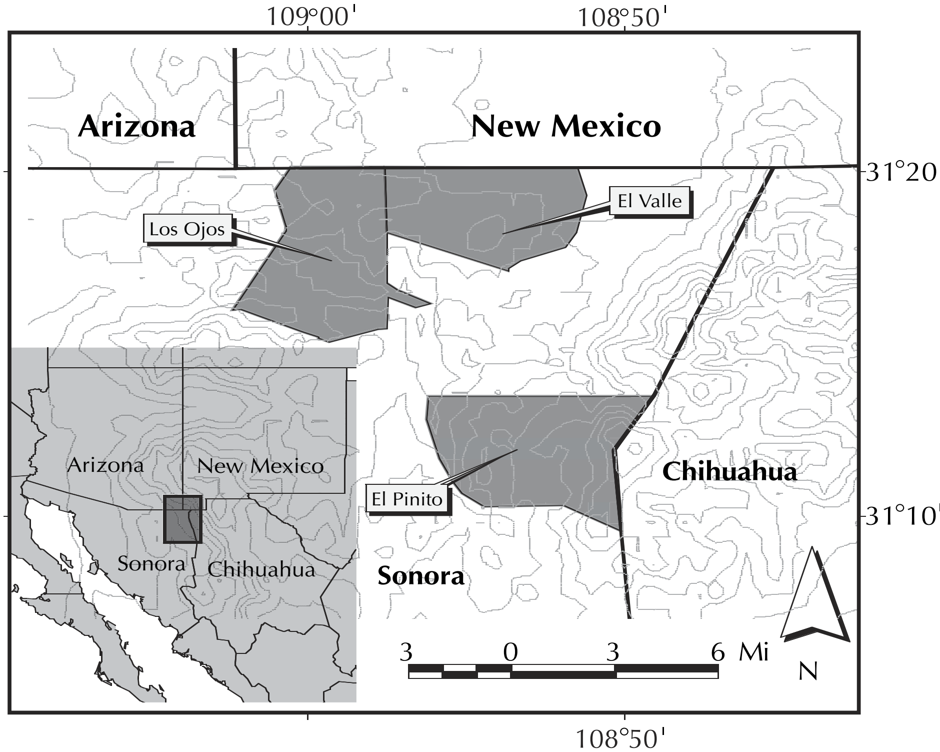

Figure 1—Study area located in the U.S.-Mexico borderland. Ranches are gray.

short vegetation associated with natural or induced fires, with a floristic composition formed principally by chamise (*Adenostoma fasciculatum*), manzanita (*Artoctaphylos* spp.), palmer oak (*Quercus dinni*), shrub live oak (*Quercus turbinella*), Parryi agave, alligator juniper (*Juniperus deppeana*), and beargrass (*Nolina microcarpa*), producing an open vegetal structure (Orth and Lewis 1995).

Methodology

Coyote Abundance

We selected transects on which to place scent stations (Knowlton et al. 1999) to test our hypothesis. We established 3 transects of 3 km of length per ranch. Each transect consisted of ten scent stations with 0.3 km of separation between stations. Each scent station consisted of 1 m^2 of sifted dirt with an attractant placed in the center (Canine Call and Bobcat Gland Lure from Minnesota Trapline Products). Scent stations were checked daily over 2 consecutive nights (hereafter, the sampling period) when weather permitted. The survey was repeated every 3 weeks from July 2003 to January 2004. We determined whether coyotes had visited the stations by examining the sifted dirt for the presence of tracks. We calculated the relative abundance of coyotes using a scent station index (SSI), where SSI was the total number of visits for each species divided by the total number of operable scent stations times 100 (Schauster et al. 2002, Wilson and Delahay 2001). We obtained a daily SSI per transect, in order to calculate an average (SD) for each sampling period, which we compared between ranches and seasons and used to characterize the population trend across specific microhabitat sites.

Microhabitat Use

Characterization of microhabitat used by coyotes was determined at each scent station through the Point Quarter Sampling method (PQS). For each scent station, we placed a point 10 m away from to the station representing the center of four compass directions (N, S, E, W). We divided the sampling site into four quadrants representing the compass directions. In this area, we classified the structure of the vegetation into three classes: trees, shrubs, and grasses. For each individual plant, we determined the species and measured basal cover, aerial cover, height, and the point to plant distance (Brower et al. 1998).

We obtained data for the following 11 variables: arboreal, shrub, and grass density; arboreal, shrub, and grass basal cover; arboreal and shrub aerial cover; and arboreal, shrub, and grass height. To determine if the microhabitat structure influenced coyote abundance, we used Principal Components Analysis to determine which variables represented the most variability (Garigol et al. 2000). Finally, we correlated coyote records and vegetation structure in order to detect a direct relation with any given variable.

Results

Coyote Abundance

We obtained 110 coyote visits: 74 for El Valle, 35 records for Los Ojos, and one for El Pinito. But we did not find a significant difference between the seven surveys or between the two seasons. We detected a population trend to decrease in El Valle, whereas in Los Ojos we observed an increase. We had a single visit to El Pinito throughout the study (figures 2, 3, and 4).

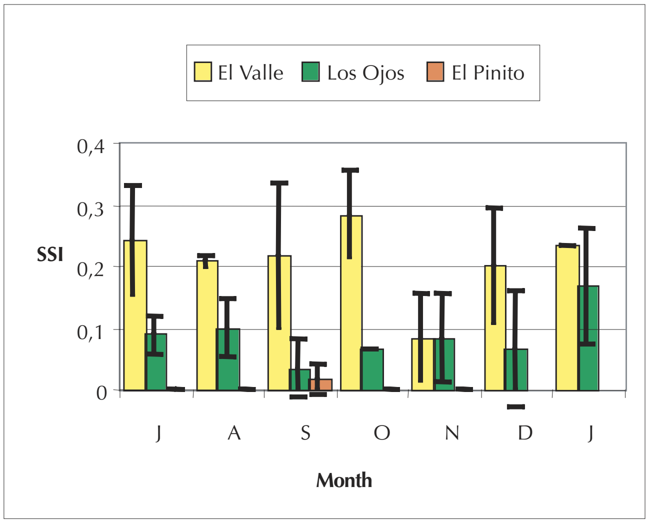

Figure 2—Comparison of the Scent Station Index (SSI) in each of the three sites studied and in each month surveyed

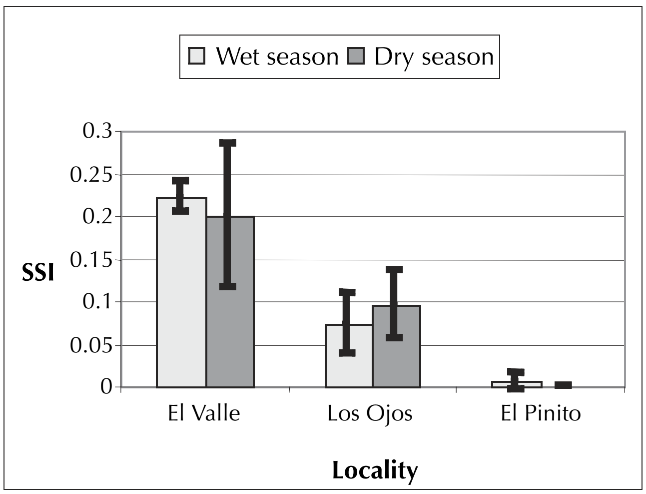

Figure 3—Comparison of the Scent Station Index (SSI) in each weather season and in each of the three sites surveyed.

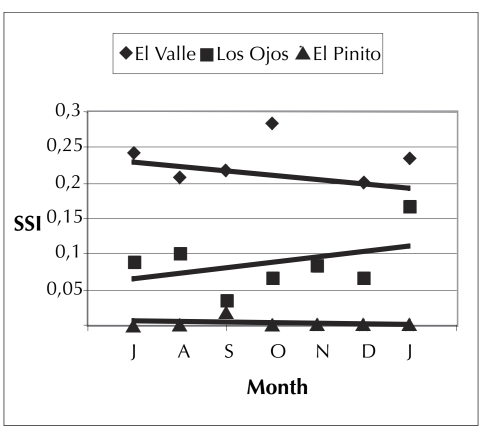

Figure 4—Correlation between the SSI of each site per month that shows the tendency of coyotes to use a type of habitat during some months.

Vegetation Structure

El Valle had lower tree and shrub density than the other two ranches but higher density of grasses. We found a significant difference between El Valle and El Pinito, namely in the grassland and the pine-oak forest; Los Ojos had an intermediate density between the other two areas (table 1).

The Principal Components Analysis (hereafter PCA) was done in two parts, because the scale of variables varied greatly. The first part was with the tree and the shrub layers, and the second was with the grass layer. Ninety-two percent of the stations (n=83) were affected by 3 principal variables: the total density of shrubs, and the basal and aerial cover of shrubs (loadings of 0.573, 0.551, and 0.427, respectively). In general these stations were characterized as open ground. On the other hand, the remaining 7 stations (8%) were located in areas of dense vegetation. In the second analysis recording the grass layer (table 2), the majority of the stations were grouped by the PC2 reducing the three variables to only one: the height of the grass layer (loading of 0.998). Correlating the PCA results above with the coyote records, we found that 93% of the records were found in the big grouping of the PC2, and only the 7% were scattered (table 3).

Discussion

It seems clear that the forest in the Sierra San Luis might provide a marginal habitat for the coyotes, similar to other northern forests (Crete et al. 2001). The relatively low abundance of coyotes in the forest may be due in part to the increased presence of larger and competing predators (mountain lions and black bears) as a result of low human activities in the forest. Coyotes seem to be well-adapted to life in open lands, but in dense areas the shrub layer can play an important roll in the protection of prey species (Gese et al. 1996, Palomares 2001). Dense vegetation structure makes hunting for lagomorphs or rodents more difficult for coyotes, and the difficulty increases with shrubs such as the manzanita, sotol, and junipers that were found in our study areas and that can form an impenetrable layer for coyotes when the plants are sufficiently dense. In open habitats such as grasslands, coyote can detect, pursue, and capture prey with less energy costs. The chaparral in the Sierra San Luis, despite having an open structure, is generally surrounded by dense areas such as the forest, so it is possible that the coyotes within these areas were transient individuals.

It is also possible that we did not find significant differences between the wet and dry seasons because 2003 was a year of El Niño, therefore the pattern of rains in Sonora exacerbated the already harsh drought.

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Table 1—Vegetational structure in each locality. Average of the 11 variables measured in each vegetation type.

		Total density (ind/100 m²)			Basal cover (m²/100 m²)			Aerial cover (m²/100 m²)		Average height (m)			Coyote
Locality	**Vegetation type**	**trees**	**shrubs**	**grasses**	**trees**	**shrubs**	**grasses**	**trees**	**shrubs**	**arborial**	**shrub**	**grass**	**registries**
El Valle	Natural grassland	0.2	5.4	7094.3	0.0	1.4	283.5	0.2	2.6	1.4	0.7	0.2	74
Los Ojos	Open low forest	10.7	5.7	799.4	0.8	2.5	53.8	13.6	25.3	2.2	0.7	0.3	35
El Pinito	Chaparral	5.3	36.1	504.8	0.6	5.0	34.5	5.2	24.9	2.2	1.0	0.4	1
El Pinito	Pine-oak forest	39.4	62.6	698.6	3.1	3.0	39.8	39.5	68.9	2.8	0.9	0.3	0

Table 2—Values of the Principal Components Analysis of the grass layer. The PC2 is the principal where most stations are grouped. Significant values are in **bold**.

Principal components			
EigenValue:	1.9723	0.9974	0.0303
Percent:	65.7436	33.2455	1.0108
Cum. percent:	65.7436	98.9892	100
Eigenvectors:			
Grass layer			
Total density	0.70597	-0.04316	0.70692
Basal cover	0.70628	-0.03129	-0.70724
Average height	0.05264	**0.99858**	0.0084

Table 3—Values of the Principal Components Analysis of the tree and shrub layer. The PC2 is the principal where most stations are grouped. Significant values are in **bold**.

	Principal components							
EigenValue:	2.7957	1.8165	1.136	0.8508	0.6864	0.4253	0.2425	0.0468
Percent:	34.9468	22.7064	14.1998	10.6351	8.5801	5.3163	3.0309	0.5846
Cum. percent:	34.9468	57.6532	71.853	82.4881	91.0682	96.3845	99.4154	100
Eigenvectors:								
				Tree layer				
Total density	0.49559	-0.22125	-0.08377	0.13819	0.29366	-0.10744	0.74595	0.15843
Basal cover	0.56117	-0.13413	0.03674	-0.01241	-0.06629	0.04754	-0.50775	0.63335
Aerial cover	0.56992	-0.15179	-0.01152	0.07383	-0.00222	0.04101	-0.27132	-0.75582
Average height	0.22959	0.25432	0.57098	-0.44394	-0.4797	0.20777	0.2928	-0.02245
				Shrub layer				
Total density	0.18597	**0.57343**	-0.17864	-0.17448	-0.01104	-0.75635	-0.04263	-0.01495
Basal cover	0.11497	**0.42764**	-0.30106	0.63134	-0.4716	0.27744	0.11644	0.04171
Aerial cover	0.11411	**0.55196**	-0.09735	-0.20194	0.6076	0.51012	-0.05164	0.00138
Average height	-0.0338	0.17025	0.73038	0.55534	0.29588	-0.17912	-0.09139	0.00566

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Prospects for Mexican Gray Wolf Recovery in the Sky Islands

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On November 1, 1917, the first Mexican gray wolf (*Canis lupus baileyi*) of many to follow was killed by the Federal government in Arizona. The female animal was one of a pair of the diminutive subspecies of the much more widely distributed gray wolf (*Canis lupus*). Typical of their kind, and of the arid and less biologically productive habitat in which they evolved, the two peripatetic animals covered a territory much larger than those of northern, heavier wolves. They ranged from Sonora, Mexico, into the Canelo Hills of southern Arizona, traveling in a regular circuit of about seventy miles that crossed the international border at two places.

The wolf pair had been killing newborn calves, and their tracks were distinguishable by the male's missing middle toe on his right front foot—previously lost to a leghold trap. For that reason, he was particularly trap-wary, and possibly she was also. The pair had avoided poison and attempts to track them down with hunting dogs.

The government hunter assigned to their demise, Stanley P. Young of Oregon, had set up a home two years earlier next to his brother's ranch in the Canelo Hills, and after a stint with the Forest Service, gained employment with the U.S. Bureau of Biological Survey in October 1917. This was his first assignment, one that directly benefitted his brother's business. He started off tracking the wolves to learn their habits.

On most of their route, the wolves' trail ranged too widely—from a few to dozens of yards in width—for Young to be able to set traps accurately. In addition, much of their trail also was used by free-ranging cattle and by cowboys, and the traps would not likely stay unsprung long enough to catch the wolves. But finally Young discovered a spot at a 6,000-foot-high pass in the Canelo Hills where the animals detoured for about thirty feet from their main route to a flat limestone rock, from which they could rest while observing the San Rafael Valley below. At the spot where the wolves stepped from the ground to the rock, on or around his twenty-eighth birthday, October 30, Young placed two traps.

The wolf pair was always suspicious of new odors on the trail, particularly scent posts seemingly established by strange wolves. (A scent post is a bush or other upraised feature where the dominant wolf in a pack habitually urinates to mark his territory.) But nothing alerted the female wolf to the trap beneath the soil as she approached the rock. As the steel teeth bit into her foot she lunged away, pulling the trap (attached to eight feet of quarter-inch linked chain) with her and yanking a foot and a half long steel stake pin out of the ground. Pulling these behind her, she ran two hundred yards into the thick cover of manzanita bushes, and then stopped to bite at the trap, seeking freedom and respite.

When Young returned to the spot on November 1, 1917, he saw that the trap was sprung and missing. Though he could have tracked the wolf on his own, he went back to the valley and returned with two ranchers and their hounds. The dogs tracked the wolf into the nearby thicket. The wolf, trailing the chain and pin, scrambled nearly five hundred feet up a ridge and then down into a creek bed, running down a rocky gully crowded thick with vegetation. Each time the dogs got close, she turned on them and snapped, leaving no doubt that even handicapped she could defend herself ably. After five miles, she reached the open valley and kept running. Every time she leaped, the steel stake swung around and hit her in the flank. Still, she was alive and escape seemed possible. But Young and the ranchers followed the hounds on horseback. After more than a mile of pursuit in the valley, they gained on the wolf and her seven pound encumbrance. She could not keep ahead of the galloping horses, and as they came upon her Young ended the wolf's travail with a shot from a .38 caliber Colt revolver.

Young was proud of his achievement. But he still wanted the male wolf, the more trap-wary animal. Seventeen days later that animal returned, and from following his distinctive track Young surmised he was searching for his lost mate. In anticipation, Young had collected the dead female's urine, ground up her gall bladder and her anal glands, and combined these elements into an odiferous tonic. This he sprinkled on a scent post right at the point where the wolf trail had detoured to the fatal rock outcropping. The male wolf, his caution overpowered by longing, stepped into another trap at that spot (Young, no date).

Stanley P. Young's proficiency in this endeavor presaged a wider competence in bureaucratic procedure and intrigue that catapulted him into the most instrumental figure within the Biological Survey and helped ensure its single-minded attention to its war on predators and rodents. Through traps and through poison the agency eliminated all breeding wolves in the Western United States by the early 1930s, though a few lone animals still survived and others roamed up from Mexico and down from Canada. To address the potential of "re-infestation," beginning in 1950 the U.S. Fish and Wildlife Service, successor to the Biological Survey, began sending American salaried personnel and poison to Mexico to duplicate this program south of the border. (And Young traveled to Canada to attempt the same for that nation.)

The agency's success can be measured by the fact that after this extermination program was finally reigned in through President Richard M. Nixon's signing of the Endangered Species Act on December 28, 1973, only five Mexican wolves could be trapped alive in Mexico for an emergency captive breeding program intended to stave off extinction and provide animals for later reintroduction. Although Roy McBride, the Fish and Wildlife Service hunter who captured these last wolves between 1977 and 1980, estimated that perhaps as many as fifty more survived in Mexico, none has been confirmed since then and the subspecies was presumed extinct in the wild until reintroduced to the United States in 1998 (McBride 1980).

The reintroduction to the Apache National Forest in Arizona and the Gila National Forest in New Mexico took place largely outside the long recognized historic range of the Mexican gray wolf. Current policy, and subsequent agency actions, may dictate that the Mexican wolf not be allowed to roam its historic range—the Sky Islands region—in the United States.

The original taxonomy of gray wolves was elucidated by Major E. A. Goldman of the U.S. Fish and Wildlife Service in 1944, in *The Wolves of North America*, co-authored with Stanley P. Young (Young and Goldman 1944). The agency retained many of their victims' skulls and pelts for comparative examination, and on that phenotypic basis Goldman drew the line that delineated the northern range of *C. l. baileyi*—at the Gila River in Arizona and New Mexico. His analysis and subspecies boundary line was confirmed in 1959 by E. Raymond Hall, Ph.D., of the University of Kansas (Hall and Nelson 1959), the most prodigious academic mammalogist in the twentieth century and an indefatigable and effective opponent of the predator extermination program from 1928 until his death in 1985. (His congressional testimony helped delay for over a year passage of the 1931 Animal Damage Control Act, which gave sanction and authority for the program to continue, and in 1967 he succeeded in ending the program in his home state of Kansas.)

Most of the United States portion of that agreed upon range for the Mexican wolf consists of the Sky Islands and the Chihuahuan and Sonoran Desert surrounding them. But the 1982 Mexican wolf recovery plan suggested releasing the progeny of the remnant members of *baileyi* into the ranges of two extinct Southwestern subspecies, *C. l. monstrabilis* and *C. l. mogollonenis*, where existed larger tracts of roadless habitat—and where some degree of genetic intergradation would have naturally occurred. After they were exterminated, at various times in the twentieth century dispersing *baileyi* individuals from Mexico had traveled into their ranges, demonstrating that *baileyi* could survive in these regions (USFS 1982). (It is worth noting that the several-hundred mile maximum recorded dispersal distances of wolves is largely an artifact of their extirpation from vast regions; it is likely that prior to extirpation wolves generally dispersed much shorter distances before finding mates and settling down, hence limiting the extent of genetic mixing between regions and allowing the evolution of subspecies.)

The recovery plan cited a 1980 paper by biologists Michael A. Bogan, Ph.D., and Patricia Mehlhop, Ph.D. (1980), suggesting these other subspecies could in fact be attributable to *baileyi*, but took no position on their proper assignation, merely stating that the "additional room provided by the Bogan and Mehlhop assessment" would help the team find "suitable wolf release areas." The expansion created a new northern boundary that encompassed the Mogollon Plateau in Arizona and the southern half of New Mexico, along with most of Texas—thousands of square miles that had not originally been regarded as the range of *Canis lupus baileyi.*

In 1986, another Fish and Wildlife Service taxonomist, Ronald M. Nowak, affirmed the original northern range boundary for *baileyi* (and extended it to the east), but nonetheless endorsed placement of Mexican wolves outside their historic range in the interests of providing them habitat where conflicts with livestock interests could be minimized and the wolves' protection could be maximized. In 1992, a DNA study indicated that Mexican wolves were markedly different from all other North American wolves—but could not assign a specific boundary to their unique assemblage of genes (Wayne and others 1992).

The 1996 Final Environmental Impact Statement for the proposed reintroduction, and the 1998 Federal Register notice approving it, established a Mexican wolf population area designated under the experimental, non-essential clause of the Endangered Species Act, whose northern boundary is Interstate 40 and southern boundary Interstate 10—in essence extending the 1982 recovery plan's range of possible release areas dozens of miles northeastward and outside the historic range of *C. l. monstrabilis*, the subspecies which Bogan and Mehlhop had attributed to *baileyi* and which Nowak had attributed to the Great Plains wolf, *C. l. nubilus*. This created a boundary line approximately 200 miles north of the most widely accepted subspeciation boundary at the Gila River, in recognition that a reintroduced population was likely to send dispersers considerable distances. Within this broad region, the reintroduction would take place in a recovery area comprising the Gila and Apache National Forests. About 80% of this recovery area was originally identified as the range of *mogollensis* (and 20% in *baileyi*'s old range). Through this official range re-assessment, the "Mexican gray wolf" was redefined as a subspecies that also inhabited part of northern New Mexico and Arizona.

Even as official range maps for *baileyi* twice skipped northward, the reintroduction program run by the Fish and Wildlife Service under authority of the Endangered Species Act ensured that Mexican wolves would not be allowed to return to the Sky Islands. At the insistence of ranchers and State game agencies, the Federal Register notice for the program required the Federal government to kill or capture wolves who establish territories outside the official recovery area on the Apache and Gila National Forests, even if the wolves are on other public lands (although wolves would be allowed to exist on private and tribal lands where their presence was specifically requested) (Federal Register 1998).

In June, 2001, a panel of four independent biologists, led by Paul C. Paquet, Ph.D., of the University of Calgary, Alberta, issued an 86 page report that had been contracted by the Fish and Wildlife Service as the official three-year review of the reintroduction program. The Paquet Report urged rescinding this provision of the regulations and allowing wolves to roam freely, unless they were causing a tangible problem (Paquet and others 2001). The Fish and Wildlife Service has not revised the rules, and as the scientists suggested was likely to occur, the wolf population has not met subsequent demographic targets—largely as a result.

Another measure by the same agency threatens to enshrine the absence of Mexican wolves from the Sky Islands into the broader recovery plan governing the species' future. On April 1, 2003, the Fish and Wildlife Service created the Southwestern Gray Wolf Distinct Population Segment (DPS), extending from (and including) Mexico to Interstate 70 of northern Colorado and Utah. In so doing, the agency replaced a previous rule that assured that subspeciation would be considered in gray wolf recovery planning (Federal Register 1978, 2003). A DPS is a unit of listing under the Endangered Species Act, and FWS has appointed a new recovery team to develop de-listing criteria for this DPS.

The DPS's northern boundary is hundreds of miles north of the 1996 line that itself already represented two steps beyond *baileyi*'s originally conceived range. The DPS encompasses the historic range of five originally conceived gray wolf subspecies: *baileyi*, *monstrabilis*, *mogollensis*, *nubilus*, and *youngi.* (The latter is the Southern Rocky Mountains wolf named for Stanley P. Young, who had moved from Arizona to Colorado to oversee exterminating wolves there.) But among these, because of the late date at which the Fish and Wildlife Service began extermination activities in Mexico, only *baileyi* survives. Because it includes such a broad region, the configuration of this DPS undervalues the genetic uniqueness and the specialized evolutionary course of *bailey*. And since Fish and Wildlife Service policy requires that designation of DPS's is to be based on, among other factors, the "physical, physiological, ecological or behavioral" differences "from other populations of the same taxon" (Federal Register 1996), the designation of this DPS can be interpreted as an act of biological gerrymandering. (Its designation is being challenged in Federal court by a coalition of seventeen conservation organizations.)

From Goldman to Nowak, phenotypic analyses of *baileyi* stressed the striking differentiation of these wolves even from their immediate neighbors, whether depicted as mogollonensis or nubilus. Goldman wrote, "In southeastern Arizona and southwestern New Mexico, baileyi intergraded with mogollonensis. Although wolves are known to wander over considerable distances, the transition from baileyi to mogollonensis is remarkably abrupt" (Young and Goldman 1944: 471). Nowak wrote: "I have long been impressed by the tendency to small size shown by gray wolves of Mexico and the border region. A complete gray wolf skull found at a late Pleistocene site in Nuevo Leon is the smallest of any adult North American C. lupus that I have seen." This evidence of uniqueness is corroborated in the genetic record.

That is not to gainsay a certain degree of arbitrariness in original assessments boundaries, because of course there was genetic interaction along the fringes. Nevertheless, the abrupt phenotypic changes in the gray wolf cline correspond to striking differences in other life forms precisely where the originally conceived boundary between *baileyi* and *mogollensis* occurs. The prey base in *baileyi*'s range in the United States (as recognized by Goldman, Hall, and Nowak) included collared peccary (*Pecari tajacu*), also known as javelina, and Coues white-tailed deer (*Odocoileus virginianus couesi*), both species among the smallest of ungulates anywhere, and historically limited at their northern extent to the Sky Islands region. Conversely, there were few or no elk historically known in this original range; the southernmost extent of elk is thought to have terminated where the mountains met the desert.

The differences in prey base along this line is also reflected in a significant difference in habitat. In 1992, the Arizona Department of Game and Fish published a "Summary of Information on Four Potential Mexican Wolf Reintroduction Areas in Arizona." The Department looked at four regions—one of them the Blue Range where wolves were eventually reintroduced and the other three comprising the Sky Islands of Arizona—and listed their attributes for wolves. The three Sky Island areas (plus a few hundred thousand acres in New Mexico) more or less correspond to the original United Statees range for *baileyi* and together comprise approximately 7.5 million acres. (Precise acreage is difficult to ascertain because two of the three overlap each other.)

The Sky Islands contain approximately 1,159,000 acres of Chihuahuan and Sonoran desertscrub (around 15% of the total), 4,552,000 acres of semidesert grassland (61%), 1,521,000 acres of Madrean evergreen and interior chaparral (20%), 97,000 acres of Petran montane conifer (1%), and 3,812 acres of Petran subalpine conifer forest (0.05%—a precise figure because the area of overlap does not include this vegetation type). The Blue Range (not including the New Mexico portion of the current recovery area) includes 26,000 acres of Petran subalpine conifer forest (3 percent of its total), 577,000 acres of Petran montane conifer (57%), 251,000 acres of Great Basin conifer (25%), and 73,000 acres of Madrean evergreen and interior chaparral (7%) (Johnson and others 1992).

Canis lupus baileyi is successfully adapting to the Apache and Gila National Forests, even though most of this recovery area lies outside *baileyi*'s evolutionary bailiwick. It may be instructive to view the Apache and Gila, thus, as a substantial portion of the region of intergradation between Mexican wolves and northern forms—whether they are regarded as Southern Rocky Mountain wolves, Great Plains wolves, or the forms originally identified by Goldman. What the Blue Range principally has in common with both the Southern Rocky Mountains and the Sky Islands is Petran montane conifer vegetation associations.

The very uniqueness of the Sky Islands region in habitats and prey base, which presumably helped shape *baileyi* into the wide-ranging, small creature it is, threatens to prove the rationale for omitting it from future recovery considerations. Because the Southwestern gray wolf DPS includes most of the Southern Rocky Mountains of Colorado, a region of high ungulate density and thus ideal for wolves to exist in small home ranges, a decision to introduce *baileyi* in the Southern Rocky Mountains may make it seem less urgent to secure its recovery in the only United States portion of its original range, where aridity has dictated a lower vegetative fecundity and corresponding lower density of ungulates.

The bureaucratic legerdemain represented in the DPS's configuration spanning many subspecies' ranges undermines the very reason that the Endangered Species Act articulated a basis for listing (and recovering) not just species, but subspecies and distinct populations as well. For the purposes of developing a recovery plan for *Canis lupus baileyi*, a different task than developing such a plan for the Southwestern DPS, one might consider how subspeciation and regional differences developed in the face of gray wolves' tremendous vagility—and that question might reasonably lead to a consideration of the purposes of the Endangered Species Act.

There is little doubt that Mexican gray wolves would adapt to Colorado, as would Northern Rocky Mountain gray wolves from Yellowstone National Park. But there is more at stake. The Endangered Species Act is intended to "provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved." Putting Mexican wolves in Colorado should not come at the expense of allowing them to recover in the habitats in which they evolved along the United States-Mexico border. The diminutive Coues white-tailed deer deserves the predator which graced it with dashing speed. The javelina should not be cheated of the reason for its inch-long tusks and occasionally aggressive disposition. And the Sonoran desert itself, crowded with thick, sharply-attired and potentially dangerous vegetation, should have as one of its crowning unintended consequences the presence of a wolf small enough to navigate it with ease—just as it did in 1917 when two lobos trotted through the cooler uplands of the Canelo Hills.

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Return of the Tarahumara Frog to Arizona

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Abstract*—The last wild Tarahumara frog (*Rana tarahumarae*) in Arizona was found dead in Big Casa Blanca Canyon, Santa Rita Mountains, in May 1983. However, the species is still well represented in the majority of its range in the northern Sierra Madre Occidental and adjacent Sky Islands of Sonora and Chihuahua. Plans to re-establish* R. tarahumarae *in Arizona were initiated in 1992 and have been coordinated by the Tarahumara Frog Conservation Team. Initial experimental releases of Tarahumara frogs to Big Casa Blanca Canyon, Santa Cruz County, Arizona, are tentatively scheduled for June 2004. If successful there, releases of* R. tarahumarae *would also be considered at Sycamore Canyon and other historical Arizona localities.*

Introduction

The Tarahumara frog (*Rana tarahumarae*) is a medium-sized, drab green-brown frog with small brown to black spots on the body and dark crossbars on the legs (figure 1). The species is known from 63 localities in montane canyons in extreme southern Arizona south to northern Sinaloa and southwestern Chihuahua, Mexico (Rorabaugh and Hale, in press; see figure 1 in Hale et al., this proceedings). Its habitat is located within oak and pine-oak woodland and the Pacific coast tropical area (foothills thornscrub and tropical deciduous forest; Hale et al. 1995, McCranie and Wilson 1987), where it breeds in permanent springs and "plunge pools" in bedrock or among boulders, often with deep underwater and streamside retreats. Similar to the plight of leopard frogs in the Southwestern United States, *R. tarahumarae* has declined or disappeared from portions of its range, including all localities in Arizona. Herein we detail the decline of the *R. tarahumarae* and initial efforts to re-establish the species in Arizona.

Discovery, Decline, and Disappearance From Arizona

In 1931, G. W. Harvey showed Berry Campbell "Mexican frogs" or *R. tarahumarae* in a series of pot holes and a "tumbled-in mine that had filled with water" in Alamo Canyon in the Pajarito Mountains, Santa Cruz County, Arizona. That same year Campbell published this first United States record of *R. tarahumarae* in Copeia (Campbell 1931; Wright and Wright 1949). The frog was subsequently discovered at two more locations in the Pajarito Mountains, including Peña Blanca Springs in 1933 (Campbell 1934) and Sycamore Canyon in 1938. Williams (1960) reported 1948 collections from Tinaja Canyon in the Tumacacori Mountains, and then in 1972 the range of the species in Arizona was extended to the Santa Rita Mountains where it was found in Big Casa Blanca, Gardner, Adobe, and Walker canyons (Hale et al. 1977).

Fifty-two years after their discovery in Alamo Canyon, a wild *R. tarahumarae* was observed for the last time in Arizona when a large female frog was found dead in Big Casa Blanca Canyon by Stephen Hale and Jim Jarchow on May 28, 1983. Hale and his colleagues investigated the status and ecology of all *R. tarahumarae* localities in Arizona from 1966-1992, the results of which were detailed in Hale et al. (1977, 1995) and unpublished reports to the Arizona Game and Fish Department (AGFD) or U.S. Fish and Wildlife Service (FWS) in 1983, 1988, and 1992. The first indication of decline was on April 7, 1974, when Clay May and Darrell Frost observed 19 dead *R. tarahumarae* in Sycamore Canyon below Yanks Spring. Several live but lethargic *R. tarahumarae* were also observed, and the skin on top of the head of some individuals was dry. Two live leopard frogs (*Rana yavapaiensis* or *R. chiricahuensis*) showed no escape movements. However, when Stephen Hale visited the canyon in August, frogs were abundant and appeared healthy. Although leopard frogs have persisted in Sycamore Canyon, that was the last time *R. tarahumarae* were observed there (Hale et al. 1995).

A similar pattern of decline and then extirpation occurred in the Santa Rita Mountains from 1977-1983. In October 1977 a very strong tropical storm drenched the area, dropping 194 mm of rainfall on Patagonia from October 6-9. Big Casa Blanca and adjacent canyons were scoured and littered with debris. When Big Casa Blanca Canyon was surveyed in the spring of

Figure 1—Tarahumara frog at the Kofa National Wildlife Refuge semi-captive holding and propagation facility.

1978, no juvenile frogs from the 1977 cohort were found, and it was thought that many frogs had been flushed downstream or drowned. However, many tadpoles survived the flood and metamorphosed frogs were observed in 1978 and 1979. Yet in July 1980 no tadpoles or metamorphosed frogs were found. From that time until the last frog was observed in May 1983, only one or two frogs and no tadpoles were observed during visits to the canyon. No *R. tarahumarae* were observed in the limited habitat of Adobe Canyon after August 1974, nor in Gardner Canyon after 1977. Leopard frogs declined and disappeared from these same areas during 1977-1978, although they persist to this day at lower elevations in Gardner and adjacent canyons to the north. A visit to Tinaja Canyon in 1980 revealed limited habitat and no Tarahumara frogs, and from 1980 to the present we have not found *R. tarahumarae* at Peña Blanca Springs or Alamo Canyon.

Evidence From Sonora

From 1981-2000, Hale and his colleagues investigated the distribution and status of *R. tarahumarae* populations in Sonora. Visits were made to numerous historical localities and apparently suitable habitats through 2000 to search for frogs. *Rana tarahumarae* were found at 23 sites from the Sierra San Luis and Sierra de la Madera in northern Sonora to the Sierra el Rincón and Sierra Milpillas east of Alamos in southern Sonora. *R. tarahumarae* were not found at 8 sites where they had been recorded or collected in the past. From 1981-1986, Hale and his colleagues observed population declines in progress in the lower reach of Arroyo La Carabina (La Bota) in the Sierra el Tigre (Hale et al. 1995; also see Hale et al., this proceedings). No frogs were found in this lower reach in 1998.

Causes of Decline

Likely causes of decline include chytridiomycosis, a fungal disease; airborne pollutants from copper smelters; predation by non-native organisms; flooding; habitat alteration; drought; and winter cold (Hale et al. 1995; Hale et al., this proceedings; Rorabaugh and Hale, in press). Habitat degradation at Arroyo El Cobre, Sierra el Rincón, in southern Sonora following clearing and planting of buffelgrass (*Pennisetum ciliare*) on the slopes above the canyon and subsequent erosion and sedimentation in the canyon bottom appear to have favored the pustulose frog (*R. pustulosa*). No frogs identified as *R. tarahumarae* have been found there since 1993. Predation by *R. catesbeiana* at Peña Blanca Springs and by chubs (*Gila* sp.) at one site in southern Sonora likely contributed to disappearance of *R. tarahumarae* from those sites. Flooding in 1977 at Big Casa Blanca Canyon probably contributed to the extirpation of *R. tarahumarae* from that canyon, and recent drought was probably a factor in some declines in Sonora. However, frogs in natural habitats should be able to survive periodic flooding or drought, suggesting additional causal factors may have been important.

Stephen Hale, Jim Jarchow, and others (1995) provided evidence that die-offs at Sycamore Canyon and Arroyo La Carabina may have been caused by cadmium toxicity resulting from airborne pollutants from copper smelters in northern Sonora and Arizona. However, in retrospect, symptoms during these die-offs were consistent with what is now known to be chytridiomycosis, a disease that is affecting frog and toad populations around the globe (Carey et al. 2003). *Rana tarahumarae* collected during a die-off in Sycamore Canyon in 1974 were infected with chytridiomycosis (T. R. Jones and P. J. Fernandez, personal communication), and histology of Chiricahua leopard frogs collected in Sycamore Canyon as recently as 2003 confirm frogs are still infected with chytrids. Chytridiomycosis has not been documented in Big Casa Blanca Canyon; however, *R. tarahumarae* captured in 1977 showed symptoms similar to those exhibited by frogs in Sycamore Canyon in 1974. As a result, although flooding was an apparently important cause of decline, we cannot rule out the possibility that chytridiomycosis contributed to the extirpation of *R. tarahumarae* from Big Casa Blanca and adjacent canyons in the Santa Rita Mountains. Chytridiomycosis was confirmed from *R. tarahumarae* collected at several sites in Sonora from 1982-1999, including Arroyo La Carabina, but frogs have persisted with the disease at most of these sites (see Hale et al., this proceedings). Although chytridiomycosis has been present at some sites of decline or extirpation, airborne pollutants from copper smelters could still have contributed to declines of *R. tarahumarae*, as hypothesized by Hale et al. (1995). Stress associated with cadmium toxicity could compromise immune function and make frogs more susceptible to chytridiomycosis (Carey et al. 1999; Rollins-Smith et al. 2002). *Rana tarahumarae* may be particularly affected by disease or toxicants during winter at colder sites (see Hale et al., this proceedings). If copper smelters contributed to declines in the past, they are probably no longer a factor, as they have either closed (Douglas and Cananea) or are now equipped with pollution control scrubbers (Nacozari).

Tarahumara Frog Conservation Team 1992-1998

A group of biologists and land managers first met in June 1992 to develop a plan to re-establish *R. tarahumarae* into

Arizona. That group, which became the Tarahumara Frog Conservation Team (TFCT), began to outline a re-establishment and monitoring program under the AGFD's 12 step "Procedures for Nongame Wildlife and Endangered Species Re-establishment Projects," a required process to re-establish the frog in Arizona. A proposal abstract, step 3 of the procedures, was drafted in 1993, and a "Conservation Plan for the Tarahumara Frog" was produced in 1995 by the TFCT as a more detailed re-establishment plan that could potentially meet the requirements for a proposal to AGFD as step 8 of the procedures.

The TFCT suffered from a lack of dedicated funding until 1998 when Stephen Hale received a small grant from the Arizona Zoological Society to evaluate the status of the frog and potential source populations for re-establishment at five sites in northern Sonora. Arroyo el Tigre, Sierra el Tigre, was identified as the best source population for a re-establishment program. Also in 1998, FWS obtained a Department of the Interior Border XXI grant to re-establish the *R. tarahumarae* into Arizona. These funds were distributed to Stephen Hale and the Instituto del Medio Ambiente y El Desarrollo Sustentable de Estado de Sonora (IMADES—Eduardo López Saavedra and Andrés Villareal) for additional status surveys in Sonora and collection and transport of *R. tarahumarae* to Arizona for captive propagation. AGFD was also funded out of the grant to complete the 12-step procedures and to begin re-establishment and monitoring of frogs. Additional FWS funds were transferred to the Arizona-Sonora Desert Museum (ASDM) to cost-share development of rearing and captive propagation facilities.

Collection, Rearing, and Propagation of Tarahumara Frogs for Re-establishment, 1999-2004

Four *R. tarahumarae* frogs and 30 small tadpoles were collected from Arroyo el Tigre during October 25-27, 1999, for rearing and captive propagation at the ASDM. One of the frogs died on 27 October, and the other three succumbed soon thereafter. Frogs from this canyon were later confirmed to be positive for chytridiomycosis, and stress associated with their capture and transport may have pre-disposed them to chytridiomycosis. The tadpoles did well initially, but growth slowed and eventually stopped after 8 weeks in captivity. At that point, mortalities began and continued for 4 weeks until the last tadpole died.

In 2000, a new population was found at Arroyo el Chorro, Sierra de la Madera, southeast of Imuris. This is the nearest-known population of *R. tarahumarae* to Arizona (approximately 72 km south of the border). On May 1, 2000, about one-third of an egg mass was collected and transported to the FWS office in Phoenix for initial rearing. The partial egg mass contained an estimated 850-900 eggs, which hatched in 8 days (Rorabaugh and Humphrey 2002). The tadpoles grew rapidly and were eventually transferred to captive facilities at the ASDM and San Bernardino National Wildlife Refuge (NWR), and semi-captive, contained facilities at Coronado National Memorial, Arizona State University, a backyard pond in Tucson, and at Kofa and Buenos Aires NWRs (figure 1). Metamorphosis occurred in as little as 86 days, but most tadpoles did not metamorphose until the spring or summer of 2001. In 2001-2002, 25 *R. tarahumarae* were reared by the Detroit Zoo's National Amphibian Conservation Center. Ivanyi and Poulin (appendix 2 of Sredl et al. 2003) prepared a *R. tarahumarae* husbandry protocol that details outdoor and indoor rearing and propagation facilities, recommended animal densities, and tadpole and frog diets.

The frogs matured and bred under a variety of conditions at the San Bernardino and Kofa NWRs and the ASDM in 2001-2004. By May 2004, approximately 70-90 mostly adult frogs and many hundreds of late stage tadpoles were available for release in Arizona.

Completion of the 12 Step Procedures and Other Environmental Compliance and Coordination

AGFD revised the 1995 TFCT re-establishment proposal (Sredl et al. 2004), which became steps 8-11 in the 12-step Procedures for Nongame Wildlife and Endangered Species Re-establishment Projects. The proposal outlines a 10-year program that includes releases of frogs to Big Casa Blanca Canyon, followed by monitoring of the release site and adjacent canyons. If frogs become established at Big Casa Blanca Canyon, then releases to Sycamore Canyon and potentially other historical localities could be considered. Big Casa Blanca and Sycamore canyons were the stronghold of the species in Arizona historically. Of the two, Big Casa Blanca Canyon is considered optimal due to apparently intact habitat, absence of non-native predators, and no confirmation of chytridiomycosis. If *R. tarahumarae* thrive in Big Casa Blanca Canyon, they would likely disperse to Gardner, Adobe, and Walker Canyons where the species occurred historically. Chytrids are present in Sycamore Canyon, and *R. catesbeiana* have been found recently in the canyon near Ruby Road. As a result, re-establishment may be more difficult in that canyon. Protocols are described in the proposal to ensure that diseased frogs are not released, and frogs would be marked with an individual or cohort mark for identification. The 12-step process was completed in May 2004.

Endangered Species Act compliance, in the form of a formal intra-service FWS section 7 consultation to evaluate the effects of the proposed re-establishment on threatened and endangered species and critical habitat in the release areas, was completed in November 2003. A FWS Environmental Assessment (EA) and Finding and No Significant Impact were finalized and signed in March 2004. Both the draft re-establishment proposal and draft EA were made available for public comment; the final documents were revised in response to those comments. A coordination meeting was held among AGFD, FWS, Nogales Ranger District of the Coronado National Forest, and livestock grazing permittees in the vicinity of Big Casa Blanca and Sycamore Canyons in April 2003 to brief ranchers on the proposal and seek their input.

Initial Releases and Monitoring

Initial releases to Big Casa Blanca Canyon are tentatively scheduled for June 2004. We are hopeful that our efforts to re-establish *R. tarahumarae* into Arizona will be successful. However, the causes of decline and extirpation of *R. tarahumarae* in Arizona are not fully understood. We do not know if those causes are still operating to a degree that will preclude successful re-establishment. As a result, re-establishment has been designed to be experimental. Careful monitoring of frogs and environmental conditions will be necessary to fully evaluate the re-establishment effort. If our initial attempts to re-establish *R. tarahumarae* fail in Big Casa Blanca Canyon, we will use those monitoring data to better understand the causes of failure. We would then adapt this new information by revising our approach to hopefully be more successful in future efforts.

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Rangeland Degradation and Restoration in the "Desert Seas": Social and Economic Drivers of Ecological Change Between the Sky Islands

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Abstract—*The relative importance of different factors in driving ecological change in the valleys of southeastern Arizona and southwestern New Mexico has been debated for decades. Clearly, both anthropogenic and natural drivers have played roles: the focus should be on their interactions over time. I suggest that historically, debt and government policies interacted with periodic drought to cause degradation related to livestock. More recently, however, different interactions have emerged. Climate dominates over livestock because stocking rates have declined to relatively low levels, and the distribution of homes and conservation resources now determines where fire and other tools are employed for rangeland remediation.*

Introduction

Degradation of semiarid grasslands in the "desert seas" of the Madrean Archipelago is a well-established fact. In the most recent of many assessments, Gori and Enquist (2003) found that significant shrub encroachment has occurred on 3.5 million ha (84.1%) of historic grasslands in the Arizona and New Mexico portion of the Apache Highlands Ecoregion. In addition, most of the region's major floodplains have been incised by arroyos, beginning in the late nineteenth and early twentieth centuries, with pronounced effects on hydrology, riparian vegetation, and disturbance regimes (Bryan 1928, 1940; Cooke and Reeves 1976; Hastings 1959). A variety of techniques for reversing these changes have been attempted over the past century, but most have not succeeded on any long-term or large-scale basis (Roundy and Biedenbender 1995).

Much scholarly work has turned on the seemingly simple but effectively unanswerable question of whether or not human activities caused degradation. The list of potential culprits is long: livestock grazing, agricultural clearing, irrigation, fire suppression, timber cutting for mining and firewood, installation of railroad embankments and roads, and introduction of non-native flora (Bahre 1991, 1998; Cooke and Reeves 1976; Dobyns 1981; Humphrey 1958). That many of these activities began or peaked at about the time when degradation commenced has strengthened the case for anthropogenic causality. On the other hand, climatic factors remain difficult to exclude as drivers of ecological change (Hastings and Turner 1965; Turner and others 2003). The extraordinary rains of 1905, for example, might have cut arroyos in floodplains regardless of human activities. Similarly, the droughts of the 1890s, 1920s, and 1950s might have decimated perennial grass populations, and increased winter precipitation such as occurred during 1975-1995 might have encouraged shrub dominance, regardless of livestock effects (Curtin and Brown 2001; Herbel and Gibbens 1996).

Clearly the dichotomous theorizing of degradation as either human caused or not has reached the limits of its usefulness. It issues from the same philosophical tradition as equilibrium ecological theory, and it generally relies on a similar set of assumptions: that nature is self-equilibrating in the absence of human disturbance; that removal of a human disturbance will result in reversion to pre-disturbance conditions; that humans and history are separate from or outside of a timeless nature (Zimmerer 2000). These are flawed assumptions, for reasons both metaphysical and ecological. Rather than seek a single cause, or type of cause, of degradation, we should ask how multiple drivers have interacted over time, recognizing that impacts may be interactive, non-linear, and effectively irreversible. Whether degradation could have been prevented is a worthy question for scholarship, but it may have little practical bearing on what should be done to remedy the damage now.

A Historical Approach to Grassland Degradation

The interaction of human and natural drivers of grassland change in the Southwest must be studied historically. Evidence from around the region suggests that the ecological effects and relative importance of different drivers have changed over time. Consequently, the relative importance of different land management options has also changed. Here, I focus on the social and economic drivers determining the interactive effects of climate, livestock grazing, and fire.

Climate

The relevant feature of Southwestern climate, for present purposes, is the high variability of precipitation over space and time. Alternating periods of wet and dry conditions produce highly variable aboveground net primary production (ANPP) and recurrent ideal conditions for fire: large amounts of extremely dry fuels during periods of high temperatures and frequent lightning (McPherson 1995; McPherson and Weltzin 2000). Generally speaking, the region's flora and fauna are adapted to these biophysical circumstances, but the same cannot be said for human activities and institutions over the past 150 years.

Debt, Drought, and Overgrazing

Managing livestock grazing systems sustainably requires matching forage demand and supply, especially in response to drought. Natural grazing systems have built-in mechanisms to limit herbivore demand in response to low forage production (outmigration, mortality, reduced fecundity). But in the Southwest, several factors converged to interrupt this negative feedback mechanism for most of the twentieth century.

First, markets for credit and livestock were national in scale and overheated by speculation. After the Civil War, lenders and investors had strong incentives to send their capital West, where interest rates were high and opportunities apparently boundless (Atherton 1961; Frink and others 1956; Graham 1960). The cattle industry of the time was more dependent on credit than any other sector of the booming Western economy (White 1991). When forage gave out at one location, indebted livestock owners chose to move rather than sell in a sagging market, because liquidating at low prices was tantamount to defaulting (Abruzzi 1995). Arizona and New Mexico were among the last areas to experience the Cattle Boom, and the livestock they received were already refugees from adverse conditions elsewhere in the West (Wagoner 1952, 1961). When severe drought struck the Southwest in 1891-1893, there was no place left to go—the frontier had closed (Bahre and Shelton 1996).

Second, there were other obstacles to rapid destocking in the face of drought. One was perceptual: Rainfall was relatively high during the 1880s, when large-scale ranching took off in the region, so early ranchers were prone to stock at levels that would prove unsustainable when the rains failed (Bahre and Shelton 1996; Hadley and Sheridan 1995). Most were probably unfamiliar with such highly variable precipitation. Another obstacle was structural: The rapidly consolidating and industrializing meat processing sector began refusing to buy older cows in the 1890s (Wagoner 1952). This left ranchers who sought to destock with no economical way of doing so.

Third, government policies rewarded aggressive stocking as a means to control land. The public domain was an open access free-for-all, and "use it or lose it" was the prevailing ethic of the range. Free land was a major part of the extraordinary profitability of livestock production early in the Cattle Boom, but it became an equally significant threat to profitability once the frontier was closed (Frink and others 1956).

Unfortunately, the reforms enacted in the early 20th century to tame the excesses of the boom addressed only the issue of open access, not the question of temporal variability in ANPP. Exclusive leasehold to fenced allotments was implemented on National Forests after 1905, on State lands after 1912, and on the remaining public domain after 1934. Ranchers and their financial backers sought to capitalize leases, and agencies sought an objective basis for setting lease fees. All sides thus shared a common interest in assigning relatively fixed "carrying capacities" to allotments to facilitate credit and administration (Sayre and Fernandez-Gimenez 2003; Sayre 2003). The resulting system effectively institutionalized inflexible stocking.

In theory, carrying capacity estimates accounted for dry years and allowed for recovery during wetter years, assuming a moderate level of resilience (Wooton 1916). It is unknown, however, how closely actual stocking matched official capacity estimates, especially on State and BLM lands where enforcement was minimal. One study, conducted in the late 1950s and early 1960s, inadvertently learned that actual stocking on these lands was roughly double official allowed rates (Martin and Jefferies 1966). This may have reflected another bubble, inflated by cheap credit and high cattle prices during the period of post-war prosperity (Sayre 2002). Or it may have been the norm for decades. The available evidence is too meager to judge one way or another, although the larger pattern shows a steady decline in stocking over the twentieth century. Today's rates are less than half—in some cases less than one-fifth—of estimated stocking at the height of the cattle boom (Fredrickson and others 1998; Hadley 2001; Sayre 2000).

There is even less available evidence bearing on the most important question: To what extent did ranchers vary their stocking rates over time, as rainfall and ANPP rose and fell? Prices typically declined during drought, and many ranchers had invested heavily in the genetic make-up of their herds. Cow-calf production became the dominant form of ranching in the region by about 1930 (Wagoner 1952), so destocking required selling a capital asset: mother cows. Anecdotal evidence indicates that most ranchers chose to purchase (or grow) supplementary feed such as alfalfa hay, rather than sell their stock. Especially in combination with high debt loads, these factors discouraged destocking.

Land management agencies may also have had an incentive to keep stocking rates stable despite variable ANPP: fire suppression. Fire risks were highest during drought, and livestock grazing was an economical way to reduce the quantity and continuity of fine fuels across large, often remote areas. The political pressure to prevent and suppress wildfires generally outweighed other concerns in the U.S. Forest Service, which dominated fire policy and management not only on the National Forests but throughout the West. This may have prompted officials to turn a blind eye to grazing impacts that would otherwise have warranted action (Leopold 1924; Pyne 1982; Rowley 1985).

In summary, producer debt and government policy encouraged high stocking rates in the late nineteenth and early twentieth centuries. Reforms did nothing to encourage flexible stocking rates, and overgrazing became a routine consequence of drought conditions. One long-term consequence, intended or not, was large-scale suppression of fire. This led, in turn, to encroachment of woody plants into formerly grass-dominated areas, such that in many areas fire has now become either impossible (for lack of continuous fine fuels, mainly at lower elevations) or potentially catastrophic (due to continuous, highly flammable woody fuels, mainly at higher elevations).

Fragmentation, Fire, and Remediation

The interactions of social and economic processes with grasslands, climate, and fire in the Southwest have change fundamentally in the past 30 years or so. Livestock ranching is no longer the highest economic use of rangelands in the region (Workman 1986), and private ranch lands are steadily being converted to residential and recreational land uses (Sullins and others 2002). On the many ranches that remain, stocking rates are much lower than in the past, and ranchers appear to be more proactive in destocking during drought, if only because purchasing supplementary feed has become prohibitively expensive.

Gori and Enquist (2003) concluded that more than half of the grasslands overtaken by shrubs in the past 125 years have crossed an ecological threshold, such that even complete exclusion of livestock is unlikely to restore pre-settlement plant communities or fire regimes. Approximately 1.4 million ha does have potential for restoration through the use of fire, however. If the preceding analysis is correct, restoring fire to these lands is of the highest conservation importance, significantly higher than exacting further reductions in stocking rates (McPherson and Weltzin 2000).

Although many producer, environmental, and academic groups now support the use of fire as a management tool, the vast majority of wildfires are still suppressed, and prescribed fires remain few in number and generally small in size. What social and economic factors are enabling fire restoration where it is occurring, and what factors are compelling continued suppression elsewhere?

Certain conditions appear common to most sites where fire restoration is occurring. First, private landowners—either ranchers or environmental groups—are usually leading the effort to restore fire, even when the land being burned is public. Second, the sites are remote from concentrations of houses. This is not surprising, given the policy of the State Land Department to suppress all fires, and prohibit prescribed fires, within five miles of human inhabitations. Unless means are found to make houses and fires compatible, it is clear that conversion of even relatively small areas to residential uses has the potential to effectively eliminate fire as an available conservation tool in Southwestern grasslands and shrublands.

It is still the case that livestock grazing can remove the fine fuels needed to carry fires, especially in areas of mixed shrub-grass vegetation. On ranches where grazing continues, livestock exclusion is typically necessary for a period of one to two years to accumulate fuel prior to burning and for one to two years afterwards to allow recovery of grasses. Permanent livestock exclusion is not necessary, however, to achieve what is believed to be the natural fire return interval of 8-12 years (Kaib 1998).

Conclusion

Degradation and conservation of the "desert seas" of the Madrean Archipelago result from the interaction of natural and human drivers over time. Historic degradation due to livestock grazing reflected a mismatch between highly variable forage production and fixed demand. As a consequence of this mismatch and government fire suppression policy, fire was not a significant disturbance agent in the region during the twentieth century. This caused woody species to become sufficiently dominant that at present, fires either cannot occur or can only occur through active efforts to restore them. Such efforts cannot take place where significant numbers of houses have been built, however.

Although the interaction of livestock and drought triggered grassland degradation in the past, today the process is self-perpetuating and unlikely to be stopped or reversed by livestock exclusion alone. Removal of livestock grazing from State and Federal lands is more likely, in fact, to prevent fire restoration by triggering residential development of associated private lands. Most of the land in the desert seas is not Federally owned and has little or no protection from subdivision and development (Gori and Enquist 2003). Even protected areas may be disallowed from burning in the future if houses are built on adjacent private or State lands. If desert grasslands are to be preserved or restored, then, significant fragmentation and residential development will have to be prevented. This will require active cooperation with and among rural private landowners, especially ranchers, whose interest in grassland conservation is more direct than anyone else's.

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Threats to Cross-Border Wildlife Linkages in the Sky Islands Wildlands Network

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Abstract—*One of the greatest challenges facing conservationists in the Sky Islands region is finding a realistic means to maintain historic travel routes for wide-ranging species crossing the United States-Mexico border. This challenge is made difficult due to the ongoing efforts by the Federal government to install additional security infrastructure to stem the flood of undocumented immigrants now entering southern Arizona. Existing and proposed fencing, solid steel walls, all-night stadium lighting, vehicle barriers, an immense network of roads, a 24-hour flow of patrol vehicles, and low-level aircraft overflights are creating an impenetrable barrier to trans-border wildlife movement. Creative solutions are needed now.*

Introduction

In 2000, the Wildlands Project and regional partner groups, including the Sky Island Alliance, published a conservation plan covering more than 10 million acres of valuable wildlife habitat in the Sky Islands ecoregion of southeast Arizona and southwest New Mexico. The document, known as the Sky Islands Wildlands Network Conservation Plan (SIWN CP), is based on the basic tenets of conservation biology, and a science-based species protection and landscape recovery strategy known as Rewilding (Wildlands Project et al. 2000). The plan includes a proposed reserve network identifying a linked system of core habitat areas connected by wildlife linkages and surrounded by compatible use areas.

The primary goal of the SIWN CP is to protect a network of prime habitat that ensures long-term survival of native species, especially keystone species and processes. Protecting an appropriate suite of focal species has been shown to also protect numerous other species whose requirements for survival are less dynamic (Soulé and Terborgh 1999). Some examples of focal species identified in the SIWN CP that could benefit from trans-border movement, or connected subpopulations, include Mexican gray wolf, jaguar, cougar, black-footed ferret, ocelot, bighorn sheep, pronghorn, black-tailed prairie dog, Mexican spotted owl, aplomado falcon, and southwestern willow flycatcher.

Although the SIWN network design terminates at the United States-Mexico border across Hidalgo (NM), Cochise, Santa Cruz, and Pima (AZ) Counties, its authors intended that the network design's components would mesh with complimentary components in a future Sierra Madre Occidental Wildlands Network that would cover a similarly sized portion of northern Chihuahua and Sonora, Mexico.

Of particular importance in this vision for cross-border merging of conservation plans is the assumption that the Sky Islands Wildlands Network could not reach its full conservation potential unless wildlife linkages allowing focal species movement between the Sierra Madre Occidental, other ranges in northern Mexico, and the Sky Islands of southeastern Arizona were maintained.

The SIWN CP identified numerous threats to a healthy landscape in the Sky Islands, including fragmentation of habitat by roads, fences, and subdivisions; loss or extirpation of numerous species; loss of natural disturbance regimes such as fire; loss of riparian areas, streams, and watersheds; invasion by exotic species; and loss of native forests to logging and other development.

Many of these threats are being successfully negotiated throughout the Sky Islands ecoregion today by hundreds of individuals, State and Federal agencies, private organizations, conservationists, and conservation-minded private land owners. Classic conservation tools such as land and highway management changes, new land and water protection designations, and protection of private lands via conservation easements and other financial-based habitat protection incentives have provided a strong foundation for these efforts.

However, along the United States-Mexico borderlands in the Sky Islands region, these usually reliable tools have often been rendered ineffective by overriding Federal concerns related to stemming the flow of undocumented immigrants into the United States. In short, an ultimate form of habitat fragmentation across Arizona's borderlands is now being erected. A permanent, impermeable wildlife barrier, that will close key cross-border travel routes to many animals, is a distinct possibility if the current approach to border security continues.

The most endangered of these habitat linkages have likely been relied upon for centuries by numerous Sky Islands focal species for travel and dispersal between the Sierra Madres and the Sky Islands. Significant disruption of wildlife movement between similar habitats in northern Mexico and important Sky Islands landscapes in the United States could mean trouble for jaguar, ocelot, black-footed ferret, southwestern willow flycatcher, and other SIWN focal species that are in decline and already listed as Federal endangered species. Cross-border wildlife linkages with a high potential for use by these fast-disappearing species include the Peloncillo Mountains, San Pedro River corridor, San Rafael Valley, Coronado National Memorial, Patagonia Mountains, Pajarita Wilderness Area, and Buenos Aires National Wildlife Refuge. Some of these linkages remain highly intact and are largely roadless landscapes, yet lie only short distances from existing border security projects. Some other linkages are already partially or fully barricaded or fenced.

Based on this immediate threat to habitat connectivity between the two nations, the United States-Mexico borderlands region in southeast Arizona and southwest New Mexico was declared in 2003 by the Wildlands Project to be one of the five most endangered wildlife linkages along the chain of the Rocky Mountains from Canada to Mexico (Wildlands Project 2003).

Borderlands Habitat Fragmentation and Degradation

Although various forms of border fencing to control grazing have been in existence in portions of the Sky Islands for decades, it wasn't until the 1990s that serious efforts to halt undocumented immigration with various forms of barriers became more commonplace. During the end of that decade the first solid steel vertical barricades (surplus U.S. Marine amphibian landing mats up to 15 feet high) were constructed through the centers of border sister cities such as Douglas, AZ/Agua Prieta, Sonora and Nogales, AZ/Nogales, Sonora and extensions of those barricades began to creep outward into the surrounding countryside from those locations early in the new century. Following the World Trade Center attacks in September 2001, the Immigration and Naturalization Service (INS) began a concerted effort to more quickly fortify even larger portions of the United States-Mexico international boundary in the Sky Islands ecoregion.

In October 2002, the INS released a Draft Programmatic Environmental Impact Statement (DPEIS) for a massive borderlands security infrastructure project across southern Arizona. Through various means (including up to 200 miles of 15-ft high solid steel fencing, up to 1,000 "stadium-style" all-night lights, and the blading of single and dual 10-ft wide roads along the entire border), that project proposed to impact virtually all the agency's 280-mile Tucson Sector border in southern Arizona (U.S. Immigration and Naturalization Service 2002).

At that time, it became clear that ecological concerns related to that construction were not a priority for the agency. The DPEIS provided little documentation of negative environmental impacts related to the project, and following the public comment period, during which the agency received hundreds of science-based objections from a wide range of parties regarding such ecological deficiencies, the INS withdrew the DPEIS and indicated it would re-start the process from the beginning. Since that time, several separate Environmental Assessments (EA) have been issued for smaller project areas within the Tucson Sector, but most of those projects duplicated proposals included in the original DPEIS, and continued to lack significant scientific documentation of ecological impacts to wildlife. Current EAs, which require less rigorous justification than EISs, are in various stages of public comment, with some ensuing projects in the beginning stages of implementation.

Shortly after the original DPEIS was released, the creation of the Department of Homeland Security (DHS) resulted in the dissolution of the INS, which became the new U.S. Bureau of Customs and Border Protection (CBP), overseeing the activities of the Border Patrol.

To date, neither the CBP nor other public or private entities have completed conclusive scientific research into the effects of border infrastructure on native plant or animal communities in the Sky Islands border region. Despite this lack of biological data, and in response to the Federal government's apparent decision to move forward with completion of border security projects, the CBP continues to implement new border security infrastructure and policy through the use of EAs rather than EISs, and more recently through internal order from the CBP.

The likelihood that these projects will continue to move forward at a relatively rapid pace is evidenced by the Border Patrol's new "Arizona Border Control" (ABC) initiative, scheduled to begin June 1, 2004, only a few weeks after the project was announced by the CBP. The ABC initiative will grant the Border Patrol immunity to a number of existing environmental restrictions in such important Sky Islands habitat areas as Pajarita Wilderness and Miller Peak Wilderness, Baker Canyon, Bunk Robinson and Whitmire Canyon Wilderness Study Areas, and the San Pedro Riparian National Conservation Area. The relaxed restrictions would allow the Border Patrol increased off-road vehicle pursuit of undocumented immigrants on trails within those protected areas—activities that can further fragment key wildlife corridors, and that could also trigger legal challenges relating to the Wilderness Act itself. The $10 million ABC initiative was originally funded through September 2004, but reauthorization is likely.

Construction of "vehicle barriers" is an ongoing effort in several border locations, the most recent barrier being completed along the full international boundary of the Coronado National Memorial. The Border Patrol promotes these "vehicle barriers," which consist of vertically installed beams, posts, or old rail segments, connected horizontally by a second rail, with horizontal strands of barbed wire above and below that rail, as wildlife-friendly because they are not solid walls. Vehicle barrier construction also requires construction of 12-foot-wide access roads alongside the barriers, and often leaves pre-existing secondary barbed-wire fencing in place, creating a double barrier. New roads alone can often fragment a wildlife linkage, and with an estimated 2,000 Border Patrol agents driving hundreds of patrol vehicles along more than 1,000 miles of such roads around the clock, this alone could completely end all cross-border movement for endangered species like jaguar and ocelot.

The number of high-rise, all-night stadium and portable generator-style lighting installations along the border, some up to 1,000-watts each, continues to increase. Although conclusive studies on the effects of all-night artificial lighting on bird, reptile, fish, and other animal behavior are not yet available, biologists believe that such illumination causes unnatural nocturnal activity including disrupted rest cycles for migrating birds, and increased predation activity by a variety of other species (Fatal Light Awareness Program 2004).

Considering the CBP's expedited approach to policy-making and project implementation, and the attendant consequences for wildlife habitat, conservationists are faced with a disappearing window of opportunity in which to scientifically document the threats to borderlands ecosystems posed by security infrastructure. Without this critical information, much-needed construction guidelines and recommendations for incorporation of wildlife-friendly alternatives in border security projects cannot be easily produced.

Research Recommendations

Clearly, if these threats to cross-border habitat connectivity are to be properly mitigated prior to top priority wildlife linkages along the border being permanently lost, new research must be developed that examines the environmental effects of these proposed border security projects. Research is needed to document:

- Impacts of fencing, walls, and other barriers on the movements and behavior of wide-ranging species such as jaguar, cougar, ocelot, and pronghorn.
- Identification of key cross-border routes currently used by various wildlife species.
- Potential increases in distribution of invasive plant species spread through the blading of previously undisturbed natural areas, and through unintended vehicle transport.
- Environmental impacts and anticipated legal problems resulting from the proposed security infrastructure and operations within national conservation areas, national monuments, national parks, and wildlife refuges.
- Effects on plants, animals and natural fire regimes due to increased access by recreationists and hunters using newly constructed border roads.
- Impacts of all-night stadium lighting near water courses, water bodies, and riparian areas on predation of fish and other aquatic species.
- Impacts of all-night stadium lighting on bird migration.
- Impacts of noise from equipment, regular vehicular traffic, and aircraft overflights on sensitive animal species.
- Effects of immigrant travel, such as trash, water hole encampments, and human waste on habitat quality and focal species.
- Impacts of increased off-road motorized access by Border Patrol in Federal protected areas on plants, wildlife, and associated legal implications of such on the National Wilderness Preservation System.

Socio-Political Recommendations

The dilemma of maintaining undamaged wildlife linkages along the United States-Mexico border is particularly challenging because the long-term solution to borderlands fragmentation depends as much on socio-economics and international politics as on the science of conservation biology. There is little, if any, disagreement between conservationists and the Border Patrol that border security must be maintained. However, there is widespread disagreement over the best means by which to maintain that security. Add to this mix the new challenge of protecting cross-border wildlife movement, and the debate grows exponentially.

Further frustrating the situation is the fact that prevention of undocumented immigration through means other than construction of barricades could be achieved over a relatively reasonable period of time through earnest, creative immigration reform and economic cooperation between the United States and Mexico. However, the juggernaut of terrorism could easily dictate that even if immigration-related problems were eliminated through international diplomacy, political pressure to maintain a physical barrier will likely remain. Considering the extent of current security infrastructure and the rapid pace of new barricade construction, conservationists should logically assume that successful immigration policy reform, if ever enacted, may not occur in time to offer a respite for cross-border wildlife.

The reality of the situation dictates that reforming immigration policies alone cannot be counted on to halt wildlife linkage fragmentation. Rather, focus and action must be placed on a more thorough and more urgent list of linkage protection options:

- Work to legally uphold the provisions of the National Environmental Policy Act, the Wilderness Act of 1964, the Endangered Species Act, the Refuge Improvement Act of 1997, and the Clean Water Act, and oppose suspension of such laws in the borderlands region.
- Submit public comments whenever new environmental assessments or impact statements for border security projects are released by the CBP, Border Patrol, or Department of Homeland Security.
- Encourage expanded use of technology that could help secure the border without fences, including unmanned aerial vehicles, electronic ground sensor systems, remote video cameras, and surveillance aircraft operating at reasonable altitudes.
- Advocate for protection and maintenance of existing roadless areas along the United States-Mexico border, including wilderness areas, national monuments, national parks, national wildlife refuges, and other protected conservation lands.
- Promote wilderness designation for the Tumacacori roadless area, which would extend and dramatically enhance the cross-border wildlife linkage already existing via the Pajarita Wilderness Area.
- Document the effects of border security infrastructure occurring within or across international wildlife linkages on wide-ranging wildlife.
- When reasonable, legally challenge border security activities and policies that violate existing Federal and State environmental laws.
- Determine the scientific compatibility of various fencing structures with wildlife permeability.

- Advocate for vehicle barriers that do not include cross-fencing with barbed wire or horizontal rails, and for elimination of solid barriers wherever practicable.
- Support the U.S. Border Patrol, CBP, and Department of Homeland Security whenever these agencies incorporate wildlife linkage-friendly components in border security construction projects, or refrain from blocking existing wildlife linkages with new infrastructure.
- Support new immigration reform policies that result in the majority of immigration occurring legally through established ports of entries.

Border Ecological Symposium

In an effort to address the serious threats to cross-border wildlife linkages in the Sky Islands and elsewhere, the Wildlands Project announced in January 2004 its intention to organize and convene a "Border Ecological Symposium" in 2005 that would have as its goals: (1) The examination of all scientific evidence relating to the impacts of border security infrastructure and existing immigration policy on established wildlife linkages between the Sky Islands and similar habitat in northern Chihuahua and Sonora, Mexico; and (2) the creation of a science-based "Borderlands Infrastructure Ecological Guidelines" document that can serve as a reference to agencies involved in border security planning and implementation.

Such a Border Ecological Symposium would convene representatives of all involved agencies, including CBP, Border Patrol, Department of Homeland Security, U.S. Fish and Wildlife Service, Arizona Game and Fish Department, New Mexico Department of Game and Fish, and additional participants including Federal, State and local elected officials, conservationists, conservation biologists, private land owners, immigration policy reform groups, and concerned citizens. For more information, contact the Southwest Field Office of the Wildlands Project: kim@wildlandsproject.org or 520-884-0875.

Conclusion

Existing and proposed fencing, solid steel walls, all-night stadium lighting, vehicle barriers, roads, vehicular traffic, and low-level aircraft overflights threaten to create an impenetrable barrier to wildlife movement across the United States-Mexico borderlands region in southeastern Arizona's Sky Islands and elsewhere. Due to the rapid pace of related border security policy and infrastructure development, immediate action is needed to assure that science-based information on expected negative ecological impacts is incorporated in all newly proposed INS or Border Patrol policy and infrastructure projects.

Such science-based ecological information is currently lacking, and efforts need to be made to obtain such data at the earliest possible opportunity. Numerous actions and activities can be undertaken now by the agencies involved, the Federal government, and the private sector to begin the process needed to protect cross-border wildlife linkages while continuing to maintain border security.

Of major importance is the development of immigration reform policy that directs the majority of undocumented immigration through legal ports of entry. One of the first steps in protecting cross-border wildlife linkages should be convening a Border Ecological Symposium that would bring together a wide range of stakeholders to examine scientific evidence relating to border infrastructure impacts on wildlife, and to draw up guidelines to be used as a reference by agencies planning and implementing new border security policy and infrastructure.

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Conservation Planning

An Assessment of the Spatial Extent and Condition of Grasslands in the Apache Highlands Ecoregion

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Abstract*—Grasslands in the Apache Highlands ecoregion have experienced dramatic changes. To assess and identify remaining native grasslands for conservation planning and management, we used a combination of expert consultation and field verification. Over two-thirds of native grasslands have experienced shrub encroachment. More than 30% of these may be restorable with prescribed fire. Private land accounts for more than half of open, non-shrub invaded native grasslands. Almost 95% of the private lands in this study have no legal protection. Over 25% of all native grasslands are contained in the Apache Highlands ecoregional analysis' top two priority conservation areas.*

Introduction

Grasslands in the Apache Highlands ecoregion have experienced dramatic and spatially non-uniform vegetation changes over the last 130 years. Changes include decreased native perennial grass abundance and cover, conversion to shrubland, increased presence of non-native species, and fragmentation (Hastings and Turner 1965; Humphrey 1987; Bahre 1995). Explanations for the alteration of grasslands include: conversion to farmland, poorly managed cattle grazing, ground-water pumping, regional climate change, suppression of wildfire, and other activities related to human development (Humphrey 1958; Swetnam 1990; Archer et al. 1995; McPherson and Weltzin 2000).

Demographic projections and population movement patterns within the Southwestern United States suggest that grasslands will face particularly strong development pressures in the next decade (DES 2003; Theobald 2003). Suburban and exurban development results in the fragmentation of habitat and migration corridors linking adjacent mountain ranges. This prevents the restoration of important ecological processes, such as fire, that are critical to maintaining native perennial grasses by reducing shrub encroachment (McPherson 1995; Valone and Kelt 1999). Degradation of native grasslands threatens the viability of a diversity of grassland species such as pronghorn (*Antilocapra americana* Ord), the black-tailed prairie dog (*Cynomys ludovicianus* Ord), and numerous bird species. Moreover, vegetation change or loss in grasslands can negatively affect associated riparian systems (DeBano et al. 1984).

Numerous studies conducted on a variety of temporal scales have furthered the understanding of local vegetation dynamics in the borderlands (Bahre and Shelton 1993; Brown et al. 1997; Valone et al. 2002). Nevertheless, there have been few attempts to spatially characterize the spectrum of grassland changes at a landscape scale (Muldavin et al. 2001; Kepner et al. 2000).

Here we describe a field-based approach used to develop a landscape scale, rapid assessment of grasslands in the Apache Highlands ecoregion, a 12.1 million hectare planning area identified by The Nature Conservancy (TNC). Our specific objectives were to (1) map the ecoregion's extant and historical grasslands, including those with restoration potential; (2) evaluate grassland condition by land manager and protection status; and (3) relate native grasslands with priority conservation areas selected in the Apache Highlands ecoregional analysis (Marshall et al. 2003; Turner et al., this proceedings).

Methods

Turner et al. (this proceedings) give a detailed description of the Apache Highlands ecoregion. Gori and Enquist (2003) provide a detailed account of this study's methodology. We first interviewed 24 range management specialists from 10 government institutions in the United States and Mexico. Experts were asked to delineate five grassland condition types on 1:250,000 scale maps (table 1). We then conducted 17 field trips in the United States portion of the study area to assess and modify the expert drawn maps. In total, we sampled 202 random points throughout the study area, estimating percent canopy cover of all shrubs, mesquite and juniper, and perennial grasses to the nearest 5%. The abundance of exotic perennial lovegrasses, Lehmann's (*E. lehmanniana* Nees.), and Boer's (*E. curvula var. conferta* Stapf.) was evaluated at each sample site. Additionally, we estimated the potential for using prescribed fire to reduce shrubs and restore open grassland (cf. Gori and Enquist 2003). All resulting field-verified grassland maps of the United States portion of the study area were digitized and merged using a geographical information system (GIS).

Delineation of the extent of different grassland types in Mexico was accomplished through a combination of expert mapping and analysis of Landsat Thematic Mapper satellite images using a mixed strategy of supervised and unsupervised classification (Aguirre et al. 2002). Field sampling and verification was conducted by staff from the Mexican State agency, the Instituto del Medio Ambiente y el Desarollo Sustentable del Estado de Sonora (IMADES), utilizing a vegetation classification system developed for the State of Sonora (COTECOCA 1986). Two training sessions were conducted in the United States and Mexico to not only ensure that vegetation sampling techniques would be consistent across the border, but that the classification system was uniformly applied. The

Table 1—Classification of grassland condition. Experts were asked to base their opinion on their field-based experience, knowledge of local soil conditions and properties, and awareness of other data sources (historical accounts, survey points, photographs, etc.). In addition, experts were asked to identify grasslands with unknown condition types.

Grassland condition	Description
Open native	<10% shrub cover whose herbaceous component is entirely or predominantly native perennial grasses and herbs (D. Robinett, personal communication; modified from Anderson et al. 1998).
Riparian native	Riparian grassland dominated by giant sacaton (*Sporobolus wrightii* Munro ex Scribn.).
Restorable native	Native perennial grasses and herbs dominate with 10-35% total shrub cover and mesquite or juniper cover <15% (D. Robinett, NRCS, personal communication). A key characteristic of this type is its restoration potential back to open-native grassland by using prescribed burning to reduce shrub cover. In some cases, grazing rest may be required to accumulate sufficient fine fuels to carry a fire (Brunson et al. 2001).
Non-native	Non-native perennial grasses (primarily *Eragrostis lehmanniana* Nees and *Eragrostis curvula* var. *conferta* Stapf.*)* are common or dominant.
Historical	>15% canopy cover of mesquite and juniper combined and/or >35% total shrub cover; perennial grass canopy cover usually <1 %, always <3 %; soil condition and characteristics (D. Robinett, personal communication; McAuliffe 1995); type conversion to shrubland that is either permanent or will require 40+ years of livestock exclusion for partial recovery of perennial grasses (Valone et al. 2002). The historical time scale relates to vegetation accounts provided by vegetation inventories from the mid to late 1800s (Gelhbach 1993).

final digital map developed by IMADES was subsequently appended to the United States grassland map to create a seamless cross-border GIS data set.

We conducted a spatial analysis of the final ecological condition map of grasslands using available spatial data layers of land management status and legally mandated land protection status (Weinstein 2002). We also related the network of conservation areas identified by the Apache Highlands ecoregional analysis (Marshall et al. 2003) to the best remaining native grassland patches identified in our assessment. Specifically, conservation areas ranked as most critical to grassland conservation encompassed the largest areas of open-native, restorable native, and riparian grasslands.

Results

With field verification, we estimated that the accuracy of the expert opinion-based maps ranged between 76% and 88%. With subsequent mapping modifications, the accuracy of our final grassland map for the Apache Highlands was likely improved.

Our study identified 4,928,448 ha (12.2 million acres) as either extant or historical grassland, accounting for 41% of the Apache Highlands ecoregion (figure 1). Over 1,782,280 ha (4.4 million acres) is historical grassland that is now dominated by shrubs (cf. table 1). Open-native grassland accounts for 816,624 ha (2 million acres) of all identified grasslands (includes extant and historical), or 26% of extant grassland. Giant sacaton (*Sporobolus wrightii*) riparian grassland covers 21,438 ha (52,973 acres) of all identified grassland, or 0.7% of extant grassland. Shrub encroachment has occurred on 3,341,184 ha (8.3 million acres) of all identified grassland. However, 1,558,904 ha (3.9 million acres) is potentially restorable, or 49.6% of all extant grassland. Nearly 150,000 ha (380,000 acres) of all identified grasslands are of an unknown condition.

Non-native lovegrass species (Lehmann's and Boer's) are now common or dominant on 594,163 ha (1.5 million acres) of all identified grassland, or 19% of extant grassland. The distribution of non-native grassland was restricted to southeastern Arizona where the two lovegrass species were initially introduced in the 1930s to prevent soil erosion and provide forage for livestock (Cox and Ruyle 1986). We found no regional-scale exotic grass invasion on the Mexico side of the study area.

The majority of open-native and riparian grasslands are on private lands, while State lands were a distant second (table 2). Restorable native grasslands are almost evenly distributed among Federal, private, and State land management. This was also true of historical grasslands, while non-native grasslands occurred predominantly on private land. When considering specific Federal land managers, 59% of Bureau of Land Management (BLM) managed grasslands are historical, 29% are restorable, and 6% are open-native. In contrast, 61% of USDA Forest Service (USFS) managed grasslands lands are restorable, 14% are historical, and 11.2% are open-native.

Most grassland in the Apache Highlands has either a low level to no legal protection (table 3). More specifically, a majority of open-native and riparian grasslands on private (89%) and State (99%) land has no legal protection. One-third of restorable grassland occurs on Federally managed lands. Of this, 88% has a low level of legal protection. The remaining two-thirds of restorable grassland (in roughly equal proportions on private and State lands) has virtually no legal protection (91% on private and 99% on State).

Over 25% of all native grasslands identified in this study are found in the two top priority conservation areas selected in the Apache Highlands ecoregional analysis. The first is the Huachuca Mountains Grassland Valley Complex (HMGC), with 267,024 ha (659,816 acres) of native grassland (78% of which is open-native, 20% is restorable, and 3% is riparian). The second is the Sierra San Luis/Peloncillos Mountains (SLPM), with 390,558 ha (965,069 acres) of native grassland (42% is open-native, 56% is restorable, and 2% is riparian). Of total HMGC lands, 54% is private, 25% is State, and 18% is Federal. Of total SLPM lands, 66% is private, 12% is State, and 17% is Federal.

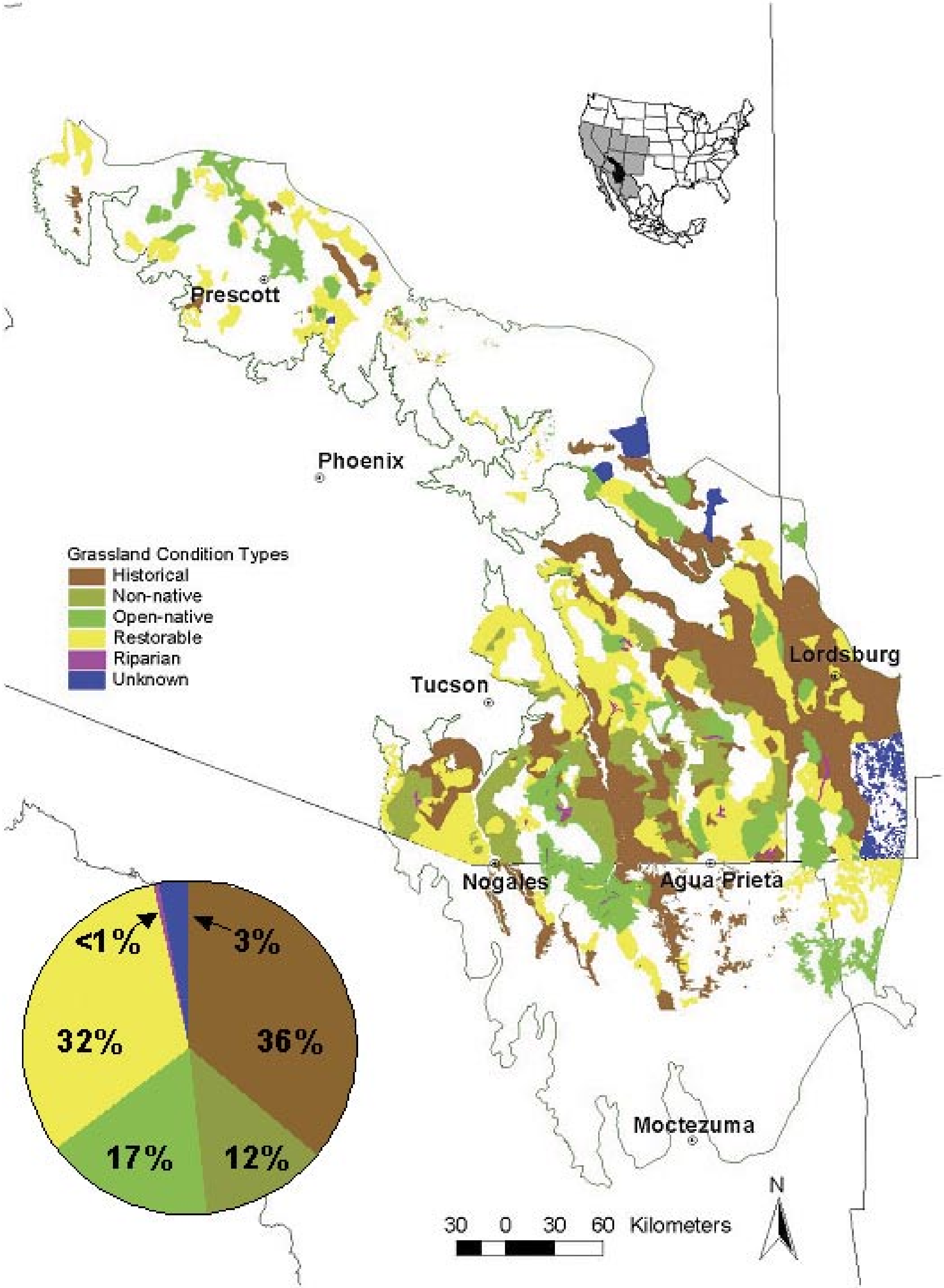

Figure 1—Ecological condition types of grasslands in the Apache Highlands ecoregion.

Table 2—Land manager by grassland condition type in area units of hectares. Percentages were calculated based on sum totals of each column.

Manager	Open native	Riparian	Restorable	Non-native	Historical	Unknown	Total
Federal	105,913 (13.0%)	1,808 (8.4%)	526,296 (33.8%)	131,294 (22.1%)	519,563 (29.2%)	49,490 (31.9%)	1,334,363 (27.1%)
Private	484,677 (59.4%)	15,368 (71.7%)	499,344 (32.0%)	259,649 (43.7%)	602,221 (33.8%)	42,039 (27.1%)	1,903,299 (38.6%)
State	140,019 (17.1%)	4,262 (19.9%)	480,151 (30.8%)	202,772 (34.1%)	526,055 (29.5%)	6,048 (3.9%)	1,359,308 (27.6%)
Tribal	85,968 (10.5%)	-- (0.0%)	49,891 (3.2%)	-- (0.0%)	125,914 (7.1%)	57,462 (37.1%)	319,235 (6.5%)
Other	47 (0.0%)	-- (0.0%)	3,222 (0.2%)	447 (0.1%)	8,528 (0.5%)	-- (0.0%)	12,244 (0.2%)
Total (ha)	816,624	21,438	1,558,904	594,163	1,782,280	155,039	4,928,448

Discussion

Over the course of a century, 36% of the grassland in the Apache Highlands ecoregion experienced a conversion to shrubland as a result of factors ranging from climate change to fire suppression. Open-native grassland constitutes less than 20% of the extant and historical grasslands identified in the Apache Highlands ecoregion. Although shrubs have invaded nearly 70% of these grasslands, nearly a third may be restorable with prescribed fire (cf. table 1). Together, open and restorable native grasslands comprise nearly 50% of identified grasslands.

Private land accounts for more than half of identified open-native grasslands. However, 94% of the private lands in the study area have no legal protection. One-third of restorable native grassland is Federally-managed, primarily by the USFS, and has some legal protection. The remaining two-thirds are State or private lands with less protection. Our results suggest that private land owners need to be engaged in native grassland conservation. Federal conservation partners should specifically be engaged in the restoration of native, shrub-invaded grassland. Native grasslands on State lands could be addressed via legislative and policy-related initiatives. These recommendations also apply to the two top priority conservation areas identified in the Apache Highlands ecoregional analysis.

The results of this study demonstrated that a field-based landscape scale assessment of the condition and spatial extent of grasslands can be used to inform conservation planning and ecological land management decisions. Moreover, our 14-month long assessment produced results with high accuracy in a time and cost effective manner. We have set the stage for an enhanced

Table 3—Legal protection status by grassland condition type in area units of hectares. Percentages were calculated based on sum totals of each column. High = USGS Gap protection level 1 or the highest level of legally mandated permanent land protection; Moderate = USGS Gap protection level 2 or lands with permanent protection but which may receive uses or management practices that degrade the quality of existing natural communities; Low = USGS Gap protection level 3 or lands with some degree of protection but that are subject to extractive uses which may involve land cover clearing; No = USGS Gap protection level 4 or lands without legal protection (Weinstein 2002).

Protection status	Open native	Riparian	Restorable	Non-native	Historical	Unknown	Grand total
High	2,752 (0.3%)	1,701 (7.9%)	18,098 (1.2%)	42,846 (7.2%)	26,712 (1.5%)	-- (0.0%)	92,108 (1.9%)
Moderate	4,220 (0.5%)	202 (0.9%)	53,578 (3.4%)	3,808 (0.6%)	23,516 (1.3%)	3,181 (2.1%)	88,505 (1.8%)
Low	152,448 (18.7%)	4,158 (19.4%)	508,506 (32.6%)	107,597 (18.1%)	486,068 (27.3%)	50,865 (32.8%)	1,309,643 (26.6%)
No	571,185 (69.9%)	15,376 (71.7%)	928,518 (59.6%)	439,911 (74.0%)	1,114,167 (62.5%)	43,530 (28.1%)	3,112,687 (63.2%)
Unknown	86,020 (10.5%)	-- (0.0%)	50,205 (3.2%)	-- (0.0%)	131,818 (7.4%)	57,462 (37.1%)	325,504 (6.6%)
Total (ha)	816,624	21,438	1,558,904	594,163	1,782,280	155,039	4,928,448

approach currently being developed by TNC of New Mexico for the BLM that includes assessments of other habitats. In Arizona, an assessment of the remainder of the State's grasslands from the perspective of fire management has been conducted as a direct result of the original Apache Highlands grassland report (Gori and Enquist 2003; Schussman and Gori 2004).

The classic basin and range physiography of the Apache Highlands ecoregion is often described as being composed of mountain islands surrounded by desert seas (Gehlbach 1993). This analogy underestimates the importance of semi-arid grasslands, or seas, in comparison to the mountain "sky" islands. In a region experiencing substantial development pressure, grasslands are at risk of becoming increasingly fragmented and vulnerable to exotic species invasion. Now, with new reconnaissance of grassland condition, conservation practitioners and partners are better positioned to protect and restore the last remaining native grasslands in the Apache Highlands.

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Building Effective International, Multicultural Alliances for Restoration of Ejido Forests in the Sierra Madre Occidental

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Abstract—*Effective NGO-government-community alliances are the key to overcoming the complex socio-political obstacles to conservation in the Sierra Madre Occidental. Over 80 percent of the territory in the Sierra Madre Occidental is communally owned. Agrarian and other socio-economic conditions present both opportunities and obstacles to conservation. Conservation, environmental justice, and community development are inseparable components of effective conservation in the communal lands of the Sierra. Case studies from the Sierra Tarahumara and Madera regions reveal the effectiveness of interdisciplinary, multicultural strategies, participatory planning, and diagnostic processes in weaving the social fabric for environmental protection and restoration.*

Introduction

Anyone concerned about bioregional conservation or restoration of the great watersheds of the Sierra Madre Occidental must recognize that over 80 percent of the endangered pine-oak woodlands of the Sierra are communally owned. The future of this endangered megacenter for biodiversity may very well depend upon the effectiveness of community-based approaches to planning and organizing coupled with resolution of agrarian issues. A second factor, essential to conservation of large regions of the Sierra, is the right to traditional territory and natural resources of the indigenous pueblos of the region. Yet, the majority of conservation efforts in the region fail to focus on community empowerment, neglect the most pressing local priorities, and ignore the tremendous conservation potential of agrarian and indigenous policies.

A regional coalition of NGOs, indigenous leaders, and municipio (county) natural resource technicians known as the Consejo EcoRegional Sierra Tarahumara A.C. with support and collaboration from Sierra Madre Alliance (SMA), U.S. Fish and Wildlife Service, National Commission for Protected Areas (CONANP), Secretariat of Social Development (SEDESOL), and other agencies and private funders is achieving significant conservation gains. Federal agencies and local government have become supportive of the aims of the Consejo and the communities they serve. Intimately tied to the state of the environment is the fate of the Raramuri and Odami (Tepehuan) traditions. Conservation strategies and institutional factors are discussed below that can lead to transformation, pueblo by pueblo, ejido by ejido, municipio by municipio of this world class bio-cultural conservation priority region.

Addressing Environmental Threats

Illegal logging, grazing, subsistence deforestation, cumulative impacts, and illicit drug cultivation are generally noted as the major threats to the pine-oak forests of the Sierra. Over 99.7 percent of the original old growth forests are gone, and an estimated 90 percent of the riparian areas in the Sierra are considered nonfunctional or at risk. The predominant ecological trend in the region is desertification due to deforestation, catastrophic fire, and replacement of pines by drought resistant trees and shrubs. The bio-cultural diversity of the Sierra is also at risk. The economic and ecological values of the great watersheds of the Sierra, including the Conchos, Fuerte, Yaqui, and Mayo Rivers are endangered.

In such an altered landscape, logging continues to threaten, but must now be seen as one of the tools for long-term restoration. The impact of logging depends upon the silvicultural model and biocultural values of the forest managers. Change in fire regime from frequent low-intensity burns to catastrophic fires is perhaps the biggest long-term threat to the region, yet fire is another essential tool for restoration.

Underlying threats to the environment are socio-economic conditions such as poverty, injustice, illiteracy, health and human rights issues, and the influence of narco culture. The following factors drive environmental decline and complicate solutions:

- Redistribution of land
- Misguided models of sustainable forest management
- Loss of traditional bio-cultural knowledge
- Weak local governance and community organization

Land Tenure and Distribution

The Agrarian Reform Law of 1992 changed one of the most sacred covenants of the Mexican Constitution, Article 27, which since the end of the Mexican revolution had enabled groups of campesinos to band together and petition for permanent usufruct rights of public (and some private) lands. The 1992 reform put an end to Federal land distribution in Mexico and established mechanisms for voluntary privatization of ejido lands. Some argue that the potential of privatization itself is a threat to indigenous pueblos, based upon historic precedents in Mexico as well as in the United States where the infamous Dawes Act of 1887, which allotted lands to indigenous families, led to the enormous losses of indigenous territory in the Western United States. Others maintain that law itself did not explicitly threaten indigenous pueblos, but established complex legal processes that in application have failed to respect specific rights of indigenous pueblos.

The new agrarian law eliminated the state administration of the ejido system. In place, a Federal court system, the Tribunal Agrario, was established to deal with land claims. A public defenders office, the Procuraduria Agraria (or PA) was established to provide free legal and advisory services to ejiditarios. A Federal agency, PROCEDE, was established under PA to conduct the necessary boundary surveys and, in practice, to promote privatization and reorganization of the ejidos.

The complex regulatory system that has evolved since 1992 has not made it easy to resolve agrarian issues; however, three factors have converged to open communal lands for conservation gains in the 21st century: (1) access to free legal services via the Procuraduria Agraria; (2) increase in NGO support services for communities; and (3) national momentum towards democracy and against corruption. In some ejidos, privatization has led to increased environmental threats, but re-organization of ejidos has in some cases created incentives for more sustainable land management. For example, in the ejido of Tutuaca, land surveys and redistribution of communal forest allotments to individual families ended a long-standing land conflict. Each family now receives an annual timber allotment, which they manage, a system that has given incentives to manage rather than mine the forest. Additionally, the community qualified to receive environmental service payments from CONAFOR (National Forestry Commission) for the protected area in 2004.

In 1995, the second largest nesting concentration of endangered thick-billed parrots was discovered in Tutuaca (figure 1). The best forest and richest nesting concentration in Tutuaca had been protected de facto by a boundary conflict with a neighboring ejido that had halted logging, but that conflict was rapidly being resolved. Biologists studying the parrots planned a protection strategy, but had limited contact with the ejiditarios. An innovative strategy was devised by ProNatura Noreste and ITESM (the Monterrey Technical Institute) to establish a wildlife sanctuary in the 2000-hectare core nesting area in exchange for a 15-year rental agreement paid by international donors. Besides the financial offer, two other factors led to establishment of the reserve. First, community workshops sponsored by ProNatura Noreste and SMA empowered women in the community who carried the vote. Second, a local land controversy had been resolved prior to the conservation initiative.

The majority of indigenous ejidos in the Sierra have resisted privatization, but some territories have been reorganized. Many ejidos continue to struggle with historic problems with boundaries and recognition of indigenous land rights. By establishing a program for resolution of agrarian conflicts in conservation priority areas, Consejo EcoRegional Sierra Tarahumara, has coupled a powerful grassroots organizing incentive with conservation initiatives. A combination of public interest legal services, training, and facilitation of community planning has shown to: (1) strengthen overall community organization, (2) improve the responsiveness of local government to community needs, and (3) create opportunities for protected area designation and watershed restoration. Fuerza Ambiental's combination of legal and community organizing tactics have been effective in stopping illegal logging and setting the stage for forest protection in two communities with highly endangered old growth forests: Coloradas de la Virgen and Pino Gordo. National Territories in the great canyons and private landowner strategies also present great opportunities for conservation and restoration.

Figure 1—Thick-billed parrots. Photo by Javier Cruz, ProNatura.

However, the net impact of land tenure reform on conservation depends on community organization and access to technical and financial support from NGOs or the government. Currently, only two NGOs assist agrarian issues linked to conservation in the Sierra of Chihuahua, Consejo EcoRegional, and CONTEC. PRI-associated Confederacion Nacional Campesino and the independent Frente Democratico Campesino also defend agrarian claims, but have not yet tied agrarian issues to conservation. In total, NGO resources are very limited, and agrarian organizing is painstakingly costly in time and resources. It can take six to 10 years to resolve a seemingly simple case of land fraud. In order for agrarian dispute resolution to produce widespread conservation results more efficiently, a larger economy of scale is needed to support an interdisciplinary team capable of handling a dozen or more cases simultaneously in collaboration with PA, and pro-bono services.

Nevertheless, there is a lot of hope in the process. Illegal logging has been halted on agrarian grounds where environmental law has failed. The old growth forests of the Tarahumara ejido of Pino Gordo have received legal and *de facto* protection due to agrarian claims and related politics, but a final resolution is still in process. In the Pino Gordo (figure 2) case, members of the traditional pueblo claim they were defrauded of their agrarian rights. As they battle to regain their agrarian rights, they have mounted a defense of their indigenous territorial rights with help of the Consejo EcoRegional, SMA, and the pro-bono services from the U.S. Law firm HellerEhrman and the Environmental Defenders Law Center.

According to the Consejo EcoRegional, the constitutional rights of indigenous pueblos under Article 2 of the Mexican constitution provide an even broader opportunity for conservation of indigenous rights in Mexico. However, it may take combined pressure from indigenous movements and international courts to convince Mexico to establish clear regulatory procedures for recognition of indigenous territorial rights. The land claims of Pino Gordo and Coloradas de la Virgen have been elevated to national priority status, yet the failure of Mexico to codify indigenous rights has opened the opportunity to appeal their cases to the InterAmerican Court for Human Rights with help from HellerEhrman, Consejo EcoRegional, and other Mexican supporters. The results may open potential for conservation nationally, but will more likely enable step-by-step advances for indigenous land claims.

Procuraduria Agraria has a mixed record, but has proven itself to be highly reliable in representing ejiditario claims when ejiditarios are well informed of their rights and responsibilities or have independent technical/paralegal support. The Tribunal Agraria has proven to be slow and dogmatic, but largely independent of political interference.

A bigger problem is maintaining community solidarity and organization during long-term land struggles. The sacrifice required of community leaders fighting for land rights is tremendous. They are among Mexico's poorest, but must find funds to make numerous costly and arduous trips to the state capital to meet with authorities, attend hearings, and comply with a myriad of meticulous regulations regarding ejido processes and documentation. The result is that access to legal rights is denied by lack of resources. Historically, it has been easier to gain official certification of falsified ejido documents than to overturn them later.

Privatization presents both opportunities and tremendous risks for conservation. During the past decade, redistribution of lands to narco-traffickers, tourist operations, and other wealthy interests through legal, coerced, and informal mechanisms has accelerated dramatically throughout the Sierra. The primary interest for most new or expanding landowners is ranching. Trees are viewed as an impediment to pasture, and logging creates short-term capital for ranching. The incentive is to log intensively to create pasture. Foresters have been known to expand logging permits to log already overcut ranches as long as oaks are removed as well as pines.

Many Tarahumara and Tepehuan are forced to sell lands (often informal sales of ejido or communal lands) to mestizos due to poverty. Indigenous families and in isolated cases entire rancherias have been forced into peonage as powerful mestizos fenced off communal forests. In some cases, young relatives have been known to sell rights to the properties of elders. Many of these sales occur on ejido lands outside legal processes, but are accepted by local custom and uncontested by fear. Commonly, mestizos purchase cattle, establish feedlots with government or narco subsidies, and graze communal lands on an unlimited basis, the canyons in the winter and highlands in the summer, with no compensation for the communal landholders. Lands that were previously at capacity with a few dozen indigenous cattle and a few herds of sheep and goats are now heavily overgrazed with large herds of mestizo cattle, whose owners may not even be ejiditarios. Indigenous people who cannot afford to feed their livestock when the pasture gives out, end up losing ground in every aspect, and their watersheds are further degraded year after year.

Sustaining conservation depends upon community commitment, skills and internal organization. Resolution of land conflicts has proven to be a powerful strategic tool for conservation in the Sierra. On the other hand, community planning to restore watersheds has also empowered communities to defend their rights. For example, a large part of the economy

Figure 2—Pino Gordo, traditional life amongst an ancient forest. Photo by the author.

in Baborigame involves drug production and trafficking, yet indigenous and mestizo leaders have agreed in concept to prevent drug cultivation in the area that impacts the town water supply. They are planning to restore 5000 acres of forests and 3 kilometers of riparian area to protect their principal watershed. The Tepehuan are currently organizing to deal with illegal logging and grazing of their lands both within and outside the proposed watershed reserve.

Public interest environmental law is of limited effectiveness in the Sierra unless accompanied by community organization and agrarian action. Mexican environmental law and the environmental side agreements of NAFTA are influential but relatively toothless. Agrarian claims stopped illegal logging and began protection of rare old growth forests in Pino Gordo and Coloradas de la Virgen.

In conclusion, strengthening land tenure advocacy and services to ejidos in conservation priority areas is an integral aspect of building bioregional conservation. Agrarian strategies are not a guarantee for conservation, but are extremely effective when coupled with locally determined conservation objectives. The biggest investment is in basic community organizing that is essential to both conservation and sustainable community development. Therefore, it is most efficient to combine land, conservation, and development objectives in an integrated, long-term strategy in which coalitions of community support organizations with complementary skills can be effective.

Misplaced Models of Sustainable Forest Management

A second overriding threat to the sierra is in the forest management model being implemented Statewide with little consideration for biological impacts, local accountability, watersheds valuable for environmental services, nontimber forest products, or traditional indigenous values. The current model, which is promoted by the National Forestry Commission (CONAFOR), calls for short rotation, selective forestry and is now being certified by the Forest Stewardship Council (FSC) in qualifying ejidos as sustainable. Unknown to FSC, local participation is often discouraged or manipulated by local foresters and caciques. Environmental assessments are nonexistent.

Prior to the establishment of CONAFOR, the most ambitious forestry programs in the Sierra were funded by the World Bank Forestry Program for Northern Mexico and the Canadian-sponsored Model Forest Program in Chihuahua. Both of these programs supported similar short rotation selective forestry models and both lacked effective local participation. A major cause for the cancellation of the World Bank program in 1994 was the resistance of forestry interests to allow biological field studies to proceed in the Sierra, a source of deep conflict between the Secretariat of Agriculture and Hydraulic Resources (SARH) and the Secretariat of Ecology (SEDUE). However, lack of real local participation, especially indigenous participation, was a major contention of NGO opposition to the program.

At the beginning of the World Bank program, only one NGO provided community support in the Sierra, insufficient to effectively challenge the power of the forest industry that dominated the ejidos. Except for isolated cases like Pino Gordo, little had changed in most of the Sierra by the late 1990s when the Model Forestry Program began a project in the Sierra Tarahumara. According to a former Canadian field manager for the program:

> "… the relationship of the program was government to government with the idea that the Canadian government's viewpoint would be accepted and adapted by Mexican counterparts. What they failed to understand is the dynamics that operate within the Mexican system where the foresters wield the power over the people and thus the forest… The Canadian Model Forest Program put a real effort into encouraging the involvement of all stakeholders in the management of the forests. They did not come in with any prescribed formula for success and found out quickly that what works in Canada cannot be duplicated in Mexico....Where it failed is when the local authorities and governmental officials recognized that empowerment of the local people potentially threatened their positions…" (Cliff Mathies, former Chihuahua Program Manager for the Canadian Model Forest Program, personal interview, April 30, 2004).

Since 2002, ejido El Largo, Mexico's largest ejido, has been upheld by CONAFOR as one of the exemplar forestry ejidos in Mexico today. El Largo is certified by FSC, and is home to the largest remaining nesting area for endangered thick-billed parrots. Yet, forestry interests have reportedly limited efforts by ProNatura Noreste to establish a thick-billed parrot sanctuary in El Largo. A sanctuary of less than 300 hectares is now under discussion. Such a small area provides no assurance against the long term threats of catastrophic fire and eventual mortality the aspen groves where they nest. Most thick-bills nest in old growth pines, but this population is limited to the only habitat remaining in the area—a few isolated groves of large but vulnerable aspen. Thick-bills eat mostly pine nuts, which are most consistently abundant in older forests.

Community-NGO action has been effective in calling attention to illegal logging, but SEMARNAT continues to lack adequate resources to enforce management plans. SEMARNAT also fails to demand environmental assessments to determine the presence of threatened or endangered species. In the areas where endangered species are documented, no agency provides protection. In the Model Forest Program area, endangered thick-billed parrots were documented nesting, but no measures were taken by the biologists or agencies to protect these areas. The World Bank Program, much larger in scale, also failed to require identification and protection of endangered species and their critical habitat.

The philosophy of many influential foresters in the region is that Mexico is a poor country and cannot afford protection of a few endangered species at the expense of rural profits. The experience of the communities is that they are left worse off following boom and bust cycles of logging, which mainly benefited a handful of families and contractors.

The recently enacted General Law for Sustainable Forest Development contemplates ecosystem forest management rather than pure administration of timber values, but the effectiveness of this legislation remains to be seen.

Thirty-six communities were represented by COSYDDHAC (a Chihuahua-based human rights commission) in a successful case that exposed systemic governmental negligence to illegal logging before the Commission for Environmental Cooperation. SEMARNAT responded to national and international pressure with a reform of the timber certification program, which has had limited success. However, illegal logging remains commonplace throughout the Sierra and especially in remote, timber rich areas like Guadalupe y Calvo. However, a growing number of foresters, with support from CONAFOR, are working against illegal logging and are promoting establishment of community protected areas, and environmental service payments for protection of watersheds and wildlife habitat, in part to gain FSC certification in selected ejidos in Guadalupe y Calvo and other municipios throughout the Sierra. This conservation and certification process suffers from lack of consultation with biologists and indigenous pueblos, but remains a positive trend in the Sierra.

Without stronger community organization and active participation in forest management and vigilance, the foresters and ejido authorities alone will not be able to stop illegal logging and other factors that threaten sustainability. NGO-community strengthening is needed if this vision of sustainable forestry is to have a chance for success. Many local foresters are now influenced by FSC management philosophies, and a new generation of foresters is more open to forest management alternatives than their predecessors. However, lacking Federal enforcement, it is up to the communities themselves to build a restorative forestry paradigm and to enforce it. It is up to the NGOs to support them and together to build strong relationships with SEMARNAT, CONAFOR, and other agencies to gain both Federal support and enforcement.

Fire Mismanagement

Another disturbing trend in forest management in Chihuahua is the emphasis on fire suppression rather than natural fire management. Not only are catastrophic fires on the increase in the Sierra, but the official fire suppression policy guarantees that this trend will continue indefinitely, and assures the continued desertification of the region. The policy promoted by CONAFOR is to surround, isolate, and extinguish fires and then to reforest. Fear of the forestry authorities has caused many indigenous people to stop the practice of frequent low intensity burning that has sustained the forests for millennium. Reforestation of burned areas is subsidized by CONAFOR, but there are not enough resources to restore even a third of the total losses to fire each year.

Community organization with NGO support is the only effective counter to the current direction of the forest industry in Chihuahua. Research and development of restorative forestry models that incorporate ethno-ecological fire management is needed. SMA is sponsoring research into the natural fire history of the Sierra in collaboration with Dr. Pete Fule at Northern Arizona University. A model ethno-ecological management plan, which incorporates traditional use of fire, is under development in Pino Gordo.

Loss of Traditional Bio-Cultural Knowledge

Loss of bio-cultural knowledge is not only devastating to traditional indigenous culture, but threatens the very management techniques that have formed landscapes and enhanced biodiversity for millennium. Fire is the most documented aboriginal landscape management tool. The NAU/SMA fire studies preliminarily show an increase in low intensity fire frequency, beneficial to the forests, that corresponds to intensification of indigenous settlement in Pino Gordo. Wildlife studies have documented 26 threatened and endangered species in Pino Gordo, many of which are absent or found in greatly diminished abundance in neighboring secondary forests. Ethnobotanist Gary Nabham has noted patterns of indigenous enhanced plant diversity in the Sierra, such as indigenous hybridization of food crops with wild relatives such as beans and corn.

Logging, loss of biological diversity and loss of traditional indigenous knowledge are directly related. Supported by SMA, biologist Andrew Miller of NAU recently completed studies comparing avian diversity and traditional indigenous knowledge in primary and secondary forests in the Sierra. His research is soon to be published and indicates significant losses of both traditional knowledge of birds and avian diversity between primary and secondary forests.

On another realm, the relationship between biodiversity, traditional knowledge and the spiritual balance maintained by the owiruame (shamans) is critical to cultural survival and conservation. As Tarahumara leader Prudencio Ramos from Pino Gordo stated: "… if they destroy our forests, the birds are going to disappear. They are important to us. They sing and make us happy. Their pretty songs call the clouds which bring the rains. After the rains, the birds are happy and sing. When we walk through the woods their songs make us happy." Two hundred and twenty-four species of birds, including over 120 migrants, and a total of 26 protected wildlife species have been documented by SMA sponsored biologists in Pino Gordo.

In Pino Gordo and Coloradas de la Virgen, this deep tie to their forests has led the communities to risk everything to stand up against agrarian fraud and illegal logging despite horrendous acts of violence and repression against their leaders. In Coloradas alone, five Tarahumara women successfully blockaded 14 logging trucks in 2003 while Isidro Baldenegro led 20 Tarhuamara into the forests to peacefully stop the illegal loggers. They overcame the terror of 20 years and 36 murders of their brethren to defend the sacred. Isidro was later arrested and spent 15 months in prison before charges were dropped under international pressure; others have resisted constant threats, but their quest for peace and the rights to their traditional lands continues.

SMA supports ethno-ecological vision mapping and forest management planning in Pino Gordo and other communities. Consejo EcoRegional and SMA are developing bilingual (Spanish-Tarahumara) environmental educational materials, videos documenting traditional knowledge of ancient shamans, and facilitate ongoing community planning processes. Even with these tools, there are substantial challenges for indigenous communities to preserve their traditional land management practices and adapt to the contemporary need for more intensive management and vigilance of their own forests.

Local Governance and Community Organization

Strengthening community organization and the capacity of traditional pueblo, ejido, and municipio governance are the keys to a sustainable and equitable future. De-centralization of Federal programs has empowered the Municipios to directly solicit and manage Federal aid programs, but many rural authorities lack the vision, knowledge, and skills to effectively organize, plan, and solicit support. Traditional powers from the PRI era remain entrenched and resist new stakeholders seeking Federal aid. Indigenous pueblos are further stymied by barriers of language, illiteracy, and traditional governance designed to deal with internal issues but often incapable of facing external threats. The ejido system was imposed upon the Tarahumara from the 1930s through the 1980s, resulting in reduction of traditional authority over their lands and forests as mestizos assumed leadership. Ejidos and municipios have been historically paralyzed to respond to illegal logging, embezzlement, violence, and land fraud. They have been ineffective in soliciting Federal support, resulting in the worst conditions of poverty and marginalization in Mexico's richest forests.

Among ejidos in the Sierra, an exception is Pino Gordo, a pueblo of pure Tarahumara that was isolated from external influence (even missionaries) for decades if not centuries. There, Tarahumara leaders work under the authority of the traditional governor, the guidance of elder shamans, and consensus of the community to defend their territory and forests.

Participatory diagnostic and planning processes, training, and project development sponsored by Coalition members have resulted in the emergence of natural leadership in indigenous communities. The founders of the Consejo EcoRegional have trained rural development coordinators in six municipios in community planning processes with an emphasis on watershed restoration. No less than ten community-based watershed restoration projects are in development throughout the Sierra with many more in planning.

Much work remains, but ejido, municipio, and pueblo governance is being strengthened by collaboration with NGOs. The founders of the Consejo EcoRegional Sierra Tarahumara, recognizing this trend, approached CONANP in 2004 with the prospect of planning a large scale Biosphere Reserve in the Sierra Tarahumara. The director of CONANP, Dr. Ernesto Enkerlin, recognized the convergence of local, State and national trends and provided his support for the reserve to be announced in 2005.

Greater NGO-municipio-community collaboration is beginning to converge with other factors such as the decentralization of Mexican rural aid, the opening of fair elections, and the emergence of opposition parties, all of which are improving responsiveness of government to the needs of rural areas. This path has tremendous obstacles and risks for the NGOs. The Municipios lack resources and experience, and have abused contracts with smaller NGOs, but the emerging local leadership backed by community approved plans are creating unprecedented opportunity for environmental restoration and protection. The recent formation of the Consejo EcoRegional Sierra Tarahumara A.C., a formal coalition of NGOs, indigenous leaders, and municipio technicians provides a forum that promises greater participation and governmental responsiveness.

Conclusion

The Consejo EcoRegional, ProNatura Noreste, and other regional partners are establishing excellent precedents for community-based conservation in the Sierra. Conesejo EcoRegional Sierra Tarahumara A.C. is exceptional among conservation organizations in Mexico as it is establishing protected areas and conducting baseline biological research while strengthening community organization and defending indigenous territorial rights (table 1). These organizations have benefited greatly from associations with SMA and other international partners such as EcoLogic Development Fund and the Wildlands Project (in the case of the Thick-billed Parrot Sanctuary at Tutuaca). The U.S. Fish and Wildlife Service has provided greatly needed support to the SMA backed coalition due to a commitment to conservation priorities over the geo-political comfort of less complicated regions. An inter-institutional forum for indigenous affairs (PIAI) sponsored by the Fundación Empresario Chihuahuense A.C. with participation of all State and Federal agencies and a number of NGOs working in the Sierra has also been supportive of the Coalition and communities mentioned above.

The results to date and potential for watershed restoration and regional conservation are impressive: a 3 million acre "Sierra Tarahumara" Biosphere Reserve has been proposed by the National Commission of Protected Areas (CONANP), the State of Chihuahua, and the Consejo EcoRegional. This large scale reserve will integrate a number of community proposed protected areas, as well as regional watershed and riparian area restoration initiatives planned in the Conchos, Fuerte, and Papigochic watersheds. Nine municipios, once dependent upon timber, have joined with over 50 indigenous governors to date to support the Biosphere Reserve proposal. They are beginning to embrace conservation as an integral part of rural development. These accomplishments are being made by listening to and supporting the most difficult local priorities such as resolution of land conflicts.

In the future, international and multilateral funded programs must respect the growing strength of NGO and citizen participation. CONANP and the Consejo EcoRegional are setting new standards of grassroots participation, a process that needs to be nurtured with greater international and national support. In the 1990s, The World Bank and Model Forestry programs spent over 13 million dollars, an order of magnitude more than the total amount of aid to the NGOs in the region during that decade. (see Mathies interview, World Bank internal report, Forestry Development Program for Northern Mexico, 1990). Those programs supported ambitious goals that can only be fulfilled once the emerging NGO-community partnerships are consolidated and strengthened. This message needs to be

Table 1—Coalition sponsored protected areas, actual and proposed.

Reserve	Area HA	Population affected	Sponsors	Status
Tutuaca Thick-billed Parrot Sanctuary	3,500	450	ProNatura NE	Federal Recognition
Pino Gordo	29,000	1000	Fuerza Ambiental	In Process
Baborigame	2,000	2000	Fuerza Ambeintal	Proposed
Cerro Mohinora	4,000	1200	Mcpo G. y Calvo, Fuerza Ambiental	Proposed
Sirupa	38,000	20	Fuerza Ambiental	Proposed

heeded by larger conservation NGOs now entering the region. Critics such as Mac Chapin (see World Watch, "A Challenge to Conservationists," November/December 2004) have alleged that the larger conservation NGOs focus on top-down, technically oriented approaches with mid-level involvement rather than community-based processes in indigenous regions.

Criteria need to be established to guide international aid in the region, whether private or public, conservation, development, or security oriented. Effective aid needs to also contribute in substantial ways to all the pillars of effective foreign policy in the region: strengthening democracy, respect for human rights, stimulating economic growth and diversification, protecting the environment, and ensuring the rights of the First Nations. These mutually supportive objectives can only be accomplished by local participation at all levels of planning and implementation and by creating special programs for autonomous indigenous planning, training, and organizational strengthening. This type of multi-tiered, intercultural, inter-institutional planning model is core to the Biosphere Reserve planning process just getting underway in the Sierra.

From past experience, government to government and multilateral support to government without direct NGO and community involvement cause more harm than good. The well-funded conservation organizations beginning to enter the region would do well to learn from the experience of grassroots support organizations active in the region, and help them out. Historically there have been huge political barriers to integrating conservation with agrarian and indigenous claims, but Mexico has opened up considerably in the past decade.

The Consejo EcoRegional and a handful of other NGOs working in the region have paved the way to more effective international conservation aid. For entrenched powers, slow but true democratic process in ejidos and indigenous pueblos may seem like a tremendous obstacle for progress. However, effective conservation in the Sierra benefits from and contributes to greater progress in Mexico today on many levels. Listening and responding to the priorities of local communities is the place to start.

(Note: More information on the Sierra Madre Occidental, the programs mentioned above, and unpublished reports can be found at: www.sierramadrealliance.org.)

History, Extent, and Future of Arizona BLM-Managed Roadless Areas in the Madrean Archipelago

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Abstract—*Roadless areas of southeastern Arizona managed by the Bureau of Land Management are becoming rare. Fragmentation by roads and development, all-terrain vehicle use, erosion, and altered hydrology are a few of the causes of loss and degradation of roadless areas. The history of BLM and publicly identified roadless areas includes the passage of the Wilderness Act of 1964, the Federal Lands Policy and Management Act of 1976, the development and passage of the Arizona Wilderness Act of 1984, the Arizona Desert Wilderness Act of 1990, the efforts of the Arizona Wilderness Coalition in the 1980s, and Sky Island Alliance's survey work in 2001-2004. Analysis of BLM and AWC wilderness studies, findings, and recommendations along with data from road surveys indicates the potential persists to protect many of the last high-quality roadless areas. Policy shifts, continued all-terrain vehicle abuse, road building, and other impacts presently threaten many of these areas.*

Setting

The Safford and Tucson Districts of the Bureau of Land Management cover more than 2.4 million acres in Arizona and New Mexico and encompass an amazing diversity of landforms and biotic communities. Only a small percentage of these communities are represented in the National Wilderness Preservation System. Specifically, 4% of semidesert grasslands and oak woodlands, and 0.6% of Chihuahuan Desert vegetation communities are represented in designated Wilderness (Loomis and Echohawk 1999).

In Arizona only 11% of the 12,200,000 acres of BLM lands are designated Wilderness, and in the Safford and Tucson Districts only 4% of the 2,200,000 acres of BLM lands are designated Wilderness (Arizona BLM Web site), even though in 1979 the BLM found 5,598,300 acres or 46% to have wilderness qualities in the State (USDI 1979). In 1984 the Arizona Wilderness Coalition proposed 4,257,972 acres or 35% Statewide (more than 4 times the BLM's original proposals), and 457,934 acres or 21% in the Tucson and Safford Districts (more than ten times the BLM's original proposals) (Arizona Wilderness Coalition 1987).

Currently there is no un-mandated inventory or review of roadless areas or comprehensive inventory or review of the road system in either the Safford or Tucson Districts. In fact no comprehensive travel management plan exists in either the Safford or Tucson Districts. Sky Island Alliance since 2001 has inventoried selected areas on the two districts that are in and adjacent to areas identified by the Arizona Wilderness Coalition as having wilderness qualities in their 1987 proposal.

Physiographical and Biological Uniqueness

The BLM lands in southeastern Arizona are unique in many respects including physiography. The region sits in a basin and range landscape—patterns of mountains and ranges separated by wide valleys or basins—that is made up of degradational landforms, piedmonts left by erosion, and constructional landforms, alluvium fans, etc. The spatially and temporally discontinuous deposition of alluvium has resulted in a mosaic of different aged and applied alluvium. Deeply incised degradational landforms result in amazing topographical relief (canyons), and incised constructional landforms results in the terraced alluvium of the larger river valleys (McAuliffe and Burgess 1995).

These lands are also unique in their biology. They are composed of mid-elevation, ecotonal lands of Madrean evergreen woodland, semidesert grasslands, Chihuahuan desertscrub, Sonoran desertscrub, interior chaparral, Great Basin conifer woodland, montane conifer forest, and riparian communities (Brown 1989; Marshall et al. 2003). They support the highest plant community alpha diversity in the Sky Island region and have a high prevalence of riparian habitats (McLaughlin 1995).

Many rare, endemic, sensitive, and special status species occur on these lands. Plants include 10 recognized by the Arizona Rare Plant Committee (undated). Animals include over 25 species listed as Threatened or Endangered by the U.S. Fish and Wildlife Service plus 7 that are Candidates or Petitioned for listing. Forty are on the BLM Sensitive Species list and 20 are on the Arizona Game and Fish Department Wildlife of Special Concern. Native fish are well represented with at least 7 species (AGFD 2004; USDI 2001b; USFWS 2004).

Wilderness Policy

Wilderness Designation

The organic act for the BLM is the Federal Lands Policy and Management Act of 1976 (FLPMA). In Title VI, Section 201(a) the BLM is directed to inventory all lands with wilderness qualities "...on a continuing basis..." In Section 603(a) the BLM must review those areas greater than 5,000 acres and make recommendations "…from time to time…" to the President on the suitability of each area for wilderness designation.

FLPMA in Section 102(a)(7) also formally established the management doctrine of "multiple use and sustained yield." Wilderness, as a resource value, is an important use, and as a designation wilderness is fully compatible with multiple use management. Wilderness designation can also further another key multiple use duty of FLPMA to "prevent permanent impairment of the productivity of the land and the quality of the environment" (Section 103[c]). Additionally, wilderness designation can act as a tool to fulfill another FLPMA duty to "take any action necessary to prevent unnecessary or undue degradation of the lands" (Section 302[b]). Every presidential administration has recognized these authorities in FLPMA for the designation of new Wilderness Areas, and most have signed Wilderness bills, including Presidents Ronald Reagan and George H. Bush.

So does the BLM have a continuing obligation to inventory and protect Wilderness Areas? According to FLPMA it does, but in September of 2003 the BLM issued Instruction Memorandum No. 2003-274, which severely undermined what FLPMA directs. Specifically this directive stated "Authority to complete Wilderness review and manage Wilderness Study Areas under the non-impairment standard under FLPMA Sect. 603 expired October 21, 1993," and rescinded the BLM Wilderness Inventory and Study Procedures Manual Handbook (USDI 2001a), which outlined the procedures the BLM must take to identify and protect wilderness quality lands. This is a slap in the face of organizations that have worked for years to protect wilderness quality lands and to get them designated under the Wilderness Act.

The Wilderness Act of 1964 defines Wilderness as an area that "… in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." The authors of the act recognized the importance of preserving areas where the public can escape from the trappings of modern civilization and where natural processes dominate. Wilderness also provides for very important ecosystem services such as clean water, clean air, and reservoirs of biological diversity.

Currently the above-mentioned directive is under litigation, and we fully expect that the courts will find that this interpretation of FLPMA Section 201(a) is incorrect.

Roads in Wilderness Areas

The BLM defines a road as "… improved and maintained by mechanical means to insure relatively regular and continuous use. A way maintained solely by the passage of a vehicle does not constitute a road." This definition is from the BLM Handbook (USDI 2001). This language originally appeared in House of Representatives Committee Report 94-1163 (May 15, 1976) on what later that year became the Federal Land Policy Management Act. This is still the only statement regarding the definition of a road in legislative history.

The BLM Handbook goes on to reaffirm and strengthen this definition by stating "A route which was established or has been maintained solely by the passage of vehicles would not be considered a road, even if it is used on a relatively regular and continuous basis" (emphasis added). Many routes on BLM lands in southeastern Arizona have not been maintained in decades and/or have been created solely by the passage of vehicles.

Currently the BLM is actively converting some wildland routes to constructed roads with fire management and recreation money on the Safford District, while ignoring repeated incursions into off-limits area such as the Gila Box Riparian National Conservation Area and some designated Wilderness Areas.

Wilderness Action

1970s

As directed in FLPMA the BLM Initial Inventory was completed in 1978. They inventoried a total of 1,180,000 acres in the Sky Island Region of Arizona, 1,169,500 on the Safford District, and 10,500 on the Phoenix District. They released 872,340 acres (74%) as unsuitable, 871,400 on the Safford District, and 940 on the Phoenix District, and they proposed that 307,660 acres, 298,100 on the Safford District and 9,560 on the Phoenix District, be intensively inventoried (USDI 1979) (table 1).

The BLM Intensive Inventory was completed in 1979. They intensively inventoried a total of 306,062 acres, 294,454 on the Safford District and 11,608 on the Phoenix District. They released a total 160,407 acres (52%) as unsuitable, 160,407 on the Safford District and 0 on the Phoenix District, and they proposed that 145,655 acres, 134,047 on the Safford District and 11,608 on the Phoenix District, be carried over as Wilderness Study Areas (12% of the original inventory and 48% of the lands intensively inventoried). A note of clarification—the BLM Initial Inventory and Initial Inventory reports report differing numbers for acreages; these numbers are taken from summary tables (USDI 1980) (table 1).

The Arizona Wilderness Act of 1984 dealt mostly with Forest Service land and lands on the BLM Arizona Strip District; however, it did designate the 6,670-acre Aravaipa Canyon Wilderness because it is "…a primitive place of great natural beauty that, due to the rare presence of a perennial stream, supports an extraordinary abundance and diversity of native plant, fish, and wildlife, making it a resource of national significance…"

Efforts to protect Aravaipa Canyon began in the early 1950s, and in 1968 the Canyon was proposed as a Primitive Area. On January 10, 1969, it was established as the 3,957 acre Aravaipa Canyon Primitive Area. In 1971 this was expanded through boundary adjustments to 4,044, and in 1978 two sections of Arizona State Land were acquired to bring the total acreage of the Primitive Area to 5,524. Also in 1978, under the mandate of FLPMA Section 201(a), a wilderness review was undertaken. It was recommended in a Wilderness Suitability Report to the President as deserving Wilderness designation, and in 1982 he concurred and sent it to Congress where it was incorporated into the Arizona Wilderness Act of 1984 (USDI 1988).

1980s

The BLM Safford District published a Final Wilderness EIS in 1987. They inventoried a total of 135,664 acres of

Table 1—Acreages of Designated Wilderness Areas, BLM, Wilderness Study Areas, Arizona Wilderness Coalition, and Sky Island Alliance Inventoried.

Unit name	Designated Wilderness	BLM Inventory 1979	Released WSA	AWC Proposal 1987	SIA Inventory 2001-2005
	---------------	----------------	Acres	----------------	---------------
Gila Mountains				68,000	
Fishhooks	10,883	32,633	4,130	[a]	+ ~20,000
Daymine	0	22,954	17,309	[a]	~20,000
Johnny Springs	0	8,382	NA	[a]	~8,000
Oliver Knoll	0	8,283	NA	[a]	~8,000
Diamond Bar	0	6,240	NA	[a]	0
Bear Springs Flat	0	12,398	NA	[a]	~10,000
Ashurst	0	11,506	NA	[a]	~10,000
Turtle Mountain	0	29,117	17,422	17,422	~17,422
Mescal Mountains		25,772[a]			
Needle's Eye	9,201	[a]	9,716	9,201	0
Mescal Mountains		[a]	7,140	12,000[a]	~12,000
El Capitan		[a]	0	[a]	[a]
Peloncillo Mountains	19,650	9,237	8,971	12,317	+ ~5,000
Aravaipa Watershed	19,381	0	12,317	27,520	+ ~8,000
Baboquivari Mountain	2,065	7,465	2,370	7,465	0
Coyote Mountain Wilderness	5,080	5,080	0	9,060	0
Dos Cabezas Mountain Wilderness	11,998	18,509	6,511	14,088	Not inventoried yet!
Black Hills	0	19,396	0	0	~10,000
Whitlock Mountain	0	18,207	17,870	18,853	~18,853
Bowie Mountains	0	37,156	0	3,7156	~37,156

[a] Included in area above.

which they proposed 38,672 acres (29%) to be Wilderness Study Areas and released 96,992 acres (71%). The individual WSAs are listed in table 1. The other alternatives considered and rejected were the All Wilderness Alternative of 135,664 acres, the Enhanced Wilderness Alternative of 101,291 acres, and the Moderate Wilderness Alternative of 48, 864 acres. The actual acreage of WSAs turned out to be slightly higher than the BLM's Proposed Alternative (USDI 1987b) (table 1).

The BLM Phoenix District published a Final Wilderness EIS in 1987 (USDI 1987a). They proposed that a total of 7,145 acres be designated as wilderness in two units: the Coyote Mountains of 5,080 acres, which was the total inventoried, and the Baboquivari Mountains of 2,065 acres, which is 28% of the original inventory area of 7,465 acres (USDI 1987a) (table 1).

In 1987 the Arizona Wilderness Coalition proposed wilderness for areas totaling 282,174 acres (in 16 units). The Coalition did an excellent job reviewing the BLM's wilderness work under FLPMA and pointed out many flaws in the BLM analysis. The Coalition's points were that the BLM ignored their own recommendation made on Wilderness Study Areas, they failed to account for public comment in favor of wilderness designation for individual areas, they misused the wilderness criteria at all steps of the process, and they applied the wilderness criteria inconsistently across the landscape (Arizona Wilderness Coalition 1987) (table 1).

Finally in 1990 the Arizona Desert Wilderness Act was passed with a total acreage in the Sky Island Region of 84,728, 51% of AWC Proposal of 167,741. The act also designated the Gila Box Riparian National Conservation Area with an acreage of 20,900, which included the Arizona Wilderness Coalition's 17,831 acres of identified roadless area (table 1).

2000s

The Sky Island Alliance started its inventory of BLM lands in 2001, and it will be complete in spring of 2005. Over 100 Alliance volunteers have donated approximately 4,000 hours over 40 weekends walking roads and taking data on the beginning and end of each road, any developments, maintenance and/or erosion along the road, and were asked to determine what the roads were being used for and who was using them. Most roads were being used for grazing structure access, and were also being used by hunters, firewood collectors, and ATVs. We focused on six areas—the Gila Mountains, Turtle Mountain, the Mescal Mountains, the Peloncillo Mountains, the Gila Box, and the Aravaipa Watershed. One result of this inventory was the identification of roadless areas that meet the definition of Wilderness (table 1).

Conclusion

Roadless areas of the Sky Island region of southeastern Arizona managed by the Bureau of Land Management are becoming rare. Fragmentation by roads and development, all-terrain vehicle use, erosion, and altered hydrology are a few of the causes of loss and degradation of roadless areas. Analysis of BLM and AWC wilderness studies, findings, and recommendations along with data from Sky Island Alliance road surveys indicates the potential persists to protect many of the last high-quality roadless areas. However, policy shifts, continued all-terrain vehicle abuse, road building, and other impacts continue to threaten many of these areas, and only through coordinated and persistent methods will we be able to ensure that these un-roaded landscapes remain.

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Conservation Priorities in the Apache Highlands Ecoregion

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Abstract—*The Apache Highlands ecoregion incorporates the entire Madrean Archipelago/Sky Island region. We analyzed the current distribution of 223 target species and 26 terrestrial ecological systems there, and compared them with constraints on ecosystem integrity (e.g., road density) to determine the most efficient set of areas needed to maintain current biodiversity. The resulting portfolio of 90 areas includes 12.5 million acres (5 million ha) that should be priorities for protection. Conservation strategies include protection and restoration of grasslands, restoration or maintenance of natural fire regimes, and learning more of probable effects of climate change.*

Introduction

Any comprehensive effort to protect our rich biological heritage must answer two questions: "What are the most important places?" and "How much conservation is enough?"

In 1996, The Nature Conservancy began developing ecoregion-based conservation assessments to answer those questions for the entire United States and portions of the 31 other countries in which the Conservancy works (Groves et al. 2002). We report here the results for the Apache Highlands ecoregion. This project was conducted as a bi-national assessment in collaboration with colleagues from IMADES, the Sonora State Institute for Environment and Sustainable Development, in Mexico.

The Apache Highlands Ecoregion

The Apache Highlands ecoregion spans 30 million acres (12 million hectares) and portions of four States in two countries: Arizona and New Mexico in the United States, and Sonora and Chihuahua in Mexico. It is bounded on the north by the Mogollon Rim (the southern edge of the Colorado Plateau), to the west by the Sonoran and Mojave Deserts, to the south by the Sierra Madre Occidental, and to the east by the Chihuahuan Desert (figure 1).

The region is best known among the scientific community for its "archipelago" of "sky islands." Over 40 mountain ranges cloaked in pine-oak woodland and mixed conifer forests rise abruptly from surrounding basins composed of grassland and desert scrub to form forested islands in a "desert sea" (Marshall 1957; DeBano et al. 1995). The juxtaposition and change in major biotic communities as one moves across landscape gradients has played a critical role in the evolution of the biodiversity present today and, likely, will continue to play a role in shaping the biodiversity of tomorrow.

Methods

This ecoregional assessment involved:

- Identification of conservation targets, a group of organisms and ecological systems that comprehensively represent the ecoregion's biological diversity. Targets included ecological systems, typically characterized by a plant community (e.g., ponderosa pine forest) and supporting ecological processes, and a broad range of species representing major taxonomic groups (amphibians, birds, fish, insects, mammals, mollusks, plants, reptiles) and spanning all levels of rarity, from rare to common. We included 26 ecological systems and 223 species, with special emphasis given to imperiled, endemic, or keystone species, or those that are limited by area, dispersal, or particular ecological processes. We also emphasized aquatic systems and species, due to their rarity and imperiled status in this region.
- Identification of conservation goals for each target that serve as a hypothesis about the number and distribution of populations needed to maintain long-term species viability.
- Identification of conservation areas sufficient in size and distribution to capture ecological variation and meet conservation goals for targets.

Our target selection was based on the Coarse Filter/Fine Filter approach to conservation planning (Groves et al. 2002). We assume that protection for plant communities and ecological systems serves as a coarse filter to capture most of the biological diversity present, while the fine filter is the deliberate choice of species with distributions that might otherwise fall through the gaps or that have habitat needs that would not otherwise be protected.

We used a variety of data sets, including species' population locality data housed in the Arizona and New Mexico

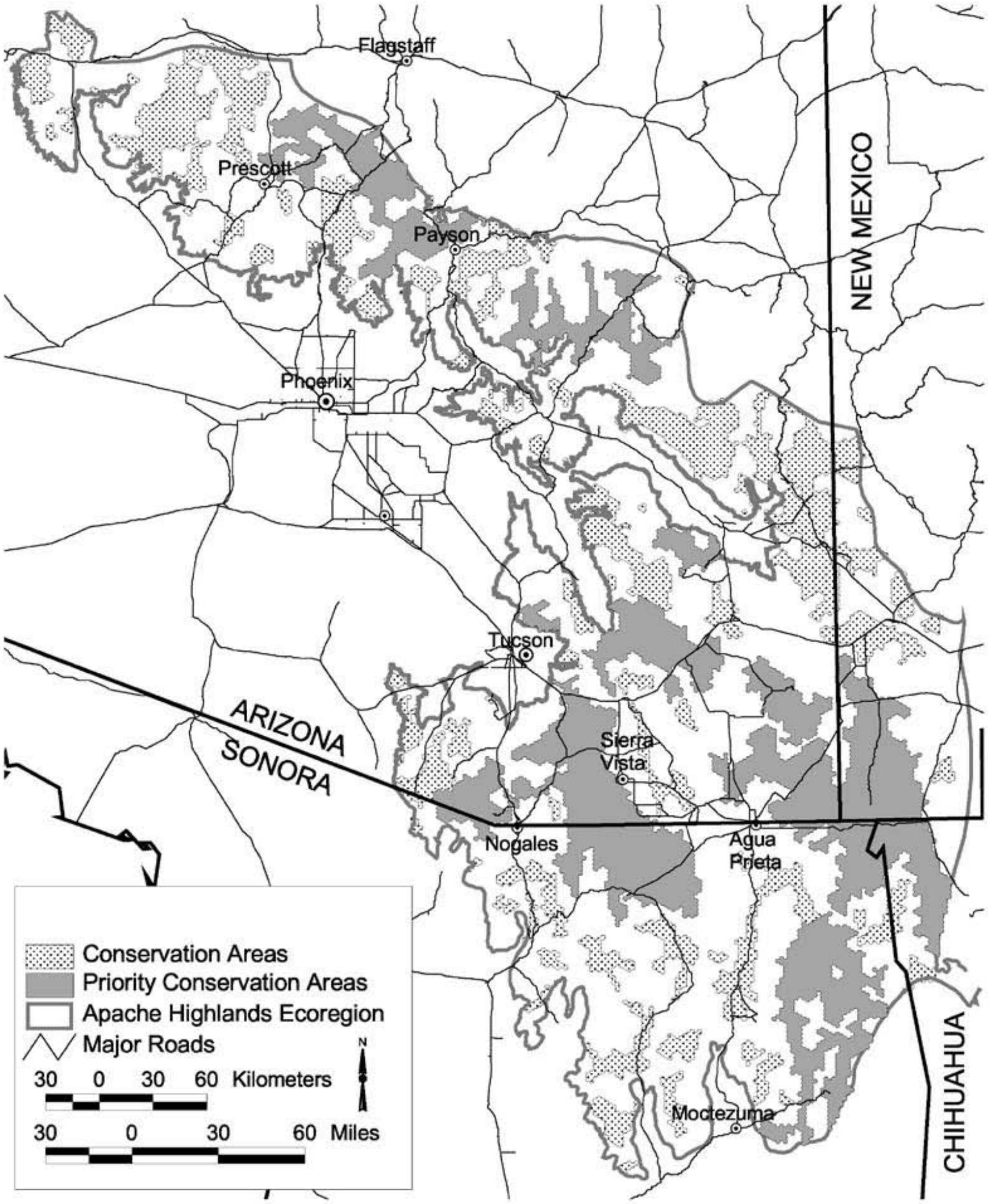

Figure 1—Apache Highlands Ecoregion with portfolio of conservation areas, emphasizing the eight areas of highest priority.

Natural Heritage programs, Sonora's Centro de Datos para la Conservación, and museums throughout North America, along with spatially referenced data on vegetation, land use, land management, hydrography, topography, infrastructure, and protection status. For target species, we incorporated 4,565 point localities into the analysis. For ecological systems, we obtained Gap Analysis Program (GAP) vegetation coverages for Arizona and New Mexico, and the Forest Inventory 2000 for Sonora and Chihuahua. Those systems' data were developed from imagery dating from the early 1990s (Halvorson et al. 2002; Palacio Prieto et al. 2000; Thompson et al. 1996; Velázquez et al. 2001). We supplemented data for riparian ecological systems with results from the Arizona Statewide Riparian Inventory and Mapping Project and the USGS National Land Cover Data (AGFD 1993; USGS 2000). Differences in the cover classifications between States were reconciled, particularly along borders, to form a consistent coverage for the ecoregion.

In addition, we developed three new spatial data sets: a complete coverage depicting the location of the ecoregion's ciénegas, the distribution and status of the ecoregion's remaining grasslands (see Enquist and Gori, this proceedings), and native fish distributions.

We considered the representative "cost" of conserving an area through a suitability index, which integrated major land use factors, such as road class density, mines/industrial development, agricultural/urban development, and minimum land area. This was a unit-less index, not directly associated with property values. We assigned each index factor a different weight depending on the assumed impact the factor might have on conservation targets (e.g., four-lane paved roads have greater influence than one-lane dirt roads, and are thus assigned higher values). We also assigned base land "cost" to the whole ecoregion in recognition that all land has some inherent costs associated with protecting it.

Table 1—GAP protected status for the Apache Highlands Ecoregion. All values are in percentages, except where noted. Unknown GAP status indicates Native American lands where we have inadequate information. See text for descriptions of GAP ranks.

	GAP 1	GAP 2	GAP 3	GAP 4	Unknown	Total area (ha)
Percent of ecoregion	1	4	27	59	8	12,154,707
Percent of combined portfolio conservation areas	2	5	30	61	2	5,061,500

We divided the ecoregion into 500-ha hexagons, which we attributed by intersecting them with point and polygon information for targeted species, ecological systems, and the suitability index.

We set conservation goals that are proportions of current known distributions of the conservation targets. Ideally, our goals would be stated in terms of historical extent to better inform recovery efforts for those targets that have declined, but we lacked adequate data for most targets to approximate their historic distributions across the ecoregion.

We tried to ensure that conservation targets were captured in a distribution that approximates their current distribution, and to avoid bias that might stem from the greater availability of locality data on the United States side of the international border. To do this we divided the input data and conservation goals according to a stratification scheme, breaking the ecoregion into nearly equal thirds.

We used the computer algorithm, SITES, to identify the portfolio of conservation areas. SITES selects areas to meet conservation target goals while balancing objectives of efficiency, defined as the greatest number of goals met for the lowest "cost" or least amount of suitable land (Andelman et al. 1999). We developed and evaluated 27 different scenarios before settling on a draft conservation area portfolio that met our goals for both number and distribution of target occurrences "captured" within conservation areas. The draft portfolio was reviewed by regional experts to identify omitted areas that are important to conservation targets as well as included areas where conservation is no longer feasible. We incorporated expert input, analysis of species distribution maps, comparison to land parcel boundary maps, and restoration potential in considering the boundaries of each area. The draft portfolio was reviewed by biologists with Arizona Game and Fish Department and IMADES, along with several taxonomic group experts from Mexico, and revisions made based on review comments.

Results

Nearly 3.7 million acres (1.4 million ha) were identified as priorities for conservation in the Mexico portion of the ecoregion, while the remaining 8.8 million acres (3.6 million ha) of the conservation portfolio was identified in the United States (Marshall et al. 2004). This distribution closely matches the proportions of the ecoregion, with 31% of the ecoregion and 28% of the portfolio in Mexico. The final portfolio consists of 90 conservation areas encompassing just over 12.5 million acres (5 million ha), about 40% of the ecoregion (figure 1). Conservation areas range in size from 1,235 to 1.9 million acres (500 to 757,500 ha), with an average of 138,967 acres (56,239 ha). The portfolio captured 2,118 miles (3,408 km) of perennial streams, 86% of the perennial stream length in the ecoregion. Aquatic or riparian targets occur in 77% (n = 69) of the conservation areas. Some conservation areas incorporate continuous landscapes from valley bottoms to mountain tops which, if fully protected, should buffer conservation targets against the impacts of climate-induced changes in habitat. Other areas form continuous mountain-to-mountain spans that are needed to maintain habitat connectivity for wide-ranging, forest-dwelling species such as black bear.

The portfolio of conservation areas met the conservation goals for 83% of the targets, including 189 species and 12 ecological system targets. Individual conservation areas captured from 1 to 119 conservation targets, with an average of 17 targets.

An analysis of protected status using a modified GAP classification (Weinstein 2002) revealed that only 5% of the ecoregion is in GAP categories 1 and 2, the highest levels of biodiversity protection afforded (table 1; figure 2; GAP 1 is managed for biodiversity with <5% of land cover converted by human uses, GAP 2 is managed for selected species and may have low-level human disturbances such as grazing and recreation). Twenty-seven percent of the ecoregion is in GAP category 3, where protection of natural land cover is balanced with extractive uses (e.g., Federal multiple-use lands in the United States). Nearly 60% of the ecoregion, however, permits intensive land uses and lacks mandates preventing the conversion of native vegetation cover by anthropogenic uses (GAP category 4). The conservation areas we identified are only slightly better protected, with 7% in GAP 1 and 2; thus, creating lasting protection for biodiversity in this ecoregion will require significant further efforts.

The portfolio captured 95-100% of Critical Habitat for 10 of the 11 species in this region with that designation under the Endangered Species Act. It only captured 64% of Critical Habitat for the Mexican spotted owl, missing portions of Saguaro National Park, but also capturing large areas of occupied spotted owl habitat that was not designated.

We used two analyses to rank the biodiversity value of the 90 conservation areas: target richness, or the number of targets found in each conservation area, and "irreplaceability," the difficulty of protecting the conservation targets in that area by substituting another area if the first is compromised. Of the 10 highest ranking conservation areas identified in each of the two analyses, 8 areas were shared between analyses (figure 1). In both the richness and irreplaceability measures the Huachuca Mountains Grassland Valley Complex and Sierra

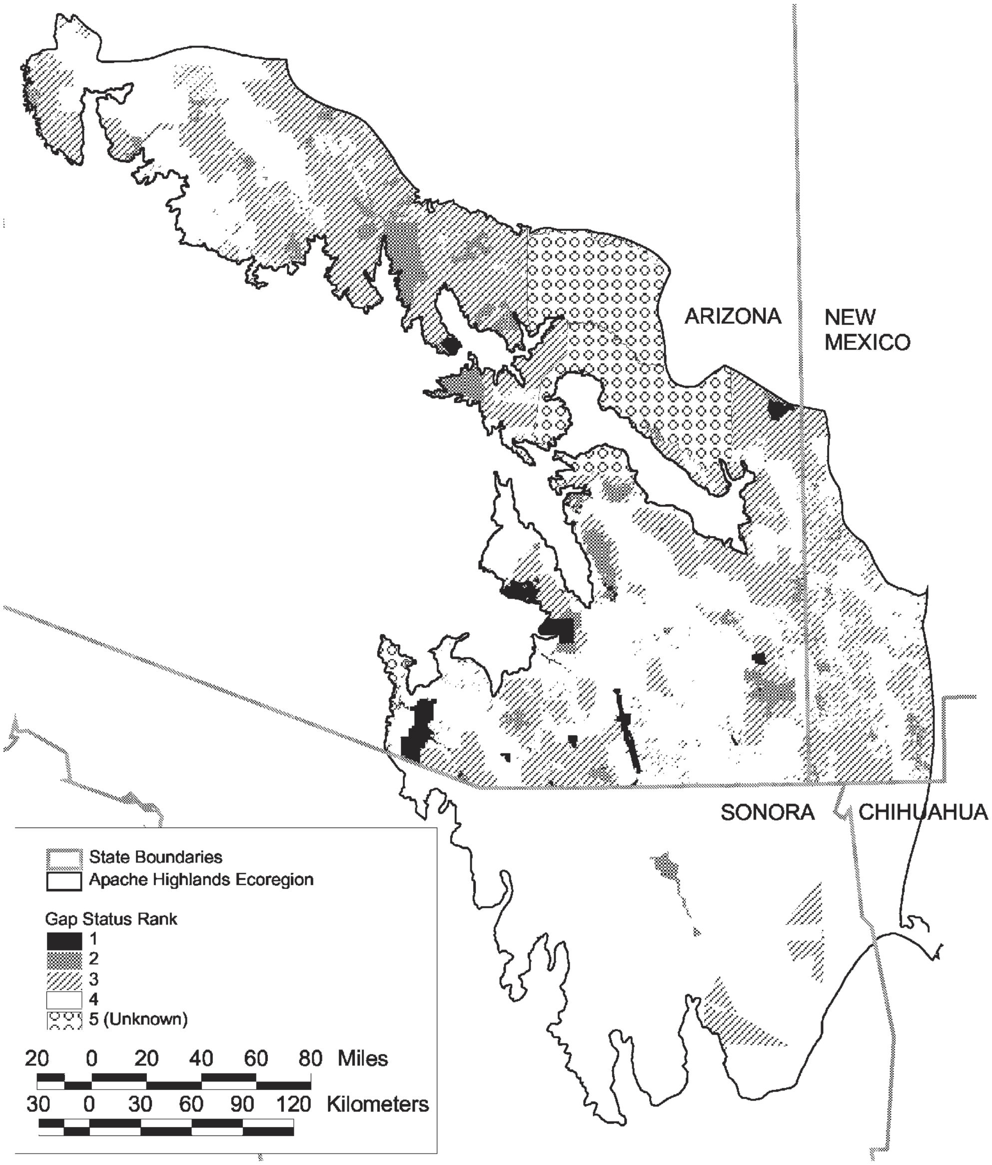

Figure 2—Gap status of land stewardship in the Apache Highlands Ecoregion. See text for descriptions of ranks.

San Luis/Peloncillo Mountains were the first- and second-ranked areas, respectively.

Discussion

The portfolio of conservation areas that we identified represents a hypothetical minimum area which, if managed well, would maintain the native biodiversity of the ecoregion through the next century.

This ecoregional analysis was meant primarily to identify those areas most important for maintaining biodiversity. During the process, we also identified strategies that address conservation issues across multiple areas. These include the need to increase protection and restoration of grasslands, maintain or restore natural fire regimes, improve conservation management in identified conservation areas, strengthen binational conservation efforts, and plan for climate-induced effects on native species and communities.

We also noted some important gaps in the information needed to move forward with protection or restoration of the region's biodiversity. These include: (1) Better mapping and analysis of the distribution of rare and declining species in aquatic and riparian communities, and the threats to those communities; (2) Field inventories on the distribution of rare species in northeastern Sonora and northwestern Chihuahua; (3) Better knowledge of needs for and distribution of large mammal movement corridors between mountain ranges; (4) Field surveys on the status and condition of ciénegas; (5) Predictions about the effects of climate change on species or vegetation communities in this region; and (6) A comprehensive survey of invasive plant and animal species in the ecoregion, and a coordinated strategy for their control.

Proactive conservation efforts, such as Pima County's Sonoran Desert Conservation Plan, need to be replicated throughout the ecoregion before conservation issues reach crisis levels, at which time it will be far more costly to develop effective solutions. Such efforts will not only require the best available scientific information, as presented here, but also commitments by community leaders to engage the public in a focused dialogue about balancing future growth with conservation of our natural heritage. The results of this analysis and the data developed for this study, collectively, provide a scientific basis for decision-making by Federal, State, county, and municipal agencies in planning for land and water conservation.

Acknowledgments

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Proceedings of Border Institute VI: Transboundary Ecosystem Management

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Abstract—*Ecosystems are bisected by international borders along the United States-Mexican border; infrastructure and the heightened security activities bisect the north-south cores, corridors, and buffers essential to preservation of ecosystems. The Southwest Consortium for Environmental Research and Policy (SCERP) and its partners convened an annual policy conference, Border Institute VI, where participants developed 10 recommendations to affect change in current trans-boundary ecosystem management policies throughout the United States-Mexican border region. Recommendations addressed institutionalization of existing programs, sovereignty concerns, education of citizens, land use planning, funding and revenue streams, approaches to water protection, watershed assessment of the Rio Grande/Río Bravo and Colorado Rivers, a public relations campaign, and specific changes to existing border programs and origanizations.*

SCERP: Promoting a Brighter Future for the United States-Mexican Border Region Through Sustainability Science

The Southwest Consortium for Environmental Research and Policy or SCERP, a collaboration of five United States and five Mexican universities located in all ten States, assists United States-Mexican border peoples and their environments by applying research information, insights, and innovations. The five American universities are Arizona State University, New Mexico State University, San Diego State University, the University of Texas at El Paso, and the University of Utah. The Mexican universities are El Colegio de la Frontera Norte, Instituto Tecnológico de Ciudad Juárez, Instituto Tecnológico y de Estudios Superiores de Monterrey, Universidad Autónoma de Baja California, and Universidad Autónoma de Ciudad Juárez.

SCERP was created in 1989 and was first funded by Congress in 1990 to address environmental issues of the United States-Mexico border region and to "initiate a comprehensive analysis of possible solutions to acute air, water and hazardous waste problems that plague the United States-Mexico border region." Since then SCERP has implemented about 400 projects involving as many as a thousand individuals.

The collaboration works closely with the EPA-HHS-SEMARNAT-SALUD IBEP, Border XXI, and 2012 Programs and other multi-national organizations and has the multi-fold mission of applied research, outreach, education, policy development, and regional capacity building for the communities, our ultimate customers.

SCERP exists to address the rapidly deteriorating border environment, to protect and enhance the quality of life and health of border residents, and to support the educational mission of our universities. SCERP's vision is to have a vital region with dynamic and diverse economy, sustainable environmental quality, intact ecological systems and processes, and a more equitable quality of life.

The approach used by SCERP, is to integrate and focus trans-disciplinary academic expertise; binational, State, tribal, and local policy making; non-governmental organization advocacy capacity; and private industry attention and influence on trans-border issues.

SCERP informs the decision-making process without advocating for or against a particular position. By interpreting the results of unbiased scientific inquiry, it provides motivation to adopt comprehensive, regional, and long-term policies and solution sets.

SCERP is also the primary sponsor of an annual think tank-style policy conference, call the Border Institute, than convenes the 100 top decision-makers and stakeholders from the region to examine complex and critical issues and recommend policy actions.

Introduction: Heightened Border Security Presents Renewed Challenges

Already a difficult process, conservation of biodiversity—the biological variety found at multiple scales, from the gene pool, to species, to habitats, to ecosystems—is further complicated by jurisdictional boundaries where cooperation and planning have typically broken down (or never developed in the first place). At international borders where national security concerns have begun to take priority over other concerns, the reduced permeability of the fences, roads, ports, and other infrastructure associated with the border results in a bisecting of many ecosystems that could become permanent.

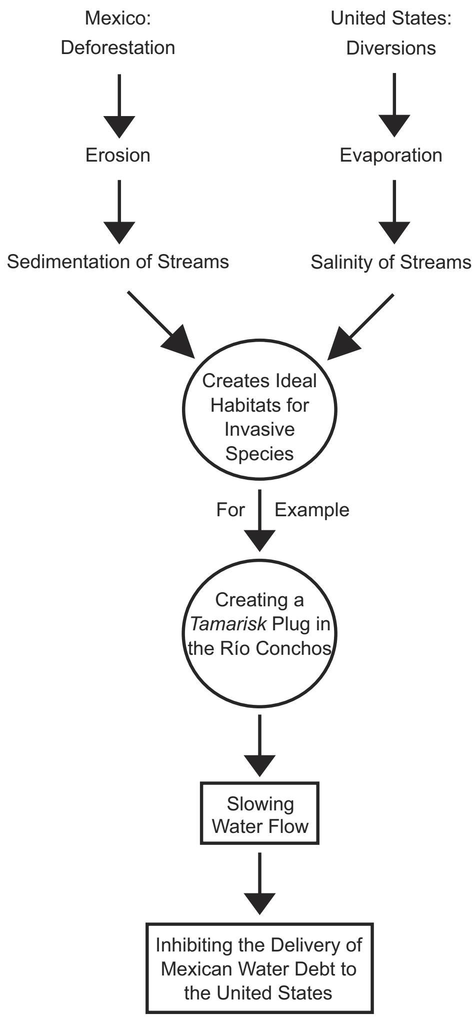

Figure 1—Effects of Mexican deforestation rate and U.S. out-of-basin water transfers.

The barriers at the border are compounded by population pressures that focus sprawl along that border and/or connect border urban areas across wildlands.

Such is the case along the United States-Mexican border, where infrastructure and the heightened security activities essentially sever the north-south cores, corridors, and buffers essential to preservation of ecosystems. The additional threats of water transfers away from nature, introduction of exotic species, and the intersection of varying traditions within each nation make many unique and rare ecosystems vulnerable. This also threatens the vitality and survival of nearly 100 individual species. For example, the deforestation rate in Mexico and the out-of-basin water transfers in the United States and their resulting direct and indirect effects have created a number of environmental hazards, ecological threats, and economic development obstacles (figure 1). They have even heightened international tensions. For example, in the transboundary Rio Grande Basin such factors as headwaters deforestation in the Conchos, large diversions for irrigation, and outdated reservoir operation have combined to stress the aquatic ecosystem, allowed large invasions of water-consuming non-native species such as salt cedar, and created binational tensions over water delivery obligations.

The Scale of Conservation: Large Tracts Need Saving

The most significant principle of biodiversity conservation involves the protection of the largest possible intact landscapes. This usually necessitates the crossing of political boundaries, a requirement that slows the process and creates difficulties in coordinating and reconciling differences between neighboring countries. While nations can easily and quickly agree to conserve migrating species in their territories, as in 1936 when Mexico signed on to the United States' Migratory Bird Treaty Act to protect migrating birds, protecting adjacent prime natural areas proves much more difficult. Often the protection consists of a convenient no-man's land of deserts and other uninhabited areas (usually Federally or State-owned), not necessarily where threats, vulnerabilities, hot spots, and threatened ecosystem processes exist.

A number of parallel policies and regulations, letters of intent to preserve adjacent natural areas, and similar land acquisition and easement mechanisms exist (see appendix; available on the SCERP website at www.scerp.org), but they are too few and scattered. And, without consistent political leadership and continuity of public policy, progress toward transborder ecosystem protection may be derailed. Such was the finding of an annual policy conference, Border Institute VI, convened by the Southwest Center for Environmental Research and Policy (SCERP) and its partners to address transboundary ecosystem management issues throughout the United States-Mexican border region.

Findings of Border Institute VI: Recommendations for Both Sides

At the culmination of the three-day conference, participants developed policy recommendations to enhance the management and conservation of transboundary ecosystems. Overall, participants concluded that the definition of transboundary environmental protection must include locally based, overarching visions, and it must be culturally sensitive, economically compatible, and include a region that has been defined by its stakeholders. Transboundary environmental protection also must incorporate issues of border security as they are affecting the border region at the current time. Differing local and national interests must be recognized as well. Specific statements and recommendations include the following:

1. Some individual officials and their agencies currently conduct conservation across borders in an effective way. When obvious mutual benefits appear, these small projects can be linked to achieve success regionally. Working within existing local agreements (binational liaison mechanisms, for example) and organizations' existing missions—in contrast to creating a new organization to coordinate biodiversity across the border—long-term, holistic, and regional visions can be gradually implemented. To achieve

this and continue existing successful efforts, job descriptions, objectives, and programs must be institutionalized to protect them from changes in political administrations and shifting priorities.

2. Where interjurisdictional issues and sovereignty arise, neighboring populations should rely on negotiation to address the most pressing issues in their countries. This will ultimately lead to proactive binational planning and implementation that integrates biodiversity considerations into other efforts such as water transfers or infrastructure projects. This starts with such tangible steps as transboundary environmental impact assessments (TEIAs), joint surveys, binational databases, border-crossing GIS, identification of priority natural protected areas to be joined, and designation of wildlife corridors. Each side can also learn from the success and failures of the other. For example, the United States can learn how to make land productive with less water just as Mexico can learn how to reforest lost habitat; both sides can learn how their own agriculture and other subsidies negatively impact natural systems.

3. Often the political motivation for a decision comes after education and mobilization of the public. Environmental education efforts must cross the borders they address and must include explanations about the economic, environmental, ecological, educational, ethical, and esthetic value of nature. Making conservation projects, such as the "river walk," the "nature trail," or the "greenway," into recreational household words helps produce a motivated and engaged public.

4. It is not enough just to buy land—once owned it must be properly managed, and that takes money and political will. Joint or shared funding of projects offers some solutions. An excellent example of this approach is the overall effort to control erosion and protect habitat in the binational Los Laureles Canyon in the Tijuana Estuary. California Coastal Conservancy funds were passed through the International Community Foundation and its sister philanthropy, Fundación Internacional de la Comunidad, to the municipal planning organization in Tijuana and the local Municipal Urbanization Unit. Matching assistance came from two branches of the Mexican Federal government, and permitting and technical assistance came from the U.S. Fish and Wildlife Service. In practice, the United States could help Mexico provide increased water from the Río Conchos by paying for part of the cost of removing the salt cedar plug from the lower Río Conchos, providing immediate benefits for important downstream protected areas (see figure 1).

5. Incentives and revenue streams do exist. If the goal is to achieve a sustainable rural economic development alternative, "experience tourism" can be developed around the themes of cultural, agricultural, natural, and tribal tourism, which by definition and practice must be conducted so that the carrying capacity of the destination is not exceeded either by residents or tourists. Other sources of income include auctions of hunting permits; oil, gas, and transportation fees and taxes; and the resources of non-profit foundations and international entities. Finally, cost-sharing by all entities on the border should be made a priority.

6. Water for nature must be sufficient and sustained. Rivers must no longer be seen as water supplies and must be valued for their own sake. Both the United States and Mexico should pass legislation recognizing international rivers, dedicating water to them, and allowing the purchase of water to maintain their flows—all the way to their mouths. The legislation should include consideration of drought and flood years, as well as long-term global climate change predictions. Specifically, participants recommended the passage of Senate Bill 1957 U.S.-Mexico Transboundary Aquifer Assessment.

7. A binational watershed assessment for the entire Rio Grande/Río Bravo, from Colorado to the Gulf of Mexico, should be undertaken to determine how much water is needed to sustain life. It is also important to determine which stakeholders need to be at the table to make decisions about the river and plant for future conservation, which ongoing assessments can provide helpful information, and to elect a body to oversee the assessment, such as the International Boundary and Water Commission (IBWC) and its Mexican counterpart, the Comisión Internacional de Límites ye Aguas (CILA). The assessment should be divided into subbasin levels, and then the coordinating body can harmonize the data. In conjunction with or after the assessment is complete, stakeholders should identify key areas in need of protection. Several successful small watershed pilot projects exist along the border, and then can be replicated for development in other areas of the border region. Existing organizations on both sides of the border should work together to develop long-term, holistic visions for their watersheds. As well, a water budget should be developed for the border region, and specifically, tribal input on it should be sought aggressively.

8. A communications campaign is needed to target audiences, stakeholders, and decision makers about the economic benefits of conservation on both sides of the border. The campaign can be effective when the messenger is credible, champions are enlisted, and emblematic species are highlighted. Non-governmental organizations are urged to further their advocacy activities.

9. Although land use planning is different in both countries, thus making binational planning difficult, land use planning is critical to enhancing and restoring long-term health and ecosystems. Stakeholders should use memoranda of understanding, letters of intent, local agreements, conservation easements, exchange of letters, and treaties (though treaties are not preferred) to carry out binational land use planning. Available data and information—including natural resources and cultural and socioeconomic data—on existing conditions and potential threats should be organized and disseminated to interested stakeholders. A gap analysis of this information should be conducted, and those gap discovered should be addressed using remote sensing and GIS tools, ecosystem modeling tools, and focused field surveys and monitoring. In the process, stakeholders must recognize

the United States' need for border security and develop methods and approaches to maintain landscape connectivity, such as using remote video surveillance systems rather than physical barriers.

10. Finally, certain specific recommendations were made for existing border organizations:

- The Border 2012 Program must reintegrate the Natural Resources Working Group of its predecessor program, Border XXI.
- IBWC-CILA must follow up on and broaden their use of a Science Advisory Council to explore ways of conserving biodiversity within their purview (which is addressed in their Minute 308).
- The Border Environment Cooperation Commission (BECC) must include and elevate conservation and sustainability criteria and the North American Development Bank (NADBank) must expand its mandate to include ecosystem conservation.
- The U.S. Department of Homeland Security (DHS) must consider non-invasive techniques—including seismic sensors, remote video surveillance systems, and laser crossing detectors—to monitor remote sites for illegal immigration and other security-related concerns.

Conclusions

The United States-Mexican border region has the highest rate of species endangerment in the United States. Some 31 percent of the species listed as endangered by the U.S. Department of the Interior are found in the United States-Mexican border region, and on the Mexican side of the border 85 species of plants and animals are in danger of extinction. The ecosystems in which these species are located provide services and renewable resources that humans worldwide under-appreciate, undervalue, and under-conserve.

Developed by the 60 top-level border organization representatives who attended Border Institute VI in April 2004, these recommendations aim to alter the course of the status quo. The recommendations will be widely circulated among all levels of the United States and Mexican Federal, State, and local agencies; tribal nations, NGOs; the private sector; and others who have a stake in the United States-Mexican border region. It is hoped that these recommendations will increase the inclusion of ecosystem considerations in the design and implementation of policies and projects along the United States-Mexican border.

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Ecology

Characterization of Mexican Spotted Owl (*Strix occidentalis lucida*) Habitat in Madrean Sky Island Ecosystems

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Abstract—*This project characterized Mexican spotted owl (MSO) home territories on the Fort Huachuca Military Reservation (FHMR) in the Huachuca Mountains using existing data on owl occupancy, fire history, and site characteristics. Although many nest sites were found in canyon environments with riparian, mixed conifer, and oak tree components, MSO territory composition was variable depending on topographic position. Data analysis suggests MSOs are not mixed conifer dependent and that oak and riparian tree species were important components in each territory. There is potential for adverse wildfire effects in MSO territories due to high fuel loads, stand density, and human ignitions.*

Introduction

Mexican spotted owls (*Strix occidentalis lucida*) (MSO) are widely distributed throughout the Southwest and are found typically in isolated mountain systems with sufficient habitat. Although several studies have characterized MSO habitat, few have focused on Madrean sky islands in southeastern Arizona and southwestern New Mexico (Ganey, 1988; Ganey and Balda 1989, 1994). MSO habitat in the southern part of Arizona and New Mexico varies from the northern part of the States because vegetation structure and composition is controlled largely by topographic gradients (Barton 1994; Whittaker and Niering 1965). Although nest/roost areas are identified in the field, owl territories are generally delineated without detailed knowledge of owl movements (Ganey et al. 1992).

This project characterized MSO habitat on the Fort Huachuca Military Reservation (FHMR) in the Huachuca Mountains of southeastern Arizona using data collected from annual MSO surveys, a wildland fuel inventory, and fire history studies. This paper will focus on vegetation composition in owl territories.

Methods

A vegetation map was developed for the Huachuca Mountains using remote sensing imagery by combining a land cover/vegetation type classification with field data collected from a fuel inventory conducted on the FHMR (Miller et al. 2003). A geographic information system (GIS) was used to clip the MSO critical habitat, territories, and a 200 m buffer centered on each nest/roost site from this map to compare vegetation composition using pixel counts (figure 1). Vegetation communities follow the taxonomy in Brown (1994). Surface and aerial fuels (i.e., tree and shrub density, downed woody material (DWM), herbaceous material) were sampled from 47 randomly distributed fuel inventory plots that fell within MSO territories. Fuel loads were calculated using equations from Brown (1974); shrub biomass was calculated using dimension analysis developed by Ludwig et al. (1975); and herbaceous biomass was estimated using a relative-weight estimate method following Hutchings and Schmautz (1969).

Fire occurrence patterns were determined by collecting full and partial cross section samples from living and dead trees that contained fire scars (Arno and Sneck 1977). Danzer (1998) collected fire-scarred samples along an elevational gradient in the Garden Canyon watershed on the FHMR. Kaib (1998) collected samples in canyons, based on presence of fire-scarred pines and proximity and connectivity to lower desert grasslands. Dendrochronology provided a method to assign a calendar year to each annual ring and to each fire scar (Dieterich and Swetnam 1984; Stokes and Smiley 1968). The reconstructed fire history ranged from 1532 A.D. through 1996.

The FHMR has conducted annual MSO surveys since the early 1990s following established USDA Forest Service protocols (1990). Eight protected activity centers (PAC) and two inventory areas (IA) (from this point called MSO territories) were established as a result of the monitoring efforts.

The Chi square statistic ($\alpha = 0.05$) was used to test all relationships. MSO territories are displayed from lowest to highest in elevation based on mean elevation.

Results and Discussion

Data available for the FHMR provided several scales to assess MSO habitat. The vegetation map provided 30 m pixel resolution over the entire study area. The fire history was conducted in the mixed conifer community in the Huachuca Mountains and the fuel and MSO inventories were site specific.

Averaged percent vegetation by type for critical habitat versus all MSO territories, MSO territories alone, and nest/roost sites within a 200 m buffer is shown in figure 2. Scrub grassland and savanna were significant components of the critical habitat

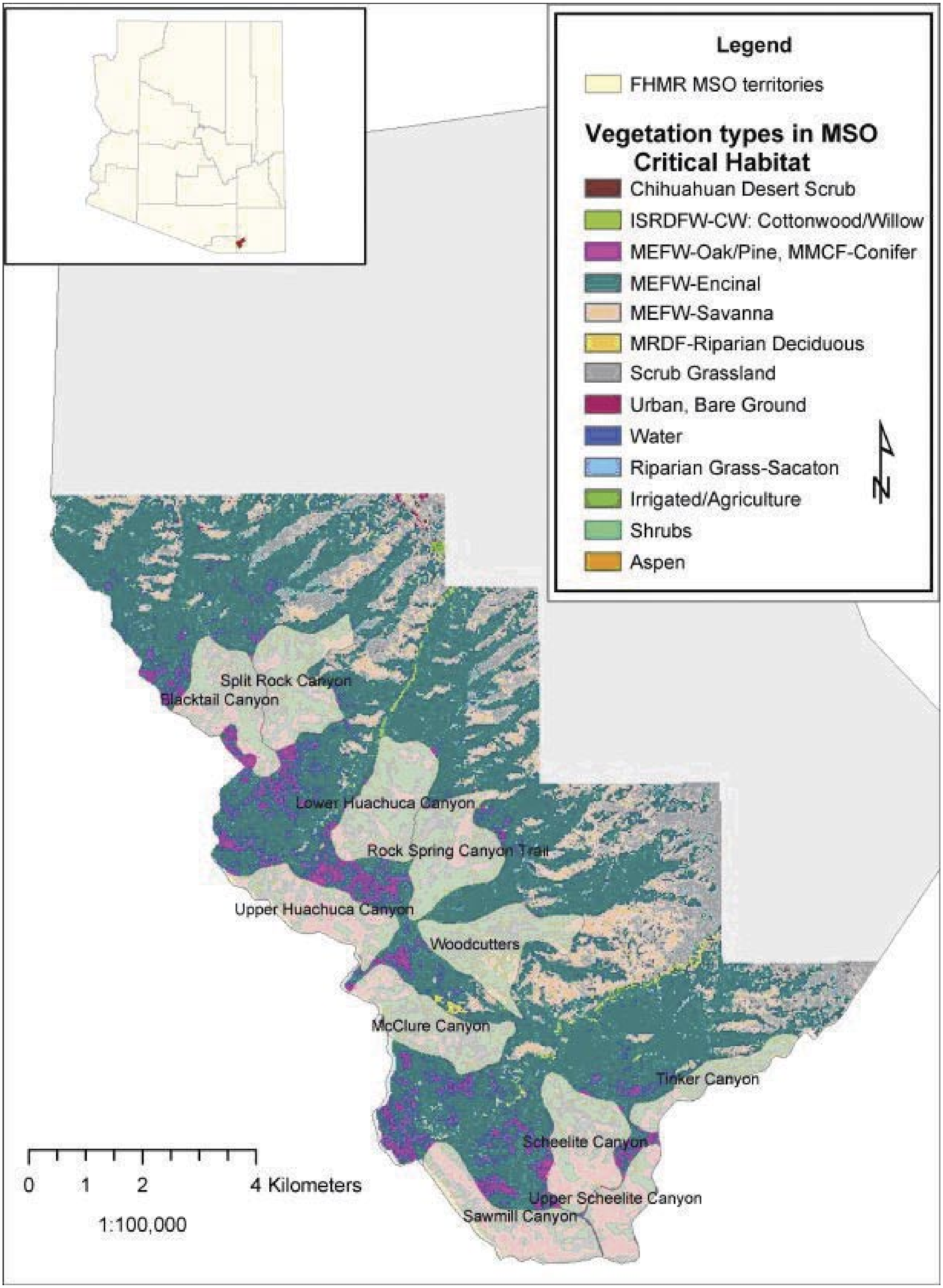

Figure 1—Critical habitat vegetation with Protected Activity Areas and Inventoried Areas (PAC/IA) on the Fort Huachuca Military Reservation (Miller et al. 2003).

and all owl territories. Scrub grassland and encinal are present in lower elevation sites and absent in higher elevation sites. The savanna component (<30% cover) is ubiquitous on lower slopes and present on south-facing slopes at all elevations, although tree/shrub composition may vary. Aspen (*Populus tremuloides*) is significant in Upper Scheelite Canyon.

Many of the owl territories were in steep, rocky canyons, with mature trees, a complex understory, and high canopy cover typical of MSO habitat identified in other areas. However, these canyons, and other small community types, are not well represented on the vegetation map because they are less than the minimum mapping size identifiable using remote sensing techniques. The oak/pine and conifer (O/P/C) categories were combined because the resolution was too coarse to separate them, and because there were not enough fuel samples to train the unsupervised classification used to create the vegetation polygons (Miller et al. 2003).

Between owl territories, scrub grassland was significant in Tinker, and O/P/C and encinal in Woodcutters and Upper Huachuca Canyons. The riparian component was significant in McClure Canyon. Within the buffered nest/roost sites, the oak component was significant in the lower elevation sites and conifer in the upper elevation sites. Tinker, Woodcutters, and Upper Scheelite were not represented in the nest analysis because there was no record of recent nest/roost sites.

Historically wide-spread, low intensity surface fires were most common in these ponderosa pine dominated forests, with a mean fire interval (MFI) of 4 to 10 years (Danzer 1998; Kaib 1998; Swetnam and Baisan 1996). The last mountain-wide fire in the Huachuca Mountains was in 1899. FHMR has mapped most wildland fires since the 1970s. These combined records indicated that there have been no fires in any of the owl territories for >100 years.

In contrast to the low-intensity, pre-settlement fires, several large crown fires have occurred in the Huachuca Mountains within the last 100 years. Areas susceptible to crown fires in the Huachuca Mountains could be characterized as mature forests (oldest trees >80 years old) with a complex structure and high canopy cover.

Number of fuel plots within MSO territories by vegetation type ranged from 2 to 11 (table 1). Stand density and composition information was obtained from 40 of the 47 plots. Tinker was eliminated from plot analysis because there were no fuel plots sampled and there have been no MSO sightings in that canyon since the late 1980s. Current tree composition based on field sampling is shown in figure 3. Pinyon (low elevation) and riparian trees (canyon sites) were significant components. Conifer species comprise 29% of the overall vegetation for the territories combined, while the oaks comprise 48%. Deciduous trees, evergreen oaks, and conifers were significant in Scheelite, which is a steep, north-facing canyon. Analysis of fuel plots indicates that oak species decrease with increased elevation while the reverse is true of mixed conifers.

Tree density ranged from 61 to 5,091 trees/ha. Total basal area ranged from 1.9 to 206 m^2/ha. Both tree density and basal area were variable within each owl territory. Shrub biomass ranged from 0 to 70,000 kg/ha, although only 43% of plots had a shrub component. A significant shrub component in these ecosystems can be evidence of both absence of fire (thus, understory is preserved) or presence of fire (resprouting after crown fire).

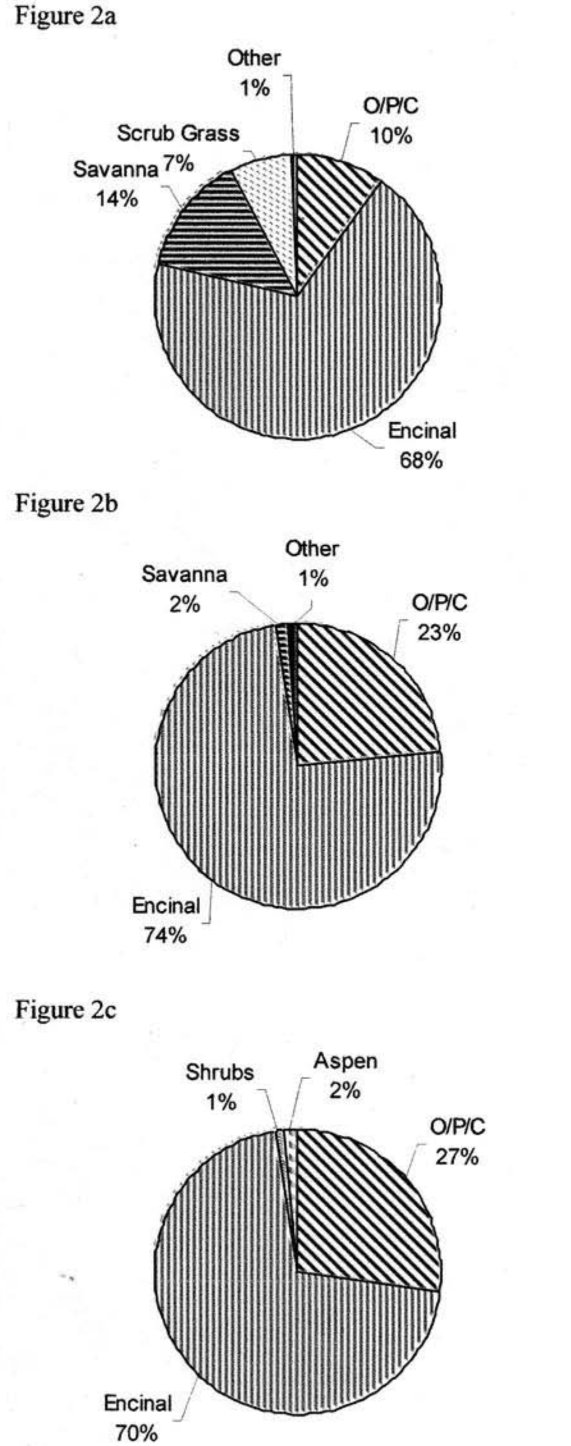

Figure 2—Percent vegetation in critical habitat: (a) MSO territories, (b) and nest/roost sites with 200 m buffer, (c) O/P/C = oak/pine/conifer.

DWM was tallied in the following size classes: 0–0.6 cm (1 h fuels), 0.6–2.5 cm (10 h fuels), 2.5–7.6 cm (100 h fuels), and >7.6 (1,000 h fuels). DWM in size classes <7.6 cm ranged from 2.9 t/ha to 52 t/ha. Most of the MSO territories on the FHMR are found in riparian corridors; there are no studies of fuel

Table 1—Number of fuel plots by vegetation type for each MSO territory. MMCF = Madrean Montane Coniferous Forest; MRDF = Madrean Riparian Deciduous Forest.

Territory	Encinal	Oak/pine	MMCF	MRDF	Total
Woodcutters	5	0	0	1	6
Split Rock	2				2
L.Huachuca	3				3
L.Scheelite				2	2
U.Huachuca	1	2			3
Rock Spring		1	1		2
McClure	5	2	1	3	11
Blacktail		3	3		6
Sawmill IA	4	2	1		7
U. Scheelite			5		5

loads for oak woodlands or riparian communities for comparison purposes. However, these fuel loads are within the range of variability reported for southwestern mixed conifer sites (Sackett and Haase 1996). Herbaceous fuels average >1,500 kg/ha for lower elevation encinal sites and <500 kg/ha sites containing more conifer species. With increase in elevation, depending on topographic position, the herbaceous component decreases as litter (e.g., pine needles) increases. There is an inverse relationship between litter and herbage yields in ponderosa pine communities (Pase 1958; Biswell 1972).

Topographic positions of nests were derived from a digital elevation model (DEM). Mean nest/roost elevation was 2,015 m (ranging from 1,772 m to 2,323 m), mean slope was 34%, and mean aspect was 207º. Of the 10 nest/roost sites analyzed, seven were on northwest facing slopes. Nest/roost sites were found on cliffs, in various oak and pine species, and in white fir (*Abies concolor*).

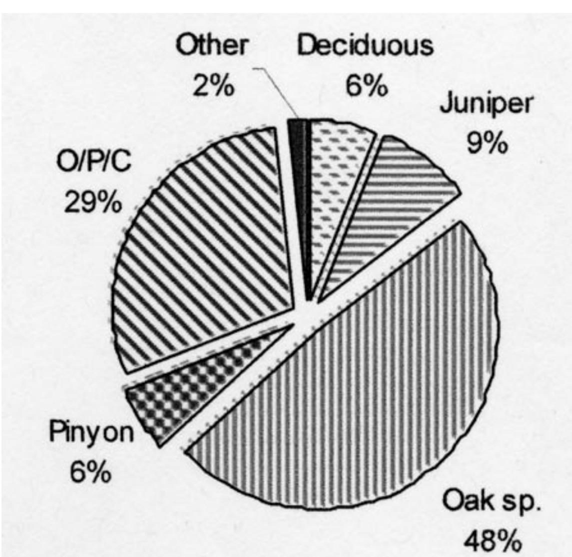

Figure 3—Tree composition based on field sampling. O/P/C = oak/pine/conifer.

Conclusions—Management Implications

The Basin and Range-West recovery unit (RU) ranks third in terms of concentration of MSO sites in the United States (USDI 1995). Most studies of MSO in other RUs suggest that mixed conifer forests dominated by Douglas fir are the most important habitat associations, with pine/oak, evergreen oak, pinyon/juniper, and riparian forests having little to no importance (Ganey and Balda 1994; Jenness 2000). May and Gutierrez (2002) suggested, based on a study in central Arizona, that MSO are not forest dependent. Data from the FHMR suggest that:

- MSO are not dependent on the mixed conifer habitat, and that
- Riparian and oak/pine (O/P/C) stands are important habitat types.

Owls were mainly found in canyon environments with riparian, mixed conifer, and oak tree components, with nests found as low as 1,772 m elevation. Oaks were a major component of all owl territories, with >65% oaks in the most productive sites based on the vegetation map and >45% based on field sampling. Both methods showed decreasing amounts of oaks and increasing mixed conifers with increasing elevation. Abundance of oaks in the Huachuca Mountains could be a result of many factors including historical overharvesting of pines, lack of fire, and oak reproduction following large stand-replacing fires (Felger and Johnson 1994). Southwestern oak species resprout vigorously following disturbance.

Because owl territories on FHMR have not sustained a fire for >100 years, the threat of catastrophic fire is real. In addition, the potential for human-ignited fires is greater here than in other mountain ranges because undocumented illegal (UDI) border traffic is purposely funneled through this area. Many of the fires in 2002 were attributed to UDI traffic. In the Huachuca Mountains, MSO habitat of uneven-aged, multi-storied stands, with high canopy closure may be a result of fire suppression. Forest communities contain high fuel loads, and the multi-storied ladder fuels contribute to catastrophic crown fires. Perhaps, fire suppression created additional habitat allowing the owls to expand into areas previously considered marginal. Because historically surface fires burned with a decadal frequency, stand density was lower; and, if we assume that this was historical MSO territory, then owls may have been adapted to a less dense stand structure.

How do we manage MSO habitat in areas that have suffered a century of fire suppression, with high potential for catastrophic fire? MSO territories should be targeted for treatment, to decrease stand density and minimize surface fuel hazard, using a combination of mechanical thinning and prescribed fire. The steep-walled canyons may be fire refugia, but if the home territories and surrounding areas are not treated the potential for catastrophic crown fires is high and probably certain.

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Safe Harbor: A Tool to Help Recover Topminnow and Pupfish in Arizona

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Abstract—*The Arizona Game and Fish Department (Department) has developed a Safe Harbor Agreement (SHA) for four native fishes in Arizona. The SHA will allow Gila and Yaqui topminnow (*Poeciliopsis occidentalis *and* P. sonoriensis*) and desert and Quitobaquito pupfish (*Cyprinodon macularius *and* C. eremus*) to be released onto non-Federal lands while safeguarding landowner options for future property use. The SHA will assist recovery of these species by: creating replicate populations; creating partnerships between State, Federal, and other groups; minimizing stocking of mosquitofish and other nonindigenous species; providing for mosquito control; and educating those outside the native fish community about the plight of Arizona's native fishes.*

Introduction

Safe Harbor Agreements are a relatively new Endangered Species Act tool for non-Federal landowners. Only three have been completed in Arizona, and two of those were in the last year. The Arizona Game and Fish Department's Safe Harbor Agreement for topminnow and pupfish will be a proactive tool that will promote the conservation and recovery of these endangered species. The conservation status of Gila and Yaqui topminnow (*Poeciliopsis occidentalis* and *P. sonoriensis*) and desert and Quitobaquito pupfish (*Cyprinodon macularius* and *C. eremus*) is poor, recovery actions have been spotty, and a great deal of work is needed.

Safe Harbor

Much of the Nation's endangered species habitat is on non-Federal property. Conservation efforts on non-Federal lands are essential to the survival and recovery of many endangered and threatened species. Safe Harbor Agreements can provide the means to garner non-Federal property owners' support for species conservation on their lands. The assurances an SHA provides to non-Federal landowners ensure that voluntary conservation actions taken for listed species covered by an SHA on their property will not restrict uses of their property, except as provided in the SHA. SHAs can encourage landowners to manage their properties for the benefit of listed species, and they must be designed to achieve a net conservation benefit to these species. Many property owners are willing to voluntarily manage their properties to benefit listed fish, wildlife, and plants.

The Species

The Gila and Yaqui topminnow were listed as endangered in 1967, and the desert and Quitobaquito pupfish were listed as endangered in 1986 (USFWS 1967, 1986c). Since then, many conservation efforts have been attempted, but the status of all four species is only marginally better than when the species were listed (USFWS 1993; Minckley 1999; Weedman 1999). Basic life history information and recovery actions can be found in the species' recovery plans (USFWS 1993, 1994; Weedman 1999).

The Agreement

The SHA will assist recovery of topminnow and pupfish through five goals: creating replicate populations; creating partnerships between State, Federal, and other groups; minimizing stocking of mosquitofish and other nonindigenous species; providing for mosquito control; and educating those outside the native fish community about the plight of Arizona's native fishes.

Aldo Leopold (1953) once said: "To keep every cog and wheel is the first precaution of intelligent tinkering." The creation of refuge habitats for topminnow and pupfish has allowed us to intelligently tinker with recovery of these species. Refuge populations of topminnow and pupfish are currently held at museums, laboratories, universities, parks, and schools under various permits. The SHA will allow for the Arizona Game and Fish Department to hold a single Endangered Species Act permit at a range-wide level, thus allowing interested parties to "sign-on" to the permit through a Certificate of Inclusion.

Recovery of topminnow and pupfish will not occur solely due to the SHA, as most available natural habitat is on Federal lands. What will occur, however, is an increase in the number of fish refuges that will be available for wild site reestablishment. Use of the native topminnow and pupfish will also lead to a decrease in the perceived need for stocking of nonnative species to control mosquitoes and other insects, and education and outreach to educate the public about the value of our native natural resources. The SHA will facilitate the use of managed waters like effluent, stock ponds, and small public or private ponds that are increasingly major features of the Southwestern aquatic environment.

In recent years there have been an increased emphasis and interest in collaborative conservation. The SHA for topminnow and pupfish will bring non-Federal land owners to the same table as the State and Federal agencies and will increase collaborative conservation for these four fishes in Arizona.

Nonnative aquatic species have had major detrimental impacts on native aquatic fauna and have been a major factor in the listing of topminnow and pupfish, as well as many other fishes native to the Gila basin (USFWS 1984, 1986a,b,c, 1991). Introduction of nonnative pathogens, parasites, plants, invertebrates, amphibians, and fish negatively affects the native fishes of the Southwest (Miller 1961; Robinson et al. 1996). The primary biological threat to the Gila topminnow is the nonnative western mosquitofish (*Gambusia affinis*), introduced to streams in the Southwest in the 1920s (Minckley 1999). Large scale reductions of Gila topminnow correspond strongly with the spread of mosquitofish.

Aquatic nonnative species are introduced and spread into new areas through a variety of mechanisms, intentional and accidental, and authorized and unauthorized (Fuller et al. 1999). These nonnative aquatic species include fishes, aquatic and semi-aquatic mammals, reptiles, amphibians, crustaceans, mollusks (snails and clams), insects, zoo- and phyto-plankton, parasites, disease organisms, algae, and aquatic and riparian vascular plants (Fuller et al. 1999). They affect native fish, including Gila topminnow, through predation (Courtenay and Meffe 1989; Marsh and Brooks 1989; Meffe 1985), competition (Baltz and Moyle 1993; Douglas et al. 1994; Schoenherr 1981), aggression (Meffe 1984), habitat alteration (Allen 1980), aquatic community disruption (Hurlbert et al. 1972; Ross 1991), introduction of diseases and parasites (Clarkson et al. 1997; Robinson et al. 1998), and hybridization (Dowling and Childs 1992; Echelle and Echelle 1997). Nonnative plants can reduce available habitat with abundant growth (e.g., water cress, giant salvinia), potentially cause loss of surface water (e.g., salt cedar), or alter ecosystem dynamics (Lovich and DeGouvenain 1998).

Allowing topminnow and pupfish to be used on non-Federal properties will reduce the public's use of nonnative fish. This will increase the number of topminnow and pupfish populations and minimize nonnative fish populations. Most movement of fish is not done legally by the Department, but illegally. Minimizing the number of populations of nonnative fish will help to reduce the spread of these problematic species.

The arrival of West Nile Virus in Arizona has created an additional, urgent need for this SHA. Since both topminnow and pupfish are known to prey on mosquito larvae as effectively as mosquitofish (Childs 2001; Walters and Legner 1980), having the SHA ready in 2004 will allow the use of topminnow and pupfish near the beginning of the mosquito season. This is a tremendous opportunity that will allow the Department and Service to market and publicize the SHA and native fishes. Making these fish available for release in suitable habitats to control mosquitoes will allow us to meet our goals for the SHA. This may create a substantial number of new populations, as well as encourage public institutions and private entities to think critically about ecosystem structure and management in terms of both mosquito control and native species recovery.

Education is always listed in species recovery plans as a task necessary to recover the species. However, since recovery plans are written and implemented by biologists with precious little time for anything but their core mission, effective and far-reaching education is rarely, if ever achieved. Because most threats impacting native fishes today are human caused or mitigated, education can go a long way to remove or reduce those threats. The two major causes of species endangerment in Arizona today are loss and modification of water from human causes and nonindigenous species such as mosquitofish and sunfishes. The propitious timing of the SHA and the arrival of West Nile Virus in Arizona is providing us with an incredible education opportunity that must be taken advantage of. Since both topminnow and pupfish are known to prey on mosquito larvae as effectively as mosquitofish (Childs 2001; Walters and Legner 1980), a tremendous marketing opportunity has presented itself that will provide us with a large audience and prodigious education opportunities. Making these fish available for release in suitable habitats to control mosquitoes will allow us to meet our five goals for the SHA, create partnerships essential to species conservation, and provide a positive public image of these fish as an environmentally beneficial biological control.

Plans and Implementation

Because of the amount of interest expressed previously by non-Federal landowners for having native fishes, and the increasing interest in mosquito control, we expect demand to initially outpace the supply of topminnow and pupfish. Therefore, the initial sites will be large sites and sites with the greatest education potential. Larger sites that receive fish early in the season can supply fish for stocking later efforts, increasing the supply of fish quickly. Utilizing other sites with high education potential will allow us to take advantage of the initial opportunity provided by the concern over mosquito control and mosquito borne diseases.

The SHA provides for two types of monitoring as required by Service policy and Federal regulation: (1) compliance monitoring to ensure that all commitments in the SHA are being met, and (2) biological monitoring to ensure that the biological goals of the SHA are being met and to help determine the effectiveness of its conservation program.

The SHA requires each landowner to comply with certain requirements. The Department will ascertain compliance to determine if each landowner is properly implementing those conservation commitments. The U.S. Fish and Wildlife Service is responsible for monitoring the Department's compliance with the ESA section 10(a)(1)(A) Permit.

The Department and the land owner will coordinate annual monitoring and reporting. Biological monitoring will address the status and distribution of fish populations established under the SHA. The biological monitoring may also address issues that require adjustment to the SHA's conservation program through adaptive management.

Biological monitoring will be funded and done primarily through the efforts of State and Federal agencies, academic institutions, conservation organizations, or other entities. Biological monitoring will be conducted uniquely by the Cooperator and agency, academic, and conservation personnel for each property as agreed upon by the Department and the Cooperator. Ultimately, the Department must ensure that required monitoring is completed for each property. The Department, as the permittee under the Agreement, will submit an annual report to the Service describing biological monitoring activities.

There is no additional funding for the Service to assist with implementation of the Agreement. All Service work time is in addition to other duties. The Department may be eligible for ESA Section 6 funding to assist with implementation costs. Other external funding sources that the Department may use to implement the SHA are the continuing Section 6 topminnow/pupfish project and Heritage funds.

The draft agreement and Environmental assessment were released for a 30-day public comment period that was announced in the Federal Register. We addressed public comments and made changes as necessary to the SHA. When the SHA is signed and the permit issued, we will advertise it as widely as possible. In late 2003 and April 2004, a Tucson newspaper ran articles on the potential SHA. The first article was picked up nationally in newspapers and on CNN, with a West Nile Virus and human health focus.

Conclusion

The Department's topminnow and pupfish SHA will contribute significantly to the conservation and recovery of the species. Of the five benefits we hope to achieve with the SHA: replicate populations, partnerships, nonindigenous species reduction, mosquito control, and education; education may be the greatest benefit. However, the potentially extensive use of these native fishes in the ever increasing well of human-created and managed waters should not be underestimated. Effective education has been the weakest link in the conservation efforts for these species. The media coverage and other opportunities for outreach are likely to be the most significant education to occur regarding native fishes and their plight in Arizona.

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Kleptoparasitic Behavior and Species Richness at Mt. Graham Red Squirrel Middens

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Abstract—*We used remote photography to assess the frequency of inter- and intra-specific kleptoparasitism and species richness at Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) middens. Remote cameras and conifer cones were placed at occupied and unoccupied middens, and random sites. Species richness of small mammals was higher at red squirrel middens than random sites. Abert's squirrels, potential kleptoparasites, were recorded only at unoccupied middens and random sites. Non-resident red squirrels were most common at unoccupied middens and rare at occupied middens and random sites. Inter- and intra-specific kleptoparasitism of red squirrel middens appears uncommon likely due to territorial behavior.*

Introduction

Many animals hoard food for future use. One type of food hoarding, larder hoarding, occurs when individuals store high concentrations of food at one cache site. Benefits of larder hoarding include higher probability of survival during periods of food scarcity, reduction in foraging time, and increased reproductive success. The most significant cost of larder hoarding is that individuals must vigorously defend caches against potential raiders (Vander Wall 1990).

The red squirrel (*Tamiasciurus hudsonicus*) is a small, territorial tree squirrel (~225 g) that larder hoards conifer cones and fungi in cone scale piles known as middens (Steele 1998). Middens can contain ≤ 4,300 cones (Gurnell 1984) and reach 13 m in diameter and 50 cm in depth (Patton and Vahle 1986). The conspicuous nature of middens may facilitate intra- and inter-specific kleptoparasitic behavior. Kleptoparasitism occurs when an individual takes food from another individual (Brockmann and Barnard 1979). Discarded seeds and fungi at middens (Brown 1984; Hoffmeister 1986) may also provide resources for other small mammals.

In the Pinaleño Mountains of Arizona, endangered Mt. Graham red squirrels (*T. h. grahamensis*) co-occur with an introduced population of Abert's squirrels (*Sciurus aberti*: Hutton et al. 2003). Abert's squirrels are large tree squirrels (~700 g) that eat conifer seeds and fungi, but do not cache or defend food (Hall 1981; Nash and Seamen 1977). Abert's squirrels have been implicated in the decline of Mt. Graham red squirrels through kleptoparasitism of middens (Spicer 1985). Abert's squirrels are known to take cones from red squirrel middens, but the frequency of kleptoparasitic behavior is unknown (Ferner 1974; Hutton et al. 2003). Survivorship or productivity of Mt. Graham red squirrels could be reduced if middens are kleptoparasitized.

Our study quantified the frequency of inter- and intra-specific kleptoparasitism at Mt. Graham red squirrel middens. We placed Douglas-fir (*Pseudotsuga menziesii*) cones at occupied and unoccupied middens, and random sites and used remote cameras to count potential kleptoparasitic squirrels. In addition, we examined mammalian and avian species richness at middens as an indicator of potential species associations.

Materials and Methods

We conducted our study in the Pinaleño Mountains, 25 km southwest of Safford, Graham County, Arizona. The study area encompassed 110 ha of mixed conifer forest at an elevation of 2,900 m. All Mt. Graham red squirrel middens were marked and examined quarterly for occupancy (Young 1995). Live trapping was conducted regularly on the study area. Captured red and Abert's squirrels were marked with uniquely colored ear tags, and adults were radio-collared.

We selected 9 occupied middens, 7 unoccupied middens, and 7 random sites from the study area. Occupied middens were inhabited by a radio-collared red squirrel. Unoccupied middens exhibited no fresh sign of occupancy (fresh feeding and digging), but still had a well-intact midden structure. Random sites were in forested areas between 50-100 m from middens.

During September-November 2002, we placed 10 Douglas-fir cones on a platform of aged plywood at each site. Remote cameras (15 Trailmaster passive infrared monitors (TM 550) and 3 Trailmaster active infrared monitors (TM 1550) equipped with cameras (TM 35-1, Trailmaster, Lenexa, KS) and 5 deercams (DC-100, Deercam, Park Falls, WI)) were used to photograph animals entering sites. Sites were checked ≥ 2 times a day for 4 d after cone placement. From 5 d to the end of trial, sites were checked once a day until all cones were removed or at least 10 days had past (Mean = 11.2 ± 0.4 days). The sites did not differ in the number of days monitored (1-way ANOVA, $F_{2,20}$ = 1.80, P = 0.191). We examined photographs to determine identity of squirrels and recorded the number of uniquely marked Abert's or red squirrel at each site. Unmarked squirrels were counted only once per site. Resident red squirrels were not included in the count at occupied middens. Species richness was measured by tallying the number of mammalian and avian species photographed at each site. We calculated 4 types of species richness: total (all birds and mammals excluding Abert's and red squirrels), small mammal (*Peromyscus maniculatus*, *Tamias dorsalis*, and *Neotoma mexicana*), large mammal (all other mammals), and avian. We identified mammals using Kays and Wilson (2002) and birds using Sibley (2000). All count data were square root transformed to better meet the assumptions of parametric tests; however, means (± *SE*) presented are from untransformed values.

Results

Kleptoparasitism

Abert's squirrels were photographed twice at random sites, once at unoccupied middens, and never at occupied middens yielding no differences among sites (table 1: 1-way ANOVA, $F_{2,20} = 1.41$, $P = 0.267$). Red squirrels were observed at all sites in differential numbers (table 1: 1-way ANOVA, $F_{2,20} = 7.60$, $P = 0.004$). More red squirrels were photographed at unoccupied middens than at occupied middens (Tukey-Kramer, $P < 0.05$) and random sites (Tukey-Kramer, $P < 0.05$). No difference existed between occupied middens and random sites in observed number of red squirrels (Tukey-Kramer, $P > 0.05$).

Species Richness

Excluding red and Abert's squirrels, 8 mammalian and 2 avian species were observed at all sites combined (appendix 1). Large mammal and avian species richness were the same between sites (table 2: 1-way ANOVA, $F_{2,20} < 3.00$, $P > 0.100$). Species richness of small mammals differed among sites (table 2: 1-way ANOVA, $F_{2,20} = 4.93$, $P = 0.018$). Small mammal species richness was less at random sites than occupied (Tukey-Kramer, $P < 0.05$) and unoccupied middens (Tukey-Kramer, $P < 0.05$). No difference existed between occupied and unoccupied middens in small mammal species richness (Tukey-Kramer, $P > 0.05$). Total species richness differed among sites (table 2: 1-way ANOVA, $F_{2,20} = 4.43$, $P = 0.026$). Total species richness was higher at occupied middens than at random sites (Tukey-Kramer, $P < 0.05$). No difference was observed in total species richness between occupied and unoccupied middens (Tukey-Kramer, $P > 0.05$) and random sites and unoccupied middens (Tukey-Kramer, $P > 0.05$).

Table 1—Mean number (± SE) of Abert's squirrels and non-resident red squirrels observed at middens and random sites.

Sites	n	Abert's squirrels	Red squirrels
Occupied middens	9	0.0 ± 0.1	0.3 ± 0.2
Unoccupied middens	7	0.3 ± 0.1	1.6 ± 0.2
Random sites	7	0.1 ± 0.1	0.6 ± 0.2

Discussion

Abert's squirrels do not appear to frequently kleptoparasitize cones from Mt. Graham red squirrel middens; however, we cannot conclusively state that kleptoparasitic behavior is uncommon due to the small sample sizes and short duration of this study. We detected Abert's squirrels twice at random sites, once at an unoccupied midden, and never at an occupied midden. In addition, only 5 observations of Abert's squirrels kleptoparasitizing Mt. Graham red squirrel middens were recorded during 41,000 field hours on our study area (Hutton et al. 2003). Territorial behavior of red squirrels (Gurnell 1984) may prevent Abert's squirrels from successfully raiding middens. Out of 75 agnostic interactions observed between these two species on our study area, red squirrels were the dominant aggressor 98.7% of the time (Hutton et. al. 2003). If red squirrels are successfully defending middens against Abert's squirrel incursions, detrimental effects can still occur. Increased territorial defense could lead to energetic costs, decreased foraging time, and increased exposure to predators. Further research is needed to determine the potential effects of introduced Abert's squirrels on the survival of Mt. Graham red squirrels.

Kleptoparasitism of red squirrel middens by Abert's squirrels is not unique to the Pinaleño Mountains and has been noted in Colorado (Ferner 1974) and northern Arizona (Hall 1981). Other known inter-specific kleptoparasites of red squirrels include Clark's nutcrackers (*Nucifragas columbiana*: Bent 1946), black bears (*Ursus americanus*: Kendall 1983), and grizzly bears (*Ursus arctos horribilis*: Mattson and Reinhart 1997). Of these species, only black bears occur in the Pinaleño Mountains (Hoffmeister 1986; Sibley 2000).

Intra-specific kleptoparasitism of occupied Mt. Graham red squirrel middens appears to be an infrequent behavior. Non-resident red squirrels were detected in low numbers at occupied middens and random sites. Territorial behavior likely reduces the number of red squirrels entering an occupied midden area. Territories center around middens and are circular in shape. Red squirrels use calls to maintain territorial boundaries between neighbors and will aggressively chase intruders (Gurnell 1984; Steele 1998). The low numbers of red squirrels at random sites were probably due to the lack of a midden and associated structure. Without visual and olfactory cues associated with middens, red squirrels may have had difficulty locating cones at random sites. The highest numbers of red squirrels were photographed at unoccupied middens. Unoccupied middens have a conspicuous structure (Patton and Vahle 1986) and probably olfactory cues that attract red squirrels. Furthermore, there is no aggressive resident to drive away red squirrels raiding unoccupied middens.

Occupied and unoccupied middens had similar small mammal species richness that was higher than species richness at random sites. Total species richness was highest at occupied middens and lowest at random sites. Red squirrel middens may offer important resources such as food and shelter for small mammals. Middens contain large numbers of cached cones (Gurnell 1984) and small amounts of dried fungi (Hoffmeister 1986). In addition, red squirrels strip conifer cones at middens (Brown 1984) and some seeds likely fall to the ground

Table 2—Mean species richness (± SE) at Mt. Graham red squirrel middens and random sites.

Species richness	Occupied middens (n = 9)	Unoccupied middens (n = 7)	Random sites (n = 7)
Small mammal	1.4 ± 0.3	1.1 ± 0.3	0.1 ± 0.3
Large mammal	0.7 ± 0.2	0.0 ± 0.2	0.3 ± 0.2
Avian	0.3 ± 0.2	0.6 ± 0.2	0.1 ± 0.2
Total	2.4 ± 0.4	1.7 ± 0.5	0.6 ± 0.5

uneaten. Food resources at middens could attract granivorous and mycophagous deermice, cliff chipmunks, and Mexican woodrats (Hoffmeister 1986). Red squirrel middens may also provide valuable nest sites for small mammals. Mexican woodrats build nests at Mt. Graham red squirrel middens (A. J. Edelman, personal observation). Predators such as the gray fox (*Urocyon cinereoargenteus*), spotted skunk (*Mephitis mephitis*), and striped skunk (*Spilogale gracilis*: Hoffmeister 1986) may be attracted to middens due to the presence and accessibility of small mammals. Martens (*Martes americana*) utilize subnivean holes created by red squirrels around middens to hunt small mammals (Sherburne 1993). The environment surrounding middens could also favor small mammals and other forest vertebrates. Mt. Graham red squirrel middens differ from random sites by having more basal area, snags, downed logs, foliage volume, and canopy cover (Smith and Mannan 1994).

By storing large quantities of high quality food in visible larder sites, Mt. Graham red squirrels may serve as a keystone species for small mammal diversity in high-elevation forests of the Pinaleño Mountains. Further research is needed to determine the exact effect of red squirrels on species diversity and abundance. Given the precarious state of the Mt. Graham red squirrel population (224 individuals, Arizona Game and Fish Department 2003), it is vital that we understand the relationship of this species with its ecosystem.

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Appendix 1.

Presence (+) or absence (–) of mammalian and avian species found at red squirrel middens and random sites in mixed conifer forest. Number in parentheses indicates number of sites where species were detected.

Species	**Occupied middens (*n* = 9)**	**Unoccupied middens (*n* = 7)**	**Random sites (*n* = 7)**
Deermouse (*Peromyscus maniculatus*)	+ (5)	+ (4)	+ (1)
Cliff chipmunk (*Tamias dorsalis*)	+ (2)	+ (1)	–
Mexican woodrat (*Neotoma mexicana*)	+ (6)	+ (3)	–
Eastern cottontail (*Sylvilagus floridanus*)	+ (2)	–	–
Striped skunk (*Mephitis mephitis*)	+ (1)	–	+ (1)
Western spotted skunk (*Spilogale gracilis*)	+ (1)	–	–
Gray fox (*Urocyon cinereoargenteus*)	+ (1)	–	–
White-tailed deer (*Odocoileus virginianus*)	+ (1)	–	+ (1)
Yellow-eyed Junco (*Junco phaeonotus*)	+ (2)	+ (3)	+ (1)
Hermit thrush (*Catharus guttatus*)	–	+ (1)	–

Vegetative Characteristics of Oak Savannas in the Southwestern United States: A Comparative Analysis With Oak Woodlands in the Region

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Abstract—*Much has been learned about the oak woodlands of the Southwestern United States in recent years. However, comparable characterizations of the companion oak savannas are needed to help in enhancing the knowledge of all oak ecosystems in the Madrean Archipelago region. Oak savannas differ from oak woodlands in that they are more open in their structure with fewer trees and, as a consequence, a higher level of herbaceous production might be expected. Species compositions and densities of tree overstories and production of herbaceous understories in representative oak savannas are presented in this paper with comparisons of these characterizations to the more densely stocked oak woodlands. Differences observed in the two oak ecosystems suggest that they should not necessarily be considered homogeneous "management units" in terms of their tree overstory characteristics or other natural resources values linked to the characteristics of tree overstories.*

Introduction

Much has been learned about the oak woodlands—also referred to as encinal woodlands, from the Spanish word *encinal* meaning wholly or mostly oak—of the Southwestern United States in recent years. Ecological, hydrologic, and environmental characterizations have been obtained through collaborative efforts involving a large number of people. This state-of-knowledge has been presented in a variety of publications and presentations (DeBano and others 1995; Ffolliott 1999, 2002; McClaran and McPherson 1999; McPherson 1992, 1997; and others). Comparable characterizations of the companion oak savannas are needed to enhance the knowledge of all of the oak ecosystems in the Madrean Archipelago region. Oak savannas differ from oak woodlands in that they are more open in their structure with fewer trees, and, as a consequence, a higher level of herbaceous production might be expected. Species compositions and densities of tree overstories, as well as production of herbaceous understories in representative oak savannas and more densely stocked oak woodlands, are presented in this paper.

Description of Study

Study Areas

Twelve small watersheds established in the oak savannas on the eastern side of the Peloncillo Mountains of southwestern New Mexico to evaluate the impacts of cool and warm season prescribed burning treatments on hydrologic and ecological characteristics of the watersheds (Gottfried and others 2000) were collectively one study area. The areal aggregation of these watersheds, called the Cascabel watersheds, is 451.3 acres. The watersheds are situated between 5,380 and 5,590 feet in elevation and the nearest long-term precipitation station indicates that annual precipitation averages 23.5 inches with nearly one-half occurring in the summer. General geological, physiological, and vegetative characteristics of the Cascabel watersheds have been described by Gottfried and others (2000) and, therefore, will not be presented here.

The study areas in the oak woodlands were located at about 5,740 feet in elevation on the southern slopes of the Huachuca Mountains along the United States-Mexico border. Average annual precipitation in the general area is 21.6 inches, again, nearly equally split between the summer and winter. Published (Touchan 1988; Gottfried and Ffolliott 2002; Ffolliott and others 2003) and unpublished inventory data from this area have been used to characterize the tree overstories and herbaceous understories in these oak woodland communities.

Study Protocol

On each of the 12 Cascabel watersheds, between 35 and 45 sample points were located along transects perpendicular to the main stream system and situated from ridge to ridge. Intervals between the sample plots varied among the watersheds depending on the size and configuration of the watershed sampled. A total of 421 sample points were located on the watersheds. Measurements of tree overstory conditions and estimates of herbaceous production were obtained on plots centered over these sample points. Species compositions and densities of the tree overstories were measured on 1/4-acre circular plots. Single-stemmed trees were measured in terms of their diameter root collar (drc) and multiple-stemmed trees in equivalent diameter root collar (edrc) following the procedures outlined by Chojnacky (1988). Densities of the trees were expressed in stems per acre. Production (standing biomass) of grasses, forbs, and shrubs in the herbaceous understories were estimated on 9.6-square-foot plots. These components of herbage production were estimated by weight-estimate procedures (Pechanec and Pickford 1937) in the spring (early growers) and fall (late growers).

Study protocols on the southern slopes of the Huachuca Mountains (Touchan 1988; Gottfried and Ffolliott 2002; Ffolliott and others 2003) were different than those on the Cascabel watersheds. Species compositions and densities of tree overstories were tallied (in separate inventories but in the same time period) on 80 1/10-acre and 23 1/4-acre circular plots randomly located circular plots. Herbage production (biomass) was estimated by weight-estimate procedures on 100 systematically located 9.6-square-foot plots in the falls of 1985 and 1986.

Results and Discussion

Tree Overstories

Tree species found on the Cascabel watersheds and the southern slope of the Huachuca Mountains are largely the same. The dominant species tallied include Emory (*Quercus emoryi*) (60.1% of all trees tallied), Arizona white (*Q. arizonica*) (11.9%), Toumey oak (*Q. toumeyi*) (4.4%), and alligator juniper (*Juniperus deppeana*) (15.3%). Minor components of the tree overstories are redberry juniper (*J. coahuilensis*) (2.0%), pinyon (*Pinus cembroides*) (5.6%), and mesquite (*Prosopis velutina*) (0.7%). Species of trees commonly observed in inventories of the oak woodlands on the southern slopes of the Huachuca Mountains were dominantly Emory (89.3%) oak with intermingling Arizona white (8.7%) oak and a few scattered alligator juniper (1.3%) and pinyon (0.7%).

Total densities of tree species tallied on the respective study sites are shown by size-classes in figure 1. The size-classes shown in this figure coincide with the categories listed by O'Brien (2002) for the woodland types of Arizona; that is, saplings (1.0 to 4.9 inches drc), medium trees (5.0 to 8.9 inches drc), and large trees (9.0 inches drc and larger). The overall test of significance for all size-classes (all trees) was evaluated at the 0.10 level. However, because the three size-classes are nested within the overall test, a Bonferroni adjustment was applied to maintain the Type I error in a test of significance for the size-classes at a 0.30 level. The densities of medium and large trees on the Cascabel watersheds were significantly less than the corresponding densities of the tree overstories in the southern slopes of the Huachuca Mountains, while the densities of saplings on the two areas were statistically similar.

The relative variability of the spatial distributions of tree overstories on the Cascabel watersheds (coefficient of variation = 7.98) is greater than that observed for the trees tallied on the southern slopes of the Huachuca Mountains (coefficient

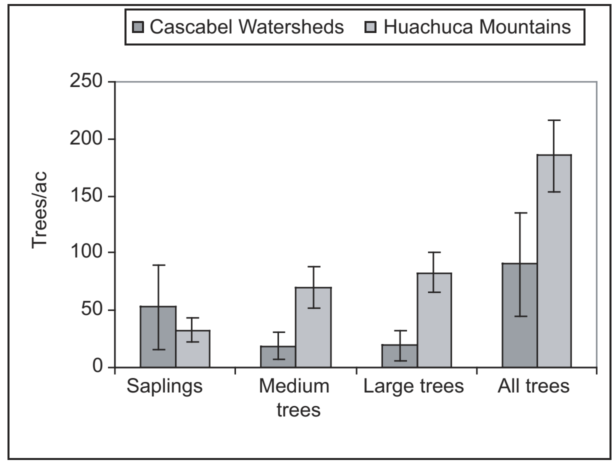

Figure 1—Average densities and 90% confidence intervals of tree overstories in the oak savannas on the Cascabel watersheds and the oak woodlands on the southern slopes of the Huachuca Mountains.

of variation = 1.08), suggesting more heterogenous stocking conditions in the oak savannas than in the oak woodlands. (This possibility must be "conditioned" by the fact that there were different sample designs and sampling intensities on the two study sites.) Openings of varying size, shape, and orientation interspersed among the tree overstories throughout the oak savannas on the Cascabel watersheds are less common in the oak woodlands on the southern slopes of the Huachuca Mountains in the oak woodlands.

Herbaceous Understories

Herbaceous species observed on the Cascabel watersheds and the southern slopes of the Huachuca Mountains (Gottfried and Ffolliott 2002) are largely similar. Included among the more commonly encountered grasses are blue (*Bouteloua gracilis*), sideoats (*B. curtipendula*), slender (*B. filiformis*), and hairy (*B. hirsuta*) grama, bull muhly (*Muhlenbergia emersleyi*), wolftail (*Lycurus pheoides*), and Texas bluestem (*Schizachrium cirratum*). Forbs are a minor herbaceous component on both sites with minimal occurrences of Fendler ceanothus (*Ceanothus fendleri*) and Mexican cliffrose (*Purshia mexicana*) present. Beargrass (*Nolina microcarpa*), fairyduster (*Calliandra eriophylla*), and sotol (*Dasylirion wheeleri*) are scattered shrubs.

Spring and fall production of grasses, forbs, and shrubs on the Cascabel watersheds for the one year (2003) of estimation is presented in table 1. This was a year of below average precipitation. Total herbaceous production in the oak woodlands on the southern slopes of the Huachuca Mountains was estimated for two falls in an earlier study (Gottfried and Ffolliott 2002). Herbage production averaged 345 lbs/acre, varying from almost 400 lbs/ac in 1985, a year of nearly average summer precipitation, to 290 lbs/ac in 1986, a year of below average summer precipitation.

Fall production of herbaceous plants in the southern slopes of the Huachuca Mountains in both years of estimation was greater than the fall estimate of herbage production on the

Table 1—Means and standard errors for the production of herbaceous plants on the Cascabel watersheds for 2003.

Plant group	Spring	Fall
	---------------------lbs/ac-------------------	
Grasses	201.5 ± 7.6	147.5 ± 6.2
Forbs	4.9 ± 0.8	6.0 ± 0.9
Shrubs	26.3 ± 6.4	41.2 ± 4.2
Total	232.7 ± 14.4	194.8 ± 11.3

Cascabel watersheds in 2003. However, comparison of herbage production is problematic, because the estimates were not obtained in the same years. Variability in the amount and seasonal distribution of precipitation in the Southwestern United States limits comparison of herbage production when limited data are available; this was the case here. Estimates of herbage production need to be made for a sufficient number of similar years to adequately reflect the variability that precipitation might have on herbage production to make comparisons. Furthermore, the year that herbage production was estimated on Cascabel (2003) was the sixth year of a drought in the region, and, it is assumed, that the herbage estimates obtained reflected these conditions.

A comparison of the frequently observed relationship of increasing herbage production with decreasing tree overstories densities (Ffolliott and Clary 1982) has been made, although this comparison is tentative because of the lack of long-term herbage estimates. There was little relationship (no significant correlation) between spring or fall herbage production and tree overstory densities on the Cascabel watersheds for the year of estimate. A lack of understory-overstory in the oak woodlands of the Huachuca Mountains relationship has also been reported (Gottfried and Ffolliott 2002). It is suggested, therefore, that tree overstory densities might not be a significant factor in "controlling" the production of herbaceous plants in oak ecosystems. This possibility is strengthened by a finding that there was little relationship between annual herbage production and tree overstory densities in the Gambel oak (*Q. gambelii*) stands that were intermingled with the ponderosa pine (*Pinus ponderosa*) forests on the Beaver Creek watersheds in northern Arizona (Reynolds and others 1970).

While the dominantly oak overstories in the savannas on the Cascabel watersheds and the oak woodlands on southern slopes of the Huachuca Mountains do not appear to affect herbage production, the reverse situation might not be true. McClaran and McPherson (1999) reported that a dense perennial grass cover can limit successful Emory oak regeneration on ungrazed sites. However, further study is necessary to verify this situation.

Conclusions

This study shows that there are differences in the tree overstories characterizing the oak savannas on the Cascabel watersheds and the oak woodlands on the southern slopes of the Huachuca Mountains. Tree overstories in the oak savannas are less dense (more open) and stocking conditions appear more heterogenous than in the oak woodlands. Assuming that this finding might reflect the more general case, it is possible that these two ecosystems (which are both are found within the Upper Encinal Type (Turner and others 1003) and classified in the *Quercus emoryi/Bouteloua curtipendula* (Emory oak/sideoats grama) habitat type) should not be considered homogeneous "management units" in terms of their tree overstory characteristics or other natural resources values linked to the characteristics of tree overstories such as wildlife habitats. More extensive study is necessary to verify this possibility.

It is premature to draw conclusions about herbage production in the two oak ecosystems. Comparative differences in herbage production can only be determined by obtaining same-year estimates of herbage production in the two ecosystems for a period of time. This is long enough to reflect the precipitation variability.

Acknowledgments

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Watershed Improvement Using Prescribed Burns as a Way to Restore Aquatic Habitat for Native Fish

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Abstract*—The Nature Conservancy and Bureau of Land Management are testing a model that prescribed burns can be used to increase perennial grass cover, reduce shrubs in desert grassland, and improve watershed condition and aquatic habitat. Results of a prescribed burn in the Hot Springs Creek watershed on Muleshoe Ranch CMA demonstrated the predicted vegetation changes and watershed improvement. Since 1991, instream cover, aquatic habitat depth, and native fish density have increased in Hot Springs Creek. Our results suggest that prescribed fire is an important tool for managing grassland watersheds and restoring aquatic habitat.*

Introduction

Desert grasslands in the Southwest have undergone significant changes in vegetation composition and structure over the last 150 years. These changes include an increase in the abundance and cover of shrubs such as mesquite, acacia, and snakeweed, and a decrease in perennial grass cover and abundance, especially mid- to tall-statured cespitose bunch grasses (Bahr 1995). The causes for these vegetation changes have been the subject of some debate; still most experts agree that (1) wildfires occurred frequently in desert grasslands prior to 1870; and (2) a decrease in fine fuels caused by poorly-managed livestock grazing and fire suppression has limited the frequency and extent of fires, permitting shrubs to invade grasslands by reducing mortality on seedlings and young plants (Cable 1967; Humphrey 1958; Kaib et al. 1996; Wright and Bailey 1982).

The vegetation change in desert grasslands has had profound effects on watershed hydrological processes (Simanton et al. 1977). In grassland and other vegetation types, decreases in grass and herbaceous cover have generally been associated with increased surface runoff, decreased soil infiltration, decreased soil moisture capacity and increased soil erosion (Lusby 1970; Thurow 1991; Woolhiser et al. 1990). These hydrological changes may affect adjacent riparian areas and aquatic habitats by increasing the frequency and intensity of floods and promoting sediment deposition (USDA 1940).

Prescribed burning has been shown to reduce shrubs; however, its effect on perennial grasses are not well understood (Cable 1965; Valone and Kelt 1999; Wright 1974). Using the relationships between watershed vegetation, watershed hydrological processes, and aquatic habitat as a conceptual model, the objectives of the study were to determine: (1) whether large-scale prescribed burns followed by grazing rest reduced shrubs, increased perennial grass cover, and improved watershed condition in a degraded desert grassland; and (2) whether improvements in watershed condition resulted in improved aquatic habitat for native fish (Bureau of Land Management 1998). We present the results of research and long-term monitoring that address these objectives.

Methods

The work was conducted at the Muleshoe Ranch Cooperative Management Area (CMA), a 20,250 ha ranch owned and managed by The Nature Conservancy (TNC), Bureau of Land Management (BLM), and Forest Service. The CMA contains 7 perennial streams including Hot Springs Creek with 5 native fish species. All or most of the watersheds for these streams are contained within the CMA boundary; the dominant watershed vegetation is degraded desert grassland that has undergone the vegetation changes described above. Stream inventories conducted in the early 1990's suggested that aquatic habitat in Hot Springs Creek and its three tributary streams was in poor condition compared to better condition reference sites on the Muleshoe (BLM, unpublished data). Frequent, intense floods had removed stream bank vegetation and instream cover for native fish and soil erosion in the uplands and along stream banks had reduced the depth of aquatic habitats, limiting the availability of deep pools for Gila chub (*Gila intermedia*), a candidate for Federal listing by the U.S. Fish and Wildlife Service, and other pool specialists.

Four large-scale prescribed burns (550 to 3,000 ha in size) were conducted in May-June in the Hot Springs watershed from 1995 to 2000. We report the results of one of these burns, the 1999 Hot Springs Burn (2,700 ha). Plots (50 m x 45 m) were established in (n = 8) and adjacent to (n = 6, controls) the burn area. In each plot, the percent cover of grasses, forbs, and litter was determined using a point intercept method along 10 45-m transects; shrub cover was measured along five 45-m transects using a line-intercept method. Pre-burn vegetation measurements were made in September 1998, and post-burn measurements were made in September 2000, 16 months or two growing seasons after the burn. All analyses of percent cover data were run on transformed data, using an arcsine transformation; results were back-transformed for reporting purposes. Two-tailed probabilities were used in all significance tests, except in one case as indicated; two sample, unpaired t-tests were used in all cases unless otherwise indicated.

We collected aquatic habitat data for Hot Springs Creek in two ways. First, a 600 meter permanent transect was established in 1994. The amount of instream cover (overhanging vegetation, emergent and floating vegetation, woody debris, and undercut bank) and the dimensions (length, width, maximum depth) of sequential aquatic macrohabitats were measured along this transect. The macrohabitats were riffle, run, glide, and pool (McCain et al. 1989). The transect was re-sampled in 1999. Second, in 1991, five permanent fish monitoring transects, 100-200 meters in length, were established along Hot Springs Creek. Along each transect, we sampled native fish by seining all aquatic macrohabitats; the number of fish captured by species and age-class and the distance seined was recorded for each macrohabitat. We estimated fish density by dividing fish number by the distance seined to control for year-to-year differences in sampling effort. The fish species were longfin dace, speckled dace, desert sucker, Sonoran sucker, and Gila chub. The length, width, and maximum depth of each macrohabitat were also measured along the transect. Sampling occurred each year in October for 9 consecutive years (1991 to 1999).

Results and Discussion

There was no significant pre-burn difference in mean shrub canopy cover on burn (38.1%) and control (32.6%) plots ($t = 0.7$, 12 df, $p > 0.50$). All plots showed a decrease in shrub cover post-burn, but the reduction was significantly greater on burn plots (84%) compared with controls (16%; paired $t = 6.3$, 12 df, $p < 0.001$). Mean shrub cover was 6.4% on burn plots versus 27.4% on control plots post-burn. No pre-burn measurements of grasses and forbs were made on control plots. On burn plots, mean canopy cover of perennial grasses increased significantly post-burn (one-sample $t = 3.1$, 7 df, $p < 0.001$), and post-burn cover was significantly greater on burn plots than on controls (figure 1). However, mean perennial grass cover was lower on control plots post-burn than on burn plots pre-burn ($t = 4.7$, 12 df, $p < 0.001$). This is probably because summer rainfall on the Muleshoe Ranch CMA was above average in 1998 and below average in 2000 (18.4 cm vsersus 8.2 cm) and because annual production by perennial grasses (canopy cover) is a function of the amount of summer rainfall (Cable 1975).

Total ground cover, calculated as the sum of litter cover and canopy cover of live grasses and forbs, is a measure of a watershed's capacity to capture and retain runoff (infiltration) and prevent soil erosion (Schlesinger et al. 1990; Thurow et al. 1988). Mean total ground cover was significantly greater on burn plots than on control plots post-burn (figure 2) due to greater (twice as much) live herbaceous cover on burn plots compared to controls. Furthermore, on burn plots, ground cover was significantly greater post-burn (+ 15%) than pre-burn even with below-average summer rainfall in 2000 ($t = 3.2$, 7 df, $p < 0.014$). More specifically, litter cover on burn plots was significantly reduced post-burn, failing to recover to pre-burn levels (figure 2; $t_{litter} = 3.7$, $p < 0.01$). In contrast, live

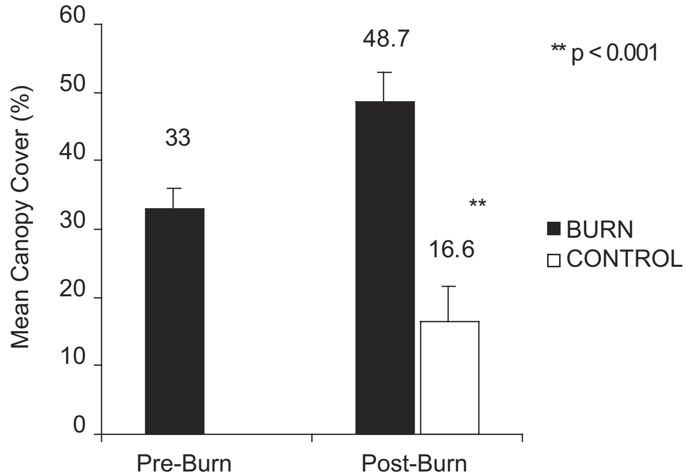

Figure 1—Mean canopy cover of perennial grasses (+ S.E.) on burn and control plots, pre- and post-burn. P-value is for the comparison of burn versus control plots post-burn (t = 6.5, 12 df).

herbaceous cover increased by over 20% post-burn, more than compensating for the loss of litter cover ($t_{live} = 4.1$, $p < 0.01$). Our results demonstrate that prescribed burning improved watershed condition after only two growing seasons in the Hot Springs watershed and mitigated the effect of below-average summer rainfall. Further increases in perennial grass cover and litter cover are expected over time as litter continues to accumulate after the prescribed burn and grass seedlings become established, taking advantage of the additional soil moisture resulting from fewer shrubs. The 1995 and 1998 prescribed burns (560 ha and 2,100 ha, respectively) had similar effects to the Hot Springs Burn: shrub cover was reduced and perennial grass cover and total ground cover increased post burn. There was a lack of controls for the 1998 burn, but the changes on burn plots were consistent in magnitude and direction with those for burns with controls (1995, 1999). No monitoring was implemented for the 2000 burn.

What effect has the improved watershed condition had on aquatic habitat and native fish populations in Hot Springs Creek? Between 1994 and 1999, total instream cover along the permanent transect established in 1994 increased by 3.7 times due to increases in cover by emergent, floating, and overhanging vegetation; the amount of undercut bank also increased (table 1). The maximum depth of aquatic macrohabitats also increased significantly (ANOVA, $F_{[1,75]} = p < 0.05$, one-tail); run habitat showed the greatest proportionate increase (+ 28%) and glide habitat the least change (+ 3%).

Improvements in aquatic habitat also occurred along the five permanent fish transects between 1991 and 1999. Undercut bank increased from 0 m in 1995, when this cover measurement was initiated, to 46.1 m/500 m of stream in 1999. The number of pools per km varied from year-to-year with no directional trend evident for the 9-year period ($R^2 = 0.17$, 7 df, $p > 0.20$). However, the mean maximum depth of pools increased significantly between 1991 and 1999 ($R^2 = 0.54$, $p < 0.03$, mean annual increase = 1 cm/year) as did the number of deep pools per km, defined as pools with a maximum depth greater than

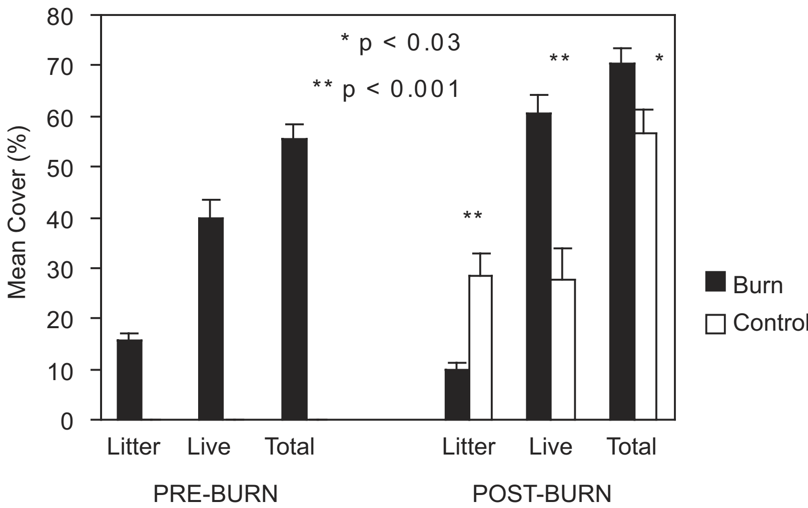

Figure 2—Mean total ground cover, calculated as the sum of litter cover and live herbaceous canopy cover, on burn and control plots, pre- and post-burn. P-values are for comparisons of burn versus control plots post-burn (t_{total} = 2.7, t_{litter} = 5.3, t_{live} = 4.6, 12 df).

0.6 meters ($R^2 = 0.70$, $p < 0.01$, mean annual increase = 0.9 deep pools/km/year). Stream flows in winter (January) and during the summer dry period (April-June) decreased significantly between 1991 and 1999 (all R^2's > 0.69, 7 df, all p's < 0.01) most likely in response to below-average winter and summer rainfall that occurred regionally during the 1990s. Therefore, the increase in the depth of pools and other habitats between 1991 and 1999 was not due to increasing stream flow over this period but more likely resulted from a structural change in the stream channel.

Native fish have responded positively to improved watershed and aquatic habitat conditions. The number of Gila chub captured per year increased significantly between 1991 and 1999 (figure 3); this increase corresponds to an average population growth rate of 45% per year. Similarly, the density of native fish adults increased significantly between 1991 and 1999 at an average annual rate of 5.6% (figure 4). These increases are even more important given the declining stream flows in Hot Springs Creek over the 9-year period. Stream flows also declined between 1991 and 1999 in nearby Sonoita Creek on TNC's Patagonia-Sonoita Creek Preserve, an unburned site, and there was a significant decline in the density of native fish over the 9-year period ($R^2 = 0.24$, 45 df, $p < 0.001$)

Although our results have focused on the effect of prescribed burns on watershed vegetation, excluding livestock from Hot Springs, may also have contributed to the observed improvements in aquatic habitat and native fish populations (Belsky et al. 1999). Grazing rest was initiated at the Muleshoe in 1984, and aquatic habitat recovery may be rapid following the removal of livestock (Ohmart 1996). However, this study was not designed to disentangle the effects of grazing rest in the uplands and in riparian areas from the effects of prescribed burning. Nonetheless, our results suggest that prescribed burning, in conjunction with grazing rest, improved watershed condition in a degraded semi-desert grassland resulting in improvements in aquatic habitat and native fish populations. We recommend that these management tools be applied to other sites in the Southwest where watershed or range improvement is an issue.

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Table 1—Changes in instream cover along a permanent transect, 600 m in length, in Hot Springs Creek between 1994 and 1999.

		Instream cover type (m^2 /500 m stream)			
Year	**Undercut bank (m/500 m stream)**	**Overhanging vegetation**	**Emergent and floating**	**Woody debris**	**Total cover[a]**
1994	7.7	2.8	0	7.6	10.4
1999	20.1	34.6	1.7	2.4	38.7

[a] Sum of vegetation and woody debris cover, but not undercut bank.

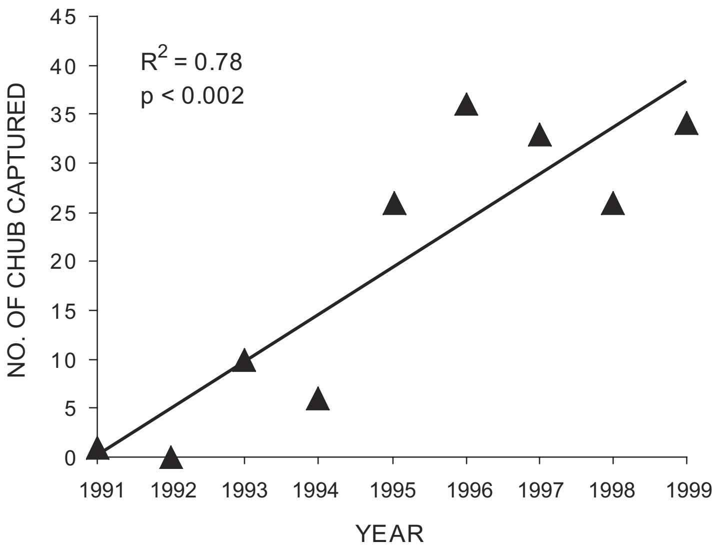

Figure 3—The number of chub captured in Hot Springs Creek from 1991 to 1999.

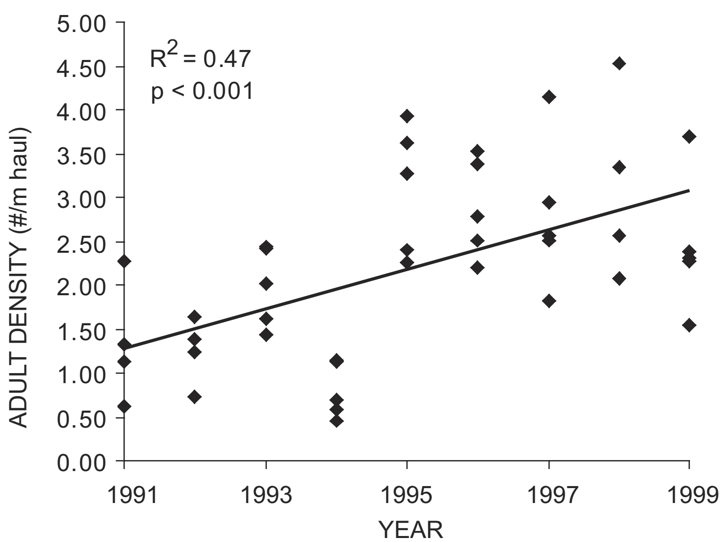

Figure 4—Density of adult native fish in Hot Springs Creek from 1991 to 1999.

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Effects of the Chytrid Fungus on the Tarahumara Frog (*Rana tarahumarae*) in Arizona and Sonora, Mexico

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Abstract—*We conducted histological analyses on museum specimens collected 1975-1999 from 10 sites in Arizona and Sonora to test for the pathogenic chytrid fungus (*Batrachochytrium dendrobatidis*) in ranid frogs, focusing on the Tarahumara frog (*Rana tarahumarae*). During 1981-2000, frogs displaying disease signs were found in the field, and all of these we tested were infected with the chytrid pathogen. Population monitoring results at localities with the infection ranged from apparent disappearance, to decline and recovery, and, in some cases, apparent stability. One population was infected over a 17-year period without apparent population decline. Our results suggest that stress, notably cold, and possibly pollution, may influence disease severity. The presence of chytridiomycosis in Sonora was confirmed for* R. tarahumarae *(1982-1999)* R. yavapaiensis *(1999),* R. magnaocularis *(1985, 1999), and* R. pustulosa *(1985).*

Introduction

A chytrid fungus, *Batrachochytrium dendrobatidis*, has been linked to recent anuran population declines in Australia, tropical America, North America, Europe, and Africa. Berger and Speare (1998) discussed clinical signs of the disease it causes (chytridiomycosis), which include lethargy, ventral reddening, convulsions with hind limb extension, accumulation of sloughed skin on the body, and occasional ulcers, with death usually occurring a few days after the onset of disease signs. Chytridiomycosis is known in several anurans and one salamander species in Arizona (Collins et al. 2003; Bradley et al. 2000; Sredl and Caldwell 2000; Sredl 2000), and may have been a factor in the 1974-1983 extirpation of the Tarahumara frog in Arizona (Jones and Fernandez, unpublished). In this paper we review mortality episodes and declines of Tarahumara frog populations in Arizona and Sonora, and examine the relationships of these events to presence of chytrid fungus.

Materials and Methods

Both diurnal and nocturnal field searches were used to survey canyon streams for ranid frogs. Whenever possible, surveys were conducted during peak frog activity in the first few hours after dark, employing a stealthy search using headlamps. Whenever possible, diurnal surveys were also conducted. If Tarahumara frogs were not found, the deepest pools providing the most favorable habitat were often searched by hand for individuals hidden under rocks and ledges and among pool-bottom debris. Surveys usually consisted of two evening passes along the selected reach of stream followed by a diurnal re-survey of the same reach. In some cases, only a diurnal survey was feasible, and in these cases the thorough search by hand was generally employed.

Populations, even if limited to less than ten observed individuals, were considered to be "healthy" and reproductive if there were frogs of various sizes, as well as larvae, and few or no dead frogs were found. A population decline is assumed in this report for cases with significant numbers of dead or moribund frogs, when a previously "healthy" population yielded markedly fewer or no observed frogs than previously, and when the age distribution had collapsed to a single observed size/age category. A population was defined as "apparently extirpated" if ≥ 3 surveys yielded no observed individuals. Capture-recapture rates averaging 20% of the Santa Rita Mountains population, and the consistent observation of large numbers of frogs during multiple surveys in the 1970s suggest the reliability of survey results for this species. Tarahumara frogs live in a less concealing environment than some other ranid frogs, and therefore tend to yield more consistent survey results. Thus, we place considerable weight on our negative as well as positive survey results.

In 1999–2004 we selected specimens from the University of Arizona Herpetology Collection for histological examination at University's Veterinary Diagnostic Laboratory as described in Bradley et al. (2002). Our focus was on Sonoran frogs collected from 1981 to 1999 from populations where a decline had been observed or where frogs showed disease signs. Additional specimens from localities with no disease signs were randomly selected to test for the chytrid pathogen for comparison to the carefully chosen disease sample.

Population Trends and Chytrid Disease Observations in Arizona and Sonora

In this section, we describe the recent history of ranid frog declines and survey observations in Arizona and Sonora at Tarahumara frog localities. Observations are summarized in table 1 and fig. 1, and locality numbers are given in parentheses in text to assist the reader with time-lines and geography.

The first evidence of ranid frog decline in Arizona was on April 7, 1974, when C. J. May and D. Frost independently observed numerous dead and moribund Tarahumara and lowland leopard frogs (*R. yavapaiensis*) in Sycamore Canyon (2), Santa Cruz County. Leopard frogs and Tarahumara frogs tested positive for the chytrid pathogen (Jones and Fernandez, unpublished), and intensive searches demonstrate the species is extirpated. Chytridiomycosis is the likely cause of extirpation in this case. Lowland and Chiricahua (*R. chiricahuensis*) leopard frogs have persisted in the Pajarito Mountains, but have remained generally uncommon, with repeated mortality events and confirmed chytridiomycosis in the Chiricahua leopard frog in Sycamore Canyon (unpublished data).

Tarahumara frogs found in the Santa Rita Mountains (1), Santa Cruz County (Hale et al. 1977), were studied by mark-recapture beginning in 1975. On June 4, 1977, several frogs kept overnight in a bag died overnight, and others appeared lethargic. Although hands-off methods were adopted, all of the estimated 600-1,000 frogs had vanished from the core study area by 1978. Larvae remained, and metamorphosed through summer 1979; but no recruitment was observed; the last frog was found dead in May 1983; and none have been seen in the wild in Arizona since then (see Hale et al. 1995). Chiricahua leopard frogs also disappeared from Big Casa Blanca Canyon (1), although they persisted in small numbers in nearby Gardner Canyon.

Thus, in the space of 10 years, the Tarahumara frog, which had been present in at least two substantial populations in

Table 1—Summary of Chytrid analyses and history of Tarahumara frog status at selected localities in Arizona and Sonora. Annotations refer to Tarahumara frog unless specified. Code legend: (+ -) = positive or negative results of chytrid analysis for frog(s) collected for indicated year. Year = healthy population observed. **Year** = population decline observed. *Year* = Tarahumara frogs no longer observed. Species abbreviations: RATA = *Rana tarahumarae*; RAMA = *R. magnaocularis*; RAYA = *Rana yavapaiensis*.

Locality	Observation years	Annotations
1. Big Casa Blanca Cyn, Santa Rita Mts., Arizona	1975-6(-), **77,** 78-82, *83-present*	Abundant into 1977. Disease signs 1977. Decline to extirpation 1977-83.
2. Sycamore Canyon, Pajarito Mts., Arizona	1934-73, **74(+),** *75-present*	Abundant into 1974. Disease signs 1974. Disappeared abruptly.
3. A. El Chorro, Sierra La Madera, Sonora	2000(-)	Small apparently healthy population.
4. A. El Pulpito, Sierra San Luis, Sonora	2000(-)	One RAYA, one RATA tested negative.
5a. A. La Carabina (lower), Sierra El Tigre, Sonora	**1981, 82, 84, 86,** *98*	Disease signs 1981. Few frogs, some larvae 1982-86.
5b. A. La Carabina (middle), Sierra El Tigre, Sonora	**1982(+), 84, 86**	Decline apparent 1982. Disease signs 1982-86. Few frogs seen 1984, 1986.
5c. A. La Carabina (upper), Sierra El Tigre, Sonora	1982-83	Abundant with no evidence of disease.
6. A. El Tigre, Sierra El Tigre, Sonora	1981, 82-3(-), 86, 98, 99(+)	Abundant all visits. Possible disease signs 1986. Definite signs 1999.
7. A. La Sauceda, S. Oposura, Sonora	1981-82, 85-86, *98*	Possible extirpation from drought.
8. A. El Vaso, S. Huachinera, Sonora	1974, *85*	Habitat favorable. Ranids absent 1985.
9. A. La Colonia, Sierra El Rubi, Sonora	**1982(+),** *85,* 99(-)	Single dead RATA 1982. Healthy RATA, RAYA 1999.
10. A. Pinos Altos, Sierra El Rubi, Sonora	1975, *82, 85, 99*	Ranids absent 1980s. Only RAYA present 1999.
11a. A. Los Lavadaros, 11b. Cajon El Infierno, S. Aconchi, Sonora	1980, 82(-), 85, 98, 99	11a. Small numbers of frogs all visits. 11b. RATA absent 1998.
12. Canada El Zoquetal, Sierra Aconchi, Sonora	2000(-)	Apparently healthy population.
13. A. Las Uvalamitas, Sierra El Datil, Sonora	1983, 85, 89, *99*	Marginal habitat, possible extirpation from drought. RAMA present in 1999.
14a. A. El Aguaje, 14b.A. El Trigo, Rancho Trigo, Sonora	1968, 75(-), 82(+), 85, 99(+)	RATA, RAMA always abundant. Symptoms in captured frogs 1986, 99.
15. A. El Potrero, Sierra Milpillas, Sonora	1985, *99*	RATA, RAMA frogs 1985. Only RAMA present in 1999.
16. A. El Cobre, S. El Rincon, Sonora	1982-84, 85(+), 86, 93, *99*	Ranids abundant all visits. Symptoms in captured RATA, RAPU, RAMA 1985. RATA absent 1999.

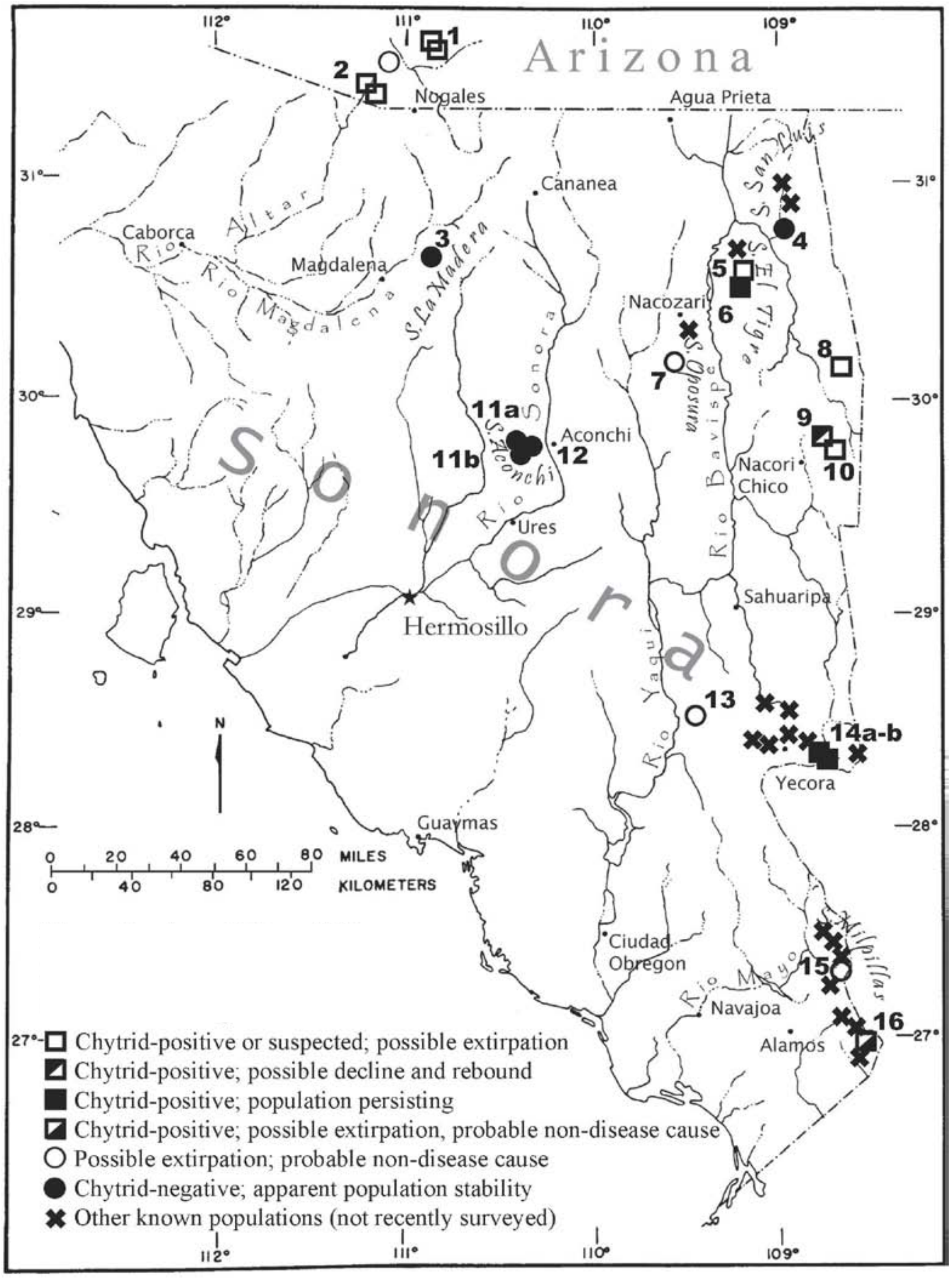

Figure1—Association of disease evidence with observed status of the Tarahumara frog in Arizona and Sonora.

Arizona, was completely extirpated during massive, rapid population-level mortality episodes. In the closely observed Santa Rita population, the primary event apparently occurred over a single winter, and within 6 years the population was extirpated. The symptoms observed indicate that disease, probably chytridiomycosis, was associated with this decline, although specimens were not tested.

In fall 1981, we observed a catastrophic die-off at Arroyo La Carabina, Sierra El Tigre (5a), in northern Sonora. From late October to mid-November, moribund frogs increased from 42% to 94% in observed samples totaling (approximately) 50 and 60 frogs, respectively. Symptoms often exacerbated by capture and handling, included ataxia (incoordination), fixed mydriasis (enlarged fixed pupils unresponsive to light), loss of the righting response, complete loss of responsiveness, extension of the limbs into a splayed-out position, and death, consistent with chytridiomycosis (Berger et al. 1998; Berger and Speare 1998; Pessier et al. 1999). An initial hypothesis was that this mortality stemmed from heavy metal poisoning (Hale et al. 1995), although it now appears more likely that chytridiomycosis was the cause. As seen in the Santa Rita Mountains decline, occasional frogs were observed in 1982 and 1984, and larvae through 1986. Frogs 5 km higher in the drainage (5b) exhibited disease symptoms, tested chytrid-positive, and declined; but they were not extirpated when last visited in 1986. Five km farther upstream in the upper reaches of the canyon (5c), frogs were abundant and displayed no symptoms when last visited in 1982-1983. Since 1986, only the lower reach of the canyon has been surveyed (in 1998) and no frogs were found.

In marked contrast, Tarahumara frogs surveyed in Arroyo El Tigre (6), also in Sierra El Tigre, in 1981-1983, 1986, spring 1998 and fall 1999, remained consistently abundant, although chytridiomycosis has probably been present since at least 1986. No frogs have been found dead in the stream, but in spring 1986 a Tarahumara frog was found with fixed mydriasis, and a red-spotted toad (*Bufo punctatus*) was underweight, lethargic, and displayed fixed mydriasis and locomotor impairment. Three Tarahumara frogs collected in 1999 for captive propagation quickly displayed disease symptoms, and they, plus a lowland leopard frog from the same sample, tested chytrid-positive. In this and the following case, populations persisted without apparent decline despite evidence of disease.

Near Yecora, in east-central Sonora, a Tarahumara frog collected at Rancho El Trigo (14a and 14b) in fall 1982 showed a mild chytrid infection. In 1985, several captive individuals exhibited disease symptoms, and some died. In fall 1999, captive frogs displayed disease symptoms or died overnight in a bag; of these, 3 of 4 Tarahumara and 3 of 5 leopard frogs (cf. *R. magnaocularis*) showed mild to moderate chytrid infection. Despite this evidence of a chytrid infection from 1982-1999, surveys have always found healthy populations of both species.

At another site in northeastern Sonora, Arroyo La Colonia (9), a single dead Tarahumara frog collected in fall 1982 was severely infected with the chytrid fungus. No ranids were observed there in summer 1985, but in fall 1999, reproductive populations of both Tarahumara and lowland leopard frogs were found, and a tested Tarahumara frog was chytrid negative. We believe this population declined or was extirpated, but rebounded or was recolonized, over a period of 17 years.

At two nearby localities, Tarahumara frogs may have declined due to disease, although we can only infer this as a plausible explanation. Tarahumara frogs were found at Arroyo El Vaso (8) in 1974, but not in 1985. Similarly, at Arroyo Pinos Altos (10), Tarahumara frogs were collected in 1969, but were not found in 1982 or 1985, and only a single lowland leopard frog was seen in 1999. Both these localities have apparently suitable habitat, and are close to Arroyo La Colonia (discussed above), where frogs were similarly absent in the 1985 survey, but where chytridiomycosis was confirmed for 1982. In the absence of other plausible explanations, we attribute apparent declines at localities (8) and (10) to disease as a reasonable hypothesis.

In southern Sonora, we infer non-chytrid-related causes for apparent population declines. At Arroyo El Cobre, Rancho Choquincahui (16), we studied the Tarahumara frog and sympatric ranids—Rana de Cascada (*R. pustulosa*), and big-eyed leopard frog (*R. magnaocularis*)—from 1982-1986. In fall 1985, 7 of 21 frogs held overnight showed symptoms ranging from lethargy to death. Histology confirmed chytrid infections in 3 of 5 specimens, one of each species. Tarahumara frogs remained abundant in fall 1993, but were not found in 1999 or 2002, while Rana de Cascada and big-eyed leopard frogs remained abundant through 2002 (J. Rorabaugh and M. Sredl, personal communication). During 11 visits to Arroyo El Cobre and multiple surveys between 1982 and 1999, dead frogs were occasionally found, but no large declines were observed. We suspect that anthropogenic habitat changes (forest replacement by exotic buffel grass [*Pennisetum ciliare*], with associated stream sedimentation) allowed Rana de Cascada to replace Tarahumara frogs (Hale, unpublished). Ranid frogs have persisted despite a long record of chytrid infection, and we have no reason to assume that disease was involved in the disappearance of the Tarahumara frog.

There are other instances for which we suspect that declines were unrelated to disease. Arroyo La Sauceda (7) and A. Las Uvalamitas (13) supported Tarahumara frog populations during 1981-1989, but in both cases only leopard frogs were found in 1998-1999. These streams had marginal habitat and Tarahumara frogs probably declined due to drought conditions (unpublished observations) in the 1990s. In another instance, Tarahumara frogs were present in Arroyo El Potrero (15) in 1985, but only big-eyed leopard frogs were found in 1999. Apparent increase of a native predatory fish (*Gila* sp.) was coincident with this change, and additional field observations (Hale, unpublished) suggest that this leopard frog may co-exist with such fish more readily than the Tarahumara frog does.

Four localities yielded chytrid-negative tests and showed no indications of population decline. Tarahumara frogs were seen in all except one survey at Arroyo Los Lavaderos (11a and b), and a 1982 specimen tested chytrid-negative. Similarly, Tarahumara frogs collected in 2000 from newly discovered populations at Arroyo El Chorro (3), Arroyo El Pulpito (4), and Cañada El Zoquetal (12)—all with no evidence of decline or age structure imbalance—tested chytrid-negative.

Discussion and Conclusions

Tarahumara frog populations in Sonora responded in a variety of ways to chytrid infections (table 1), ranging from no detectable response to apparent extirpation. In Arizona, the Sierra El Tigre, and other areas in northeastern Sonora, the disease was associated with at least three (1, 2, and 5a), and perhaps two other (8 and 10) apparent extirpations, as well as one case where surveys indicated a disease-associated decline followed by a rebound. Further south, we have not confirmed an association between chytridiomycosis and population decline, although the disease was confirmed present. There appear to have been a number of extirpations related to causes other than disease.

In many instances, stress of capture and handling produced disease signs and mortality in frogs that were not noticeably sick, and other stressors including acid rain and heavy metals from copper smelters (Hale et al. 1995) could have been involved. Stress could reduce immune response (Carey et al. 1999; but see Carey et al. 2003), general health, or overall anti-pathogen competency (see Rollins-Smith et al. 2002). The association of mortality episodes with cooler seasons, high latitudes and altitudes, and areas without warm springs in leopard frogs (Sredl and Caldwell 2000; Sredl 2000; Randy Jennings, personal communications; Rosen, unpublished) and in Tarahumara frogs all point toward cold as a stress factor.

In Arizona, we recorded a February 20 water temperature of 8.6 ºC in plunge-pool habitat at Big Casa Blanca Canyon (1) and lower minima there are a certainty. In contrast, at Arroyo El Cobre (16) in southern Sonora, where ranids remain abundant despite chytridiomycosis, minima are higher (e.g., observed minimum at 13 ºC on December 29). At Arroyo El Tigre (6) and Rancho Trigo (14), frogs persist despite the disease, but they do so near springs where water emerges at a near-constant 20-22 ºC. Thus, while the virulence with which the disease affected some populations suggests this disease is novel, and its arrival has coincided with mass mortality and previously unexplained population losses in southwestern ranid frogs, mortality and population decline are not a universal result of chytrid infection. Other factors appear to modulate the impact of the pathogen, and the most apparent of these is temperature. Such modulation may play a stronger role in disease impacts than is currently demonstrable.

While our findings are cause for concern, chytridiomycosis-related declines were not confirmed in the southern portion of the Tarahumara frog's range, in the heart of the Sierra Madre Occidental. This extensive mountainous region, dissected by numerous barrancas and innumerable lesser drainages, is well suited to the Tarahumara frog. Sightings by other researchers (Tom Van Devender, George Ferguson, Phillip Jenkins, personal communication) in this region within the last decade suggest the species is still abundant and probably widespread there. In contrast, in Arizona and northern Sonora, population losses occurred in isolated pockets of favorable habitat where extirpations may not be recoverable via natural re-colonization. Thus, while we do not suggest that the Tarahumara frog is immanently threatened with extinction; many populations in the northern third to half of its range have been infected, and several have disappeared. The longer term impact of this disease, which seems to be the best explanation for the systematic decline of this unique Madrean species, remains to be seen. Disease effects may be synergistically entwined with habitat modification, pollution, and the further spread of non-native species, factors that may have contributed to these events and are likely still suppressing native ranid populations.

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A Dearth of Data on the Mammals of the Madrean Archipelago: What We Think We Know and What We Actually Do Know

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Abstract—*The Madrean Archipelago harbors one of the most diverse mammalian communities in North America. We used the Web of Science literature search tool to assess the diversity of peer-reviewed publications on mammals in Arizona and New Mexico as an indicator of publications in the region. The number of publications of all mammals was lower than expected with a mode of 0 and a median of 1. Species were not studied equally in Arizona with most measures suggesting a disproportionately large number of publications on the Order Artiodactyla and small numbers of publications on the Orders Rodentia and Chiroptera. Large mammals and those found in many Arizona counties tend to be the subject of more publications. Despite the great diversity of the region, a dearth of published data on mammalian species is evidenced within the Madrean Archipelago, especially among the Rodentia and Chiroptera.*

Introduction

The Madrean Archipelago of Southwestern United States and Northwestern Mexico is a region of incredible biodiversity (Gehlbach 1993). Recent incursions by jaguars (*Panthera onca*: Brown and Gonzales 2000) and the reintroduction of Mexican gray wolves (*Canis lupus*: Holaday 2003) further promote the image of the region as a last refuge for biodiversity. The region consists of >40 montane islands that harbor great mammalian diversity. This diversity of mammals is in part explicable by island biogeographic theory (Lomolino et al. 1989; Patterson 1995) as well as by the absence of Pleistocene glaciation (Brown and Davis 1995). As a result, southeastern Arizona possesses the greatest mammalian diversity north of Mexico (Turner et al. 1995). Herein, we use a common electronic library resource to assess our current state of knowledge on the mammals of the region by focusing on publications produced on the mammals of Arizona.

Materials and Methods

Literature Search

Data on the mammals of Arizona were gleaned from published literature sources abstracted by the Science Citation Index using the Web of Science literature search tool that covers publications from 1945 to April 15, 2004, and searches titles, key words, and abstracts terms entered into the search. For each of 138 mammalian species, we used the scientific names found in Hoffmeister (1986), Findley et al. (1975), and Kays and Wilson (2002). Our search protocol used the "Topic" search option into which we entered the following 3 combinations: scientific name, the scientific name and Arizona, and the scientific name and New Mexico. In the case of recently used synonyms, we repeated these searches with the synonyms. While these searches returned most of the research with which we were familiar, we know that some publications did not appear due to a lack of congruence between our keywords and the search engine. The relative numbers of publications and the general trends are expected to remain similar. Gray literature is not included in our review as its peer-reviewed status is unknown and the works are not generally available to the public.

Variables

We recorded total number of publications for each species as well as number of publications on each species in Arizona and New Mexico. From these data, we calculated the percentage of all publications that were conducted in Arizona. Our proxy for body size was the midpoint of body masses; female body mass was used in sexually dimorphic species (Kays and Wilson 2002). We tallied the number of counties in Arizona (maximum = 15) occupied by each species (Hoffmeister 1986). We used the range maps in Kays and Wilson (2002) to estimate the proportion of a species' range that was found in Arizona. Endemic species received a value of 100 with other values rounded downward to the nearest multiple of 10. The proportion of a species range that is found in Arizona was used as an expected proportion of publications that should be produced from Arizona.

Data Analyses

We transformed data where possible to meet the normality assumption of parametric tests; non-parametric tests were used where normality could not be approached or attained. Means $\pm$ 1 S.E. are provided throughout the text.

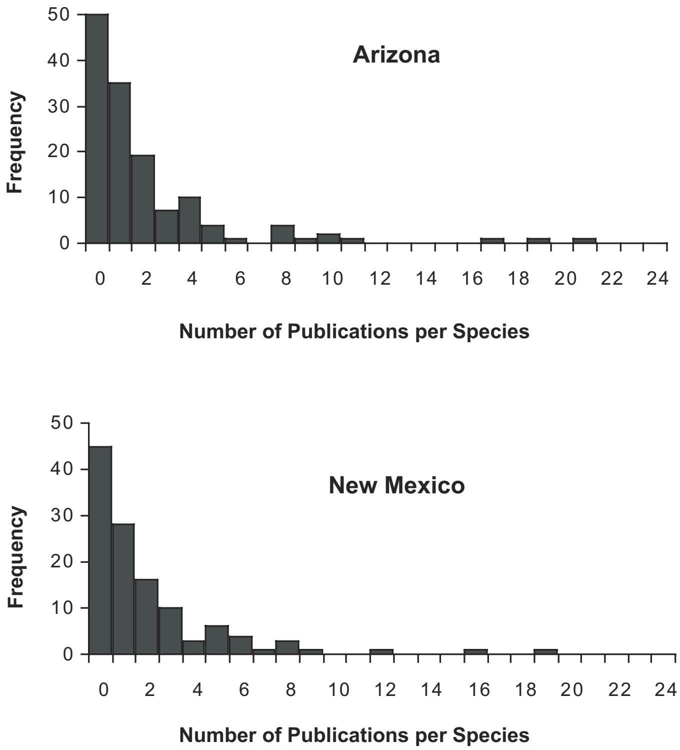

Figure 1—Frequency distribution of number of publications per mammalian species for Arizona and New Mexico.

Results

A Dearth of Data

The most common number of publications for a mammal species in Arizona and New Mexico was 0 publications (figure 1)! The median number of publications per mammal species for each State was only 1 paper. Using the percent range of a species that falls in Arizona as an indicator of the expected frequency of publications yields a similar conclusion. Publications on the mammals of Arizona average about 6.053% of the total publications across all species; this is significantly less than the estimated 10.871% of the range of each species that is found in Arizona ($t = 2.82$, $df = 233.9$, $P < 0.005$). These results collectively suggest that Arizona mammals are understudied relative to their occurrence in the State.

Is It Just Arizona?

Arizona is not alone in the Madrean Archipelago in its relative lack of studies on mammals because the mean number of publications per species for the same subset of mammals is nearly identical between New Mexico and Arizona (2.07 $\pm$ 0.28 papers, 2.09 $\pm$ 0.29 papers, respectively; $t = 0.691$, $df = 247$, $P = 0.945$). The frequency distributions of publications in the two States (figure 1) did not differ (Smirnov's $D = 0.04$, $P = 0.499$). This dearth of papers was not specific to a single taxa as no Orders differed between Arizona and New Mexico in the number of publications/species (Carnivora: $U = 283$, $P = 0.317$, Insectivora: $U = 18.5$, $P = 0.732$, Chiroptera: $U = 390.5$, $P = 0.636$, Rodentia: $U = 1{,}735$, $P = 0.115$, Lagomorpha: $U = 7.5$, $P = 0.571$, Artiodactyla: $U = 37.5$, $P = 0.107$).

Is Our Knowledge of Mammalian Species Unrelated to Taxa?

Our scant knowledge of mammals in the Madrean Archipelago does not extend equally to all Orders (1-way ANOVA: $F_{5,\ 139} = 9.847$, $P < 0.0001$). Publications on Artiodactyla are more common than all other Orders by nearly a factor of 10; other Orders averaged <2.5 publications per species and did not differ from each other (figure 2: All Tukey-Kramer post hoc comparisons $q > 7.4$, $P < 0.0001$). Similarly, an analysis of the Orders comparing data on the proportion of a species range in Arizona suggests that the Order Rodentia is most understudied in Arizona ($U = 3813.5$, $P < 0.0001$). The Orders Carnivora ($U = 262$, $P = 0.634$), Insectivora ($U = 17.5$, $P = 0.995$), Chiroptera ($U = 446$, $P = 0.406$), Lagomorpha ($U = 12$, $P = 0.984$), and Artiodactyla ($U = 12$, $P = 0.3636$) are studied about as expected based upon the percentage of the range of each species that occurs within Arizona. Within Rodentia, 3 of the 4 families with at least 5 species in Arizona were studied less than expected (Cricetidae: $U = 366.5$, $P = 0.0265$, Heteromyidae: $U = 209$, $P < 0.001$, Sciuridae: $U = 276.5$, $P = 0.0037$); only voles (Arvicolidae: $U = 17$, $P = 0.397$) were studied as expected based upon the amount of range that occurs in Arizona.

Finally, the frequency distributions across the Orders, after summing all publications within each Order, differed between "Total Publications" and "Arizona Publications" (Smirnov $D = 0.833$, $P = 0.026$) with the principal difference being a lower frequency of publications on Rodentia in Arizona (figure 3). The frequency distribution of the number of Arizona publications by Order predicted by the frequency of species within that Order in Arizona was significantly different (figure 3: $\chi^2 = 27.10$, $df = 5$, $P < 0.0001$) with the primary contributions coming from a 523.3% overabundance of publications on Artiodactyla and a 23.4% shortage of publications on Chiroptera.

What Factors Influence the Frequency of Publication?

The number of publications on a species in Arizona was not predicted by the percent of range within Arizona ($r = 0.055$, $F_{1,137} = 0.418$, $P = 0.519$). Publications were more likely to occur when a species occupied a greater number of Arizona counties ($r = 0.273$, $F_{1,137} = 10.98$, $P = 0.001$). Body size of a species was not an important predictor of the number of Arizona counties in which a species was found ($r = 0.088$, $F_{1,137} = 1.062$, $P = 0.305$); however, body size was an excellent predictor of number of publications from Arizona ($r = 0.326$, $F_{1,137} = 16.178$, $P < 0.0001$). Only body size ($t = 3.86$, $P < 0.0001$) and the number of Arizona counties occupied ($t = 3.13$, $P = 0.002$) entered a stepwise multiple regression model to predict the number of Arizona publications for a species ($R^2 = 15.4\%$; $F_{1,137} = 13.49$, $P < 0.001$: Number of Arizona Publications = 0.235 + 0.000032 Body Mass in Grams + 0.183 Number of Arizona Counties); percent area did not enter the model.

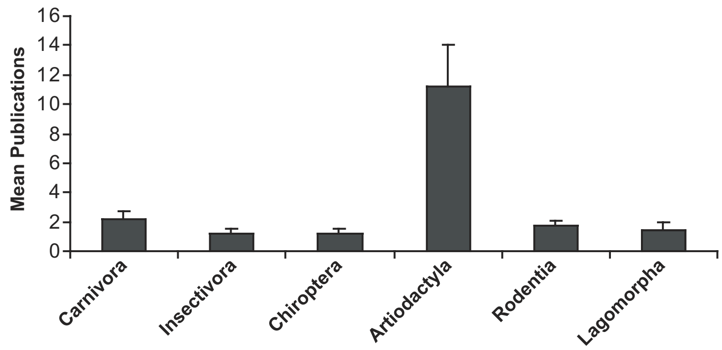

Figure 2—Mean (+ 1 S.E.) number of publications per species for each of the mammalian Orders found in Arizona.

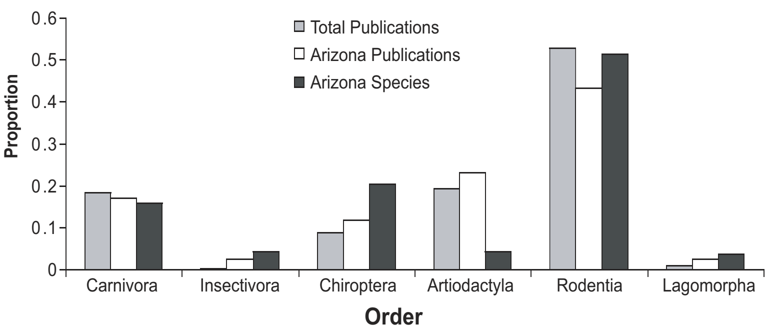

Figure 3—Proportion of total and Arizona publications as well as species for each of the mammalian orders found in Arizona.

Discussion

Our analyses suggest a "dearth of data" exists in the peer-reviewed literature despite the incredible mammalian diversity of the Madrean Archipelago (Turner et al. 1995). Some of this apparent dearth of data may be an artifact of the inability of our searches to identify papers using our literature search tool (Suarez-Almazor et al. 2000). We would not expect such biases to influence the general patterns that we found in our investigations. Papers that were missed in our search demonstrate the need for careful consideration of words when providing titles, abstracts, and keywords with submitted manuscripts. If one of the most popular and powerful search engines of scientific abstracts failed to detect a publication, the conservation value of our research is not fully realized and the funding dollars not fully maximized. Researchers that rely solely on web based searches of scientific journals are not likely to represent the majority, but these technologies continue to increase in popularity (Walters and Wilder 2003). The abundance of studies for some species and the shortage of studies for others can be influenced by a number of factors. Potential proximate causes for such divergence from expected values include the amount of funding available, proclivity of researchers to publish, legal status of the species, and the accessibility of study organisms. Rodents are among the most difficult taxa to examine due to small body size, secretive habits (subterranean, nocturnal, arboreal), and propensity to hibernate or enter torpor. After rodents, Chiroptera are the second most diverse order, comprising almost one quarter of all mammal species. In Arizona there are 28 different species of bats, due in large part to the diversity of available habitats created by the Madrean Sky Islands and surrounding arid desert seas (Hoffmeister 1986). Flight is the unique trait that distinguishes bats from all other mammals. However, flight, plus their nocturnal life style, make bats particularly difficult to study. When compared to a similar-sized terrestrial mammal, bats have larger home ranges and use flight to cross unsuitable habitat to find roosts, food, and drinking water. Bats are also unique because they are long-lived for their size and have low reproductive potential. As a result, impacts on populations can have long-term implications (Findley 1993). These characteristics of rodents and bats likely "predispose" them to a dearth of publications.

Technological limitations are also likely influential in the disproportionate publication rates. Prior to the 1990's, the study of Arizona bats was conducted primarily at roosts or where they obtain drinking water, because we could more easily capture them using either harp traps or mist nets across fly-ways. Recently, the innovation of affordable ultrasonic detectors has allowed us to understand more details of their life history and behavior (Fenton 1999). Modern technology has also provided bat and rodent researchers with small, light-weight radio transmitters that allow greater knowledge of movement patterns; however, this technology is still limited by short battery life of transmitters. In particular, Chiropteran studies are labor-intensive, often plagued by low sample size and difficult to conduct due to the nature of monitoring animals that can quickly fly across rugged terrain.

In 1990, Arizona voters passed an initiative to provide monies from State lottery revenues to wildlife and conservation efforts through the Arizona Game and Fish Department (AGFD) Heritage Program. Some of these funds have been used to study mammals throughout the State plus fund positions within AGFD. These positions were often quite progressive as in the establishment of a biologist to monitor bat research and oversee development of one of the first "Bat Conservation Strategic Plans" in the United States in recognition of the paucity of knowledge on even the most common bat species. This program has increased the volume of "gray literature," but has not yet impacted the data available to researchers through peer-reviewed journals. We can and need to do better. Often research has been conducted on mammals in Arizona that includes long-term monitoring of bat roosts, small mammal community surveys, road kill surveys, and track counts; however, these data typically are not published. We must strive to design and conduct our studies using proper scientific methodology, attempt to accurately represent the diversity of mammals in these studies, and endeavor to disseminate the resultant knowledge to scientists through peer-reviewed and abstracted outlets. Perhaps a new journal devoted to the natural history of the Madrean Archipelago is needed.

Most striking is the large number of species for which we have no peer-reviewed publications. This paucity of data occurs in one of the global evolutionary hotspots (Spector 2002) and a center of mammalian diversity (Turner et al. 1995); the conservation value of the region is clear. The

Madrean Archipelago has played a prominent role in the re-establishment of carnivores in North America due in part to its rugged and diverse topography and location that provides connectivity in the mountains of Western North America. Despite the dearth of data, the region has provided significant insights into the ecology of competition and community diversity in desert rodents (Brown et al. 2002), island biogeography (Lomolino et al. 1989), the complexities of mutualism in bats (Fleming et al. 2001), and the spread of disease such as the Sin Nombre Virus in rodents (Glass et al. 2002). The mammals of the Madrean Archipelago most certainly have much more to teach us but we must attend the lectures.

Acknowledgments

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Abundance and Food Habits of Cougars and Bobcats in the Sierra San Luis, Sonora, México

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Abstract—*Cougars (*Puma concolor*) and bobcats (*Lynx rufus*) are present throughout the Sky Islands of the Sonoran desert. We determined the abundance and food habits in northeastern Sonora, Mexico. Abundance indicated that cougars were common (4.19±5.57 cougars/100 km^2 and 0.05±0.05 scats/km). According to the scat index, bobcats were more abundant than cougars but no significant differences were found between the two ranches in the study area for both species. Cougars fed primarily on white-tailed deer (*Odocoileus virginianus*) and bobcats fed primarily on eastern cotton-tailed rabbit (*Sylvilagus floridanus*), where a small dietary overlap was estimated (0.34, Morisita index and 0.22, Pianka index). Our data help the management and conservation of this region.*

Introduction

Many carnivores have been extirpated and forced to modify their distribution as human presence increases throughout Mexico (Leopold 1977, Primack et al. 2001). Nevertheless, these carnivores are found in the most rugged, remote, and isolated areas. These species are directly linked to their herbivorous prey, directly impacting their population, and thereby altering plant production and seed dispersion (Logan and Sweanor 2001, Ripple and Beschta 2003). This web of interaction becomes rather complex as prey species are shared by multiple carnivore species (Neale and Sacks 2001). That is the case for cougars (*Puma concolor*) and bobcats (*Lynx rufus*), where they are sympatric with other species (e.g., black bears, coyotes, and eagles) at the upper levels in the food chain (Sunquist and Sunquist 1989, 2001).

Recently, anthropogenic activities (e.g., overgrazing, human population growth, and timber extraction) have modified the distribution and availability of resources to top predators, potentially reducing populations due to energy restrictions and altered spatial patterns (Primack et al. 2001, Sunquist and Sunquist 2001). In the Sierra San Luis, northeastern Sonora, livestock ranching has a long history of modifying natural conditions but in the past seven years there has been a change in the land use due to improved conservation practices. As a result, cattle were removed and consequently human impact reduced in some areas, allowing the vegetation to recover from overgrazing and soil loss.

Estimation of abundance is a useful tool for monitoring and determining management strategies of wildlife populations (Carbone et al. 2001, Wilson and Delehay 2001). Therefore we studied the populations of both bobcats and pumas on two ranches in the Sierra San Luis, El Pinito and Los Ojos, in the center of the Madrean Archipelago, with a hypothesis that the population of these predators will have different abundances according to the area, because of the diverse biotic communities at hand. Also, in places where cougars, bobcats, black bears, and coyotes coexist, there can be competition for prey affecting their abundance and distributions (Currier 1983, Maehr 1997).

Study Area

The study area encompasses the El Pinito and Los Ojos ranches, which are located in northeastern Sonora, adjacent to northwestern Chihuahua, southeastern Arizona, and southwestern New Mexico (figure 1). As part of the Sierra San Luis, they represent a combination of alpine woodlands of the Sierra Madre Occidental and some elements of the Chihuahuan and Sonoran desert of lower altitudes, as well as riparian vegetation (Brown 1994).

The El Pinito ranch is mainly covered by pine-oak forests in the highest portions of the mountains, canyons, and slopes, where we found *Abies*, *Pinus*, *Juniperus,* and *Quercus*. Chaparral and thorn scrub vegetation occur on the lower parts and plateaus with vegetation represented by *Quercus*, *Arctostaphylos*, *Juniperus*, *Opuntia*, and *Yucca*. Along the west edge of the ranch, riparian vegetation is predominant. In contrast, Los Ojos is mainly covered by chaparral and thorn scrub vegetation and with riparian vegetation in canyons where perennial rivers flow (Brown 1984).

Methods

Tracks, scrapes, and scats were recorded and collected along transects placed in the two ranches, covering 21 linear kilometers at each ranch. Scats were identified by their shape, size, and color. In the case of tracks, we used field guides (Ceballos and Miranda 1986), and for the scrapes we assumed that male cougars usually made them whereas bobcats rarely do (Shaw *et al*. 1988). In addition, we placed six cameras traps (CamTraker®) per ranch, covering as much area as possible. Both cameras and transects were surveyed approximately every three weeks between April 2003 and January 2004 with a total of nine surveys conducted.

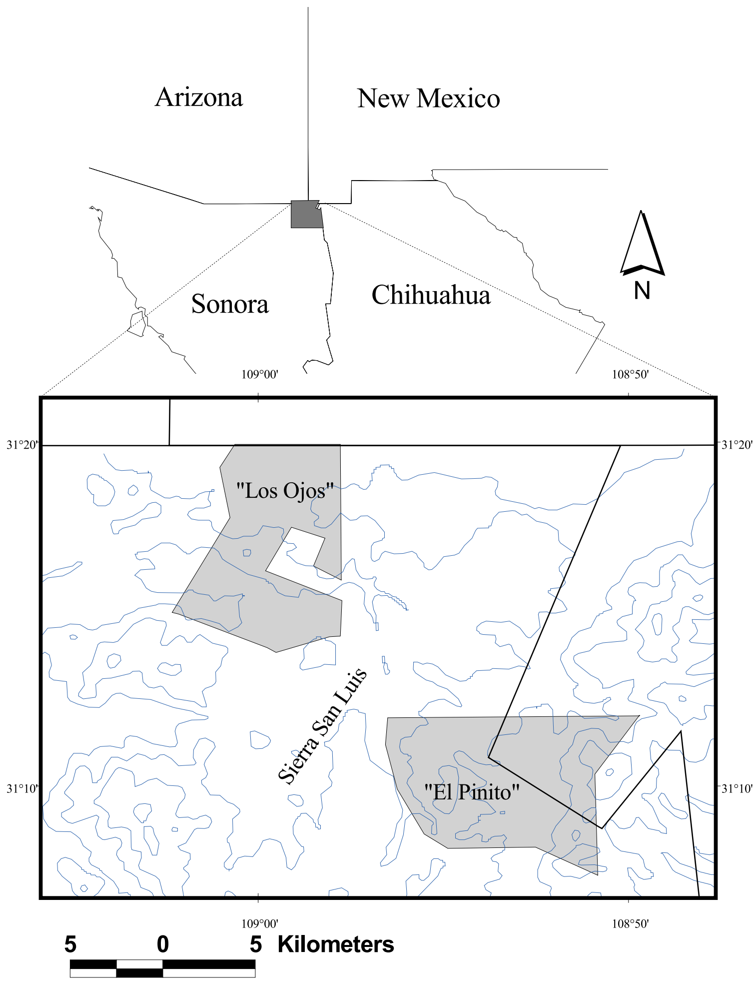

Figure 1—The "El Pinito" and "Los Ojos" ranches in the Sierra San Luis study area.

Scats were examined after being washed in nylon stockings with running water. Prey items found were identified from hair and bone fragments through identification keys (Monroy and Rubio 2003, Moore et al. 1974) and were compared with samples of hair and bones housed at the Escuela de Biología, Universidad Autónoma de Querétaro (following Ackerman et al. 1984, Fernández 2002).

Frequency of occurrence, relative frequency, and biomass consumed were calculated for each prey item (Ackerman et al. 1984, Núñez et al. 2000). Biomass calculations for cougars implied the used of a correction factor, $Y = 1.98 + 0.035 X$, where Y is the weight of prey consumed per scat and X is the estimated prey body weight (Ackerman et al. 1984). For bobcats, we used a different correction factor, $y = 16.63 + 4.09 x$, where y is the fresh weight of prey consumed (g) per g of scat produced (dry weight) and x is the estimated prey body weight (Baker et al. 2001, De Villa et al. 2002). Also the degree of dietary overlap was calculated using the indexes of Morisita (Bower 1977) and Pianka (1974).

Relative abundance was estimated as an index of scats/km and tracks/km (Shaw 1988, Wilson and Delehay 2001). Also, density was calculated with the formula $y = 140.33\, x^{-1.116}$, where y is the number of camera days until the first picture was taken and x is the estimated density in 100 km^2. This statistic was used because it does not rely on individual identity (Carbone et al. 2001). Statistical analysis between ranches and species were performed in the program Sigmastat 3.0 (Jandel Corporation®).

Results

We collected 71 scats (20 of cougars and 51 of bobcats), and registered 43 track sets (31 cougars and 12 of bobcats) and 52 cougar scrapes. We recorded 10 cougar pictures in contrast to only one bobcat picture.

Abundance

Cougar relative abundance estimation was of 0.05 ± 0.05 scats/km and 0.08 ± 0.08 tracks/km with a tendency to decrease at the end of the year. We found no significant differences between ranches for the scat index (t =-0.809, D.F=16, P=0.431) or for the tracks index (t =0.365, D.F.=16, P=0.72). Our density estimate was of 4.19 ±5.57 cougars/km^2. Bobcat abundance was 0.13 ± 0.11 scats/km and 0.03 ±0.05 tracks/km, with no difference between ranches for the scat index (T=104.5, P=0.102) and tracks index (T=82, P=0.79). The estimated density was 0.7 ± 2.1. In addition to the photographs of individual animals obtained we were able to register two different female cougars with their cubs, one of them feeding on a white-tailed deer *(Odocoileus virginianus)* (table 1).

Food Habits

Cougars fed on eight different prey species, all of them mammals (table 2). The 20 cougar scats contained 30 components, an average of 1.5 components per scat. Small mammals (<1 kg) comprised 6.67% of relative frequency and 0.74% of biomass consumed, medium-sized mammals (1-10 kg) comprised 26.66% of relative frequency and 18.2% of biomass consumed, and large mammals (>10 kg) comprised 66.67% of the relative frequency and 81% of the biomass consumed. The main prey items for cougars were four mammals with 91.76% of the consumed biomass and 80% of relative frequency: white-tailed deer, collared peccary (*Tayasu tajacu*), cattle (*Bos taurus*), and coati (*Nasua narica*), in order of importance. White-tailed deer accounted for 43.81% of biomass consumed and 36.67% of relative frequency (table 2).

Bobcats fed on 10 different prey species (table 3). The 51 bobcat scats analyzed contained 68 components of prey, with an average of 1.33 components per scat. Mammals accounted for 91.2% of the relative frequency and 93.1% of the biomass consumed. Small mammals comprised 22% of relative frequency and 16.26% of the biomass consumed, medium-sized mammals comprised 63.23% of the relative frequency and 57.43% of biomass consumed, and one large mammal, white-tailed deer, comprised 5.88% of relative frequency and 19.41% of biomass consumed. Three mammals accounted for 77.94% of the relative frequency and 82.03% of the biomass consumed: eastern cotton-tailed rabbit *(Sylvilagus floridanus),* white-tailed deer, and

Table 1—Relative abundance and density (per 100 km^2) of cougars and bobcats in the "El Pinito" and "Los Ojos" ranches of Sonora, Mexico, from July 2003 to December 2003.

	Puma concolor			*Lynx rufus*		
	"El Pinito"	"Los Ojos"	Total	"El Pinito"	"Los Ojos"	Total scats
Scats/km	0.04±0.04	0.06±0.06	0.05±0.05	0.15±0.07	0.12±0.18	0.13±0.11
Tracks/km	0.09±0.1	0.07±0.08	0.08±0.08	0.04±0.08	0.03±0.03	0.03±0.05
Density			4.19±5.57			0.7±2.1

Table 2—Relative biomass consumed by the cougars based on 20 scats collected in the "El Pinito" and "Los Ojos" ranches of Sonora, Mexico, from July 2003 to December 2003.

Prey	Frequency of occurrence	Prey weight (kg)	Correction factor	Relative biomass	Relative frequency
Sylvilagus floridanus	10	1.14	1.14	2.87	6.67
Lepus californicus	5	2.4	2.064	2.60	3.33
Mephitis sp	5	1.6	1.6	2.02	3.33
Nasua narica	20	4	2.12	10.68	13.33
Thomomys umbrinus	10	0.295	0.295	0.74	6.67
Odocoileus virginianus	55	33.79	3.16265	43.81	36.67
Bos taurus	10	100	5.48	13.80	6.67
Tayasu tajacu	35	19.5	2.6625	23.47	23.33

white-throated wood rat (*Neotoma albigula*). The cotton-tailed rabbit alone accounted for 57.35% of the relative frequency and 51.66% of the biomass consumed (table 3). A bird and a snake consumed by bobcats could not be identified and comprised 5.8% and 2.94% of the consumed biomass, respectively.

Interspecific Interactions

In both cougars and bobcats, mammals were the principal prey items, with four prey shared between them. We compared the biomass consumed using the Morisita index and the percentage of relative frequency using the Pianka index (Nuñez et al. 2000), to measure dietary overlap. The two methods indicated a low dietary overlap. The Morisita index was 0.34 (1 is complete overlap, 0 is complete separation), and the Pianka index was 0.22 (1 is complete overlap, 0 is complete separation). The skunk (*Mephitis* sp.) and the southern pocket gopher (*Thomomys umbrinus*) were consumed in low proportions by cougars and bobcats. In contrast, eastern cotton-tailed rabbit provided over half of the dietary biomass for bobcats, and white-tailed deer provided approximately half of the biomass consumed by cougars.

Discussion

Our methods used to estimate abundances of cougars and bobcats in our study sites were not consistent; whereas tracks and densities from camera traps worked for cougars, they did not for bobcats because it was more difficult for us to record bobcats indirectly through tracks and photographs. Cougar tracks are easier to spot than those of bobcats, suggesting that bobcats had a very low density compared to other regions (table 1, Lariviere and Walton 1997). Scats seem a more reliable index

Table 3—Relative biomass consumed by bobcats based on 51 scats collected in the "El Pinito" and "Los Ojos" ranches of Sonora, Mexico, from July 2003 to December 2003.

Prey	Frequency of occurrence	Prey weight (g)	Correction factor	Relative biomass	Relative frequency
Sylvilagus floridanus	76.47	1140	21.29	51.66	57.35
Mephitis sp.	7.84	1600	23.17	5.77	5.88
Thomomys umbrinus	1.96	295	17.84	1.11	1.47
Neotoma albigula	19.61	240	17.61	10.96	14.71
Chaetodipus sp.	3.92	37.5	18.16	2.09	2.94
Peromyscus sp.	1.96	34	18.02	1.04	1.47
Sigmodon	1.96	115	17.10	1.06	1.47
Odocoileus virginianus	7.84	15000	77.98	19.41	5.88
Unidentified bird	7.84	380	18.18	4.53	5.88
Unidentified snake	3.92	600	19.08	2.37	2.9

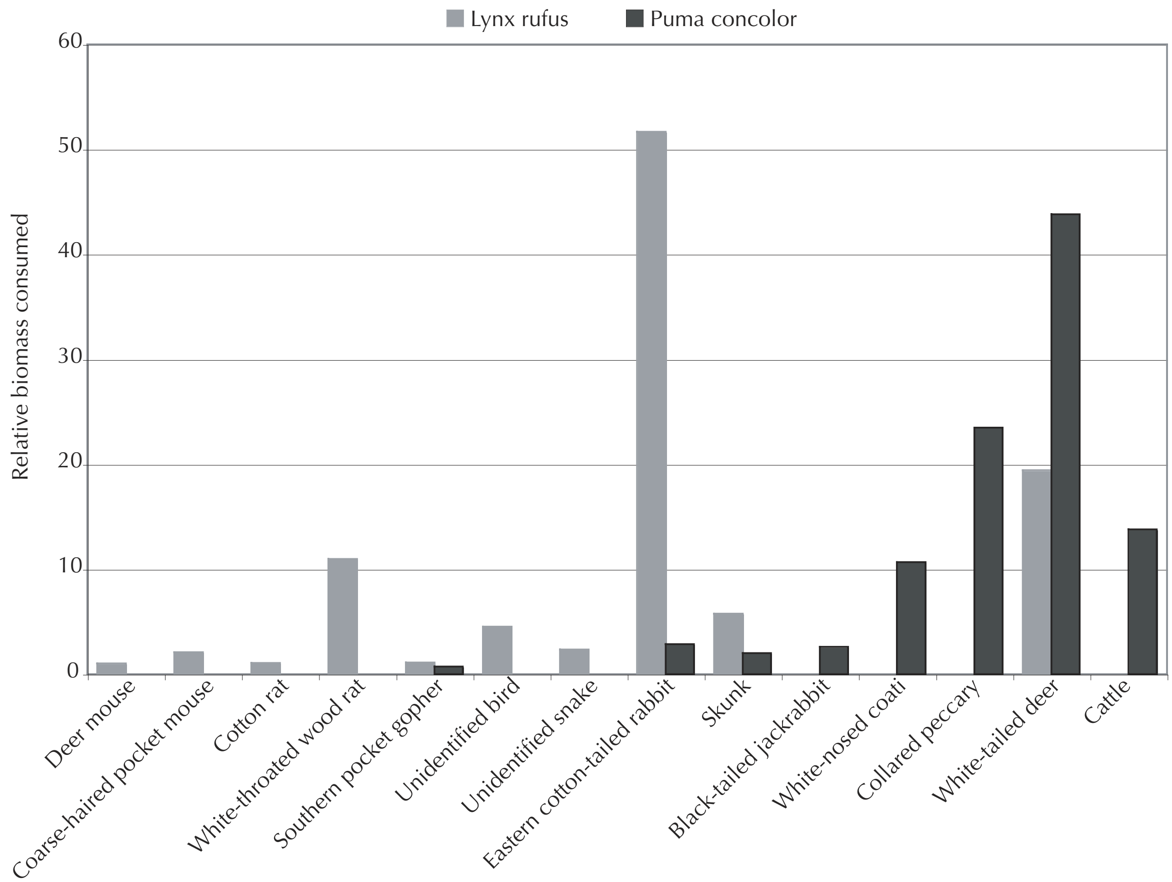

Figure 2—Relative biomass (percent of diet) consumed by cougars and bobcats in order of prey weight.

of abundance for both species (table 1). Based on scat data, there were no significance differences between the abundance of both species in the two ranches, regardless of the predominant vegetation communities. This suggested that these cats were in all vegetation types and did not prefer one over another. However, scat index of abundance (table 1) showed that cougar abundance was higher on the Los Ojos ranch whereas bobcats were more abundant on the El Pinito ranch.

Bobcats were more abundant than cougars, despite data suggesting that bobcats had relatively low abundances at the study sites. These low abundances were probably due to the effect of El Niño, which reduced populations of lagomorphs (data on file with Carlos A. Lopez Gonzalez, Universidad Autónoma de Querétaro). Estimated densities for cougars were similar to those registered for similar localities (Currier 1983, Logan and Sweanor 2001, table 1). As mentioned before, the particular year of study was very difficult for both prey and predators. Water was very scarce and some plant species did not produce fruit, resulting in a low abundance of black bears that may have allowed cougars and bobcats to occupy additional spatial resources.

The food habits showed only a small dietary overlap because cougar feed primarily on larger prey. The mean weight of cougar prey was 20.3 kg in contrast to that of bobcat prey, which was a mean weight of 1.9 kg consisting mainly of medium-sized mammals (figure 2). This difference resulted in a very low competition for prey but influenced the population dynamics of these prey for both species. White-tailed deer dominated the diet of cougars as they do in other southern regions of Mexico (Nuñez et al. 2000), but farther north the main prey seems to be the mule deer (*Odocoileus hemionus,* Currier 1983, Logan and Sweanor 2001), which is not part of the mammalian community of the study site. Bobcats fed primarily on lagomorphs as they do in most parts of North America, especially eastern cotton-tailed rabbit. Although black-tailed jackrabbits (*Lepus californicus*) are present in the area, they live in very low numbers on the ranches. Against the common belief of ranchers, neither cougars nor bobcats heavily affect cattle. The biomass consumed for both species was low, and previous studies indicate that bobcats usually consumed it as carrion (Lariviere and Walton 1997, Maehr 1997). As in other places with cattle, the best management option is to hold calves out of the cougar's range, until they are larger (136-182 kg) so they can defend themselves (Shaw et al. 1988). In neighbouring ranches, livestock killings were few, because they breed cattle so that females effectively can defend their calves, reducing predation from cougars (Personal communication, Manuel Gomez Manteca, ranch owner).

Cougars and bobcats are sensitive to anthropogenic and natural changes. Monitoring their abundance and food habits for an extended time period can give us the opportunity to evaluate the health status of populations and develop management strategies of predator populations that will find common ground between ranching activities and conservation efforts.

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Post-Fire Saguaro Community: Impacts on Associated Vegetation Still Apparent 10 Years Later

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***Abstract**—Fire impacts on saguaro (*Carnegiea gigantea*) associated vegetation were studied in unburned and burned areas over a 10 year post-fire period after the 1993 Vista View fire, Tonto National Forest, Arizona. Many associated species, crucial for saguaro survival, regenerate by vegetative growth after fire. Bushes were the most common nearest-neighbor, physiognomic, fuel group. Burned area species diversity was maintained by resprouts. Average and total cover m^2 in burned areas was less for trees, cactus, and yucca; similar for bushes; and greater for shrubs than in unburned areas. The burn site has yet to recover its tree and saguaro components.*

Introduction

Saguaro (*Carnegiea gigantea* [Engelm.] Britt. & Rose), a valuable scenic and wildlife resource, is protected in Arizona and California by law. Although saguaros rely on associated "nurse plants" for survival, they may become a liability as fuel for fire. Fire management in this desert is compounded by unpredictable weather and urban encroachment. Fires have burned and continue to re-burn across a considerable portion of mature saguaro-shrub habitat on and near the Tonto National Forest (Narog et. al. 1995, 1999; Alford 2001). Saguaro loss from fire is reported by McLaughlin and Bowers (1982), Rogers (1985, 1986), Schmid and Rogers (1988), Thomas (1991), Wright (1988), and Alford (2001), but there is little documentation on long-term associated plant species response.

The 1993 Vista View fire on the Tonto National Forest exemplifies the consequences of fuel build-up following a few wet years. Our studies track the Vista View post-fire saguaro and associated vegetation growth for a decade. We reported on post-fire initial survival, injury, and mortality of saguaro and associated vegetation (Wilson et. al. 1995), saguaro delayed mortality (Narog and Wilson 2003), and associated vegetation as fuel (Wilson et. al.1998). Long-term post-fire studies are necessary to document the impact of fire on this "slow to recover" saguaro-shrub community.

In this paper, we compare unburned and burned saguaro associated species: diversity, distribution, mortality, and cover m^2 from 2003 saguaro nearest-neighbor data, and 1994 line transect data. Trees, shrubs, and bushes are our major focus because of their dominant size and number, and contribution as fuels.

Results from this unburned and burned saguaro-shrub research provide valuable insight into 10 year post-fire associated plant recovery. This information should be useful when planning conservation and fuels management programs for this vegetation type.

Methods

Our study site is located in saguaro-shrub vegetation on The Rolls, Mesa District, Tonto National Forest, Arizona (R8E: T3-Sec. 2, 4, 5 and T4-Sec. 26, 27, 35 of the Four Peaks Quad). Within the burned 1993 Vista View fire and adjacent unburned area, sample points were placed along randomly selected 350 m transect lines at 50 m intervals. Around each point and in each of four quarters, the nearest saguaro was located and became a nearest-neighbor sample site (Wilson et. al. 1996). Two nearest-neighbor methods were used: (1) a physiognomic characterization, and (2) a quadrant specific approach. Values from the two nearest-neighbor methods provide different perspectives for species and growth forms.

We used physiognomic groups and plant status categories to describe fuel components. Our physiognomic view forces all growth forms to be included in equal numbers around the sample saguaro—if they occur within a 10 m radius. Plants were identified to species when possible. We grouped species into five growth forms based on average structural and fuel characteristics: tree—woody plant with primary trunk (3.0-3.5 m), shrub—large woody multi-stemmed plant (1.5-2.5 m), bush—low growing multi-stemmed woody plant (0.4-0.8 m), cactus—succulent (0.14-0.19 m), and yucca—fibrous woody (1.4 m).

Plant status categories used were live, resprout, and dead. Resprouts in burned areas exemplify new vegetative growth emerging from charred roots, stumps, and branches. Resprouts observed in unburned areas typically emerge from plants containing large amounts of dead material. We distinguished living non-sprouting plants from resprouting plants as "live" and "resprout live," respectively. Measurable dead material within a plant was recorded as "dead in plant." Distance from the saguaro and plant dimensions (height, and two diameters) were measured for each nearest-neighbor. In addition, 1994 data from five 100 m line transects in burned and adjacent unburned areas were used to calculate 1-year post-fire cover m^2.

The quadrant specific method was used around each sample saguaro to count species within a 5 m radius (78.5 m^2) circular plot and identify the one nearest-neighbor per quadrant—regardless of growth form. Total quadrant density and cover m^2 per species were used to calculate average cover m^2 for the circular plots.

Total cover m^2 was standardized to adjust for the higher number of saguaro sample sites on the burned plot. Values were converted to relative percent to compare burned and unburned samples of different sizes. Details for other computations are listed in footnotes on table 1.

Discussion of Results

Ten year post-fire physiognomic data from unburned and burned sample areas are represented by number and relative percent occurrence for each species under each growth form (table 1). We observed differences in species occurrence between burned and unburned areas. Plants with the highest relative percent occurrence were: trees—paloverde in unburned and crucifixion thorn in burned areas; shrubs—wolfberry in unburned and whitethorn in burned areas; and bushes—golden bush and bursage in unburned, and globe mallow and white

Table 1—Ten-year post-fire saguaro nearest-neighbor plant species and numbers for each physiognomic group[a] and species[b] in unburned (U) and burned (B) 2003 point quarter physiognomic and quadrant specific samples on the 1993 Vista View Fire, Tonto National Forest, AZ.

		Physiognomic method[c]				Quadrant specific method[d]			
		Number of samples of occurrence		Relative[e] percent occurrence		Relative[f] percent number		Abundance[g] index number	
Growth form / Scientific name	Common name	U	B	U	B	U	B	U	B
Tree—small woody trunks		**24**	**25**	**100**	**86**	**3**	**3**	**1.4**	**1.2**
Canotia holacantha	Crucifixion thorn	3	15	13	52	--	3	3.0	1.6
Cercidium microphyllum	Foothill paloverde	21	9	88	31	3	--	1.2	1.2
Unknown charred		--	1	--	3	--	--	--	--
Shrub—large woody multiple stems		**23**	**29**	**96**	**100**	**9**	**12**	**2.2**	**1.7**
Acacia constricta	White thorn	8	18	33	62	1	4	2.0	1.9
Acacia greggii	Catclaw	2	--	8	--	--	2	2.3	1.6
Larrea tridentata	Creosote bush	1	--	4	--	--	--	2.0	--
Lycium spp.	Wolfberry	12	11	50	38	8	6	2.2	1.2
Bush—woody bases and low branches		**24**	**28**	**100**	**97**	**77**	**77**	**7.1**	**5.7**
Ambrosia deltoidea	Bursage	4	3	17	10	19	10	31.8	9.3
Calliandra eriophylla	Fairy duster	1	1	4	3	4	10	5.3	9.6
Encelia spp.	Brittle bush	0	1	0	3	1	2	1.4	8.2
Ephedra spp.	Mormon tea	4	4	17	14	6	6	2.4	2.0
Ericameria spp.	Golden bush	9	1	38	3	24	7	9.5	3.5
Krameria grayi	White ratany	1	4	4	14	4	8	2.6	3.7
Sphaeralcea ambigua	Globe mallow	--	7	--	24	1	19	1.3	10.4
Thamnosma montana	Turpentine broom	2	3	8	10	7	3	2.2	1.5
Cacti—succulents		**22**	**25**	**92**	**86**	**4**	**3**	**3.2**	**1.7**
Echinocereus engelmannii	Hedgehog	2	2	8	7	--	--	2.7	1.7
Opuntia engelmannii	Prickly pear	1	2	4	7	--	--	1.5	1.0
Opuntia leptocaulis	Desert Christmas	4	1	17	3	1	--	2.5	1.0
Opuntia versicolor	Staghorn cholla	15	20	63	69	3	3	4.2	2.1
***Carnegiea gigantean*—giant woody succulent**		**2**	**3**	**8**	**10**	**--**	**2**	**--**	**--**
***Yucca torreyi*—woody and fibrous**		**4**	**15**	**17**	**52**	**3**	**3**	**2.3**	**2.4**

[a] Physiognomic group (growth form) is designated by physical structure as tree, shrub, bush, cactus, and yucca.
[b] Species with low occurrence or relative percent number were removed from the table but used in calculations they include; Asteraceae, *Eriogonum* spp., *Gutierrezia* sp., *Lonicera* sp., *Mirabilis* sp., *Palafoxia* sp., *Psilotrophe* sp., *Senna* sp., and dead.
[c] Burned (N = 29), unburned (N = 24) saguaro sample sites with 1 each nearest-neighbor physiognomic type, within a 10 m radius.
[d] Bur
[e] Relative % occurrence; for growth form = total number of sample sites for growth form *x* / total number of sample sites X 100 = %; and for species = total number of sample sites for species *x* / total number sample sites for species growth form X 100 = %.
[f] Relative % number = total number of species *x* or growth form *x* / total number of all species X 100 = %.
[g] Abundance index (number species *x* / frequency species *x*) = total number of species *x* / number of saguaro sample sites for species *x* = average number for saguaro sample sites in which species x occurs (total live N = 906, burned and 1,251 unburned.

ratany in burned areas. Mormon tea was common in both areas. Among the cacti, staghorn cholla occurrence was highest in both unburned and burned areas. Yucca occurrence was lower in unburned than in burned areas.

Quadrant specific data presented as relative percent are close if not identical for growth forms in unburned and burned samples (table 1). Among growth forms, bushes were highest and trees, yucca, and cacti were lowest. Most species were evenly distributed among sample areas. Plants with a generally widespread yet clustered pattern around the saguaro scored high in relative percent and abundance index, e.g., bursage in unburned areas, and globe mallow in burned (table 1).

Plant status data from the physiognomic method was evaluated at 10 m, 5 m, 1.5 m and 1 m radii for average cover m^2 (table 2). Tree species numbers drop off sharply as the sample radii are reduced, shrubs follow, and bush number remains relatively constant within 1 m. New branch regeneration may obscure burned skeletons and makes it difficult to distinguish resprout status. Resprouting bushes reported for 2003 are low considering the high number observed in 1994 (table 3). Among burned area trees, 56 percent were dead persistent skeletons, and 54 percent of the living trees were resprouting, some with dead branches mixed within the live—dead in plant (table 2). Among burned shrubs 62 percent are still identifiable as resprouts.

Unburned area live relative percent total cover m^2 calculated from table 2 exceeds burned (figure 1). In burned areas, resprouts have twice the cover m^2 as live, largely attributable to shrubs. Dead cover m^2 in unburned areas is twice that of burned because of five large dead paloverde.

Table 2—Ten-year post-fire saguaro nearest-neighbor plant status[a], number and average for tree shrub and bush from 2003 point quarter 10 m, 5 m, 1.5 m, and 1 m radii physiognomic samples on the 1993 Vista View fire from burned and unburned plots, Tonto National Forest, AZ.

		Plant status											
		Number and average											
		Live			Resprout			Dead			Dead in plant[b]		
Treatment / **Growth form** / Radius	Total N	Number	Distance (m)	Cover (m^2)	Number	Distance (m)	Cover (m^2)	Number	Distance (m)	Cover (m^2)	Number	Distance (m)	Cover (m^2)
Unburned													
Tree													
10.0 m	24	19	4.74	28.40		No resprouts		5	4.82	41.27	3	8.60	5.97
5.0 m	15	11	2.85	37.17		No resprouts		4	3.58	33.33		No dead in plant	
1.5 m	1	1	1.30	15.68		No resprouts			No dead			No dead in plant	
1.0 m	0		No live			No resprouts			No dead			No dead in plant	
Shrub													
10.0 m	23	23	2.13	3.89		No resprouts			No dead		1	1.60	2.20
5.0 m	23	22	1.98	3.81		No resprouts			No dead		1	1.60	2.20
1.5 m	9	9	0.79	3.26		No resprouts			No dead			No dead in plant	
1.0 m	7	7	0.64	3.02		No resprouts			No dead			No dead in plant	
Bush													
10.0 m	24	21	0.55	0.70	1	0.30	0.02	2	0.30	0.02		No dead in plant	
5.0 m	24	21	0.55	0.70	1	0.30	0.02	2	0.30	0.02		No dead in plant	
1.5 m	23	20	0.50	0.63	1	0.30	0.02	2	0.30	0.02		No dead in plant	
1.0 m	22	19	0.45	0.62	1	0.30	0.02	2	0.30	0.02		No dead in plant	
Burned													
Tree													
10.0 m	25	5	7.20	10.32	6	2.98	7.57	14	3.00	8.87	3	4.70	3.75
5.0 m	19	2	4.65	20.78	6	2.98	7.57	11	1.93	9.80	2	2.10	4.09
1.5 m	12		--		1	1.50	8.28	11	0.92	7.92		No dead in plant	
1.0 m	3		No live plants			No resprouts		3	0.53	7.25		No dead in plant	
Shrub													
10.0 m	29	11	2.91	2.44	18	2.24	6.71		No dead		4	2.43	2.82
5.0 m	27	10	2.34	2.09	17	2.04	6.89		No dead		4	2.43	2.82
1.5 m	11	3	1.22	3.57	8	0.79	7.90		No dead		2	0.95	3.33
1.0 m	6	1	0.95	3.80	5	0.53	7.78		No dead		1	0.50	3.96
Bush													
10.0 m	28	26	0.60	0.88	2	0.40	0.00		No dead		2	0.40	0.02
5.0 m	28	26	0.60	0.88	2	0.40	0.00		No dead		2	0.40	0.02
1.5 m	28	26	0.59	0.88	2	0.90	0.00		No dead		2	0.40	0.16
1.0 m	27	25	0.57	0.85	2	0.40	0.00		No dead		2	0.40	0.16

[a] Plant status classification = live, resprout, dead, and dead in plant.
[b] Dead in plant is dead plant parts in an otherwise live plant.

Table 3—Number, plant status, and average cover m² for tree, shrub and bush, saguaro associated vegetation from five 100 m line transects for both 1994 unburned and burned sample plots on the 1993 Vista View fire, Tonto National Forest, AZ.

Treatment Growth form	Number	Plant status[a]	Average cover m²
Unburned[a]			
Tree	29	Live	10.82
Shrub	46	Live	3.27
Bush	174	Live	0.55
Burned[b]			
Tree	15	Resprout	4.86
Shrub	29	Resprout	3.34
Bush	45	Resprout	0.44

[a] Unburned; dead—1 bush.
[b] Burned; dead—7 bushes, 6 trees, and live—2 bushes, 1 tree.

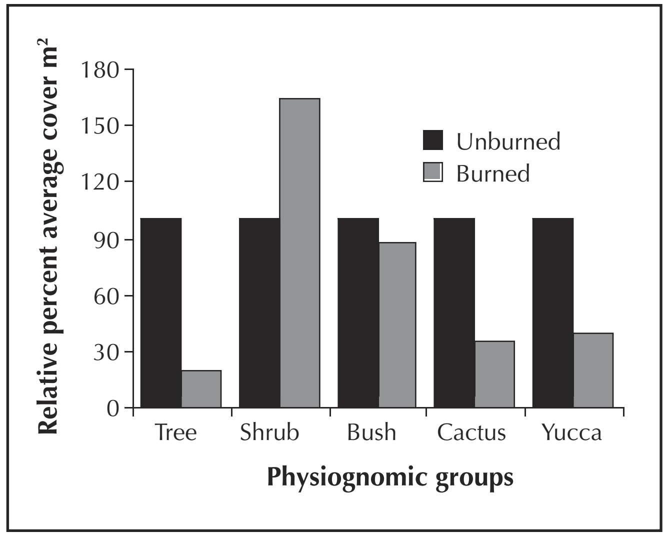


Figure 2—Quadrant specific data (saguaro nearest-neighbor per quadrant within a 5 m radius) relative percent average cover m² for unburned (100%) and burned (comparative %) areas, from 2003 samples (N = 211) on the 1993 Vista View fire, Tonto National Forest, AZ.

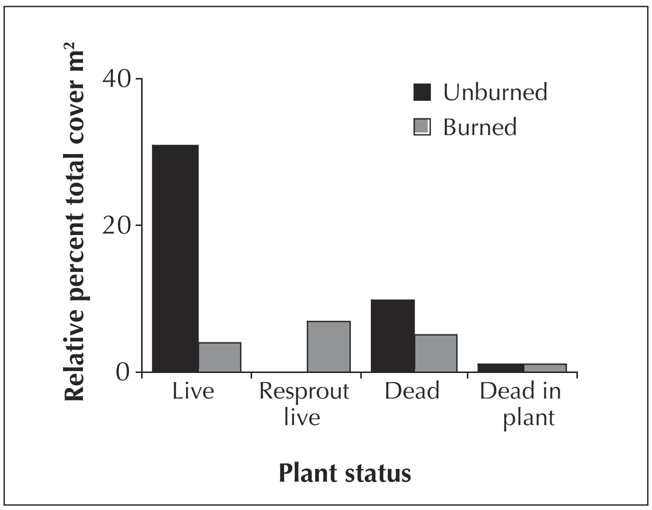


Figure 1—Physiognomic data for unburned and burned samples as relative percent total cover m² (tree, shrub, and bush; N = 1,117 m²), for plant status from 2003 saguaro nearest-neighbor 10 m radius samples (N = 153) on the 1993 Vista View fire, Tonto National Forest, AZ.

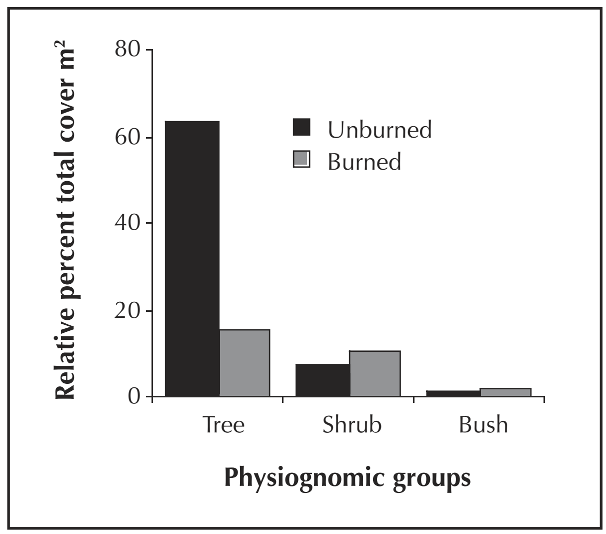
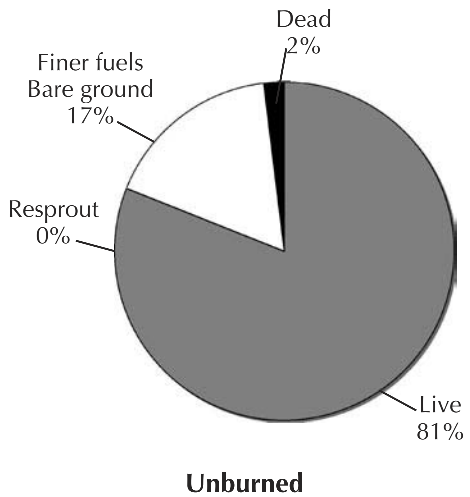


Figure 3—Physiognomic data for unburned and burned samples as relative percent total cover m² (N = 1,174 m²) for tree, shrub, and bush from 2003 saguaro nearest-neighbor 10 m radius samples (N = 153) on the 1993 Vista View fire, Tonto National Forest, AZ.

Both quadrant specific (figure 2) and physiognomic (figure 3) data reveal similar trends, in tree, shrub, and bush size relationships. Average relative percent cover m² is smaller in burned than unburned areas for trees, cactus, and yucca (figure 2). Burned area shrub average cover m² exceeded unburned by 65 percent. Bush average cover m² varied little. Total relative percent cover m², regardless of status, illustrates that plant cover remains depressed in burned compared to unburned areas—especially for trees (figure 3).

In 1994, both total number and average cover m² of burned area resprouting trees, shrubs, and bushes were about one-third that of unburned live plants (table 3). Between 1994 and 2003, both burned area tree resprouts and unburned live shrubs increased in average cover m² (table 2 cf. table 3). By 2003, burned shrub resprouts had doubled their average cover m² and were 2.7 times larger than their "non-resprouting" associates. Bush average cover m² increased for both unburned and burned areas. Live tree size was too variable to contrast between sample dates.

Fuel distribution around a saguaro is represented for unburned (figure 4) and burned (figure 5) areas. Total living cover m² in the unburned area is still about 20 percent greater than in the burned. About half of the burned area living plants are resprouts. Trees comprised most of the dead vegetation found in both burned and unburned areas. Compared to the unburned, the burn area has 12 percent more open area where the potential for fine herbaceous fuel accumulation persists while its tree, shrub, and bush components regenerate.



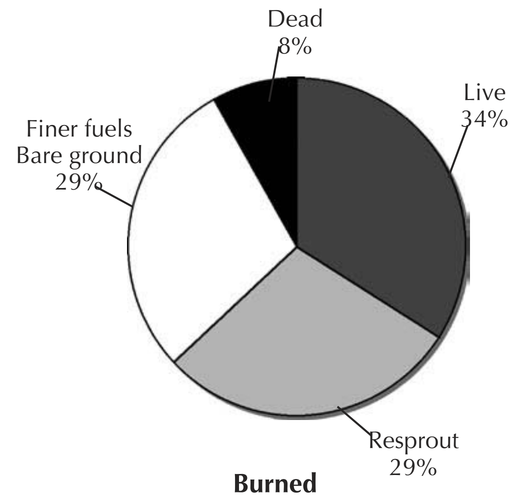


Figure 4—Relative percent cover m² for an average 78.5 m² circular plot around an average saguaro from an unburned 2003 sample site adjacent to the 1993 Vista View fire, Tonto National Forest, AZ. Quadrant density and cover m² from physiognomic and quadrant specific tree, shrub, and bush data were combined.

Figure 5—Relative percent cover m² for an average 78.5 m² circular plot around an average saguaro from a burned 2003 sample site on the 1993 Vista View fire, Tonto National Forest, AZ. Quadrant density and cover m² from physiognomic and quadrant specific tree shrub and bush data were combined.

Summary

Ten years after the 1993 Vista View fire, a once scenic vista, still displays burned and decaying giant saguaro. In this burned area, saguaro nearest-neighbor plants are recovering but still have less cover m² and twice the number of dead trees compared to the adjacent unburned area. In the burned area, trees have less than one-third the average cover m² of unburned trees and over half of them are dead. Diversity was maintained in this burned area mainly because the trees, shrubs, and bushes resprouted after fire. No indication of major species shifts between burned and unburned areas were found, only slight variations in abundance. Bush species tended to be more clustered as nearest-neighbors than shrubs or trees.

Fuels from dead and dying trees, and overlapping shrubs and bushes place the saguaro at great risk in both unburned and previously burned areas. Different approaches to fire management may be required in this complex vegetation type based on fuel accumulation that varies with time since fire. We suggest that active fire research, prevention, and suppression programs in the saguaro-shrub continue.

Acknowledgments

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Correlates of Vulnerability in Chiricahua Fox Squirrels

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***Abstract**—Chiricahua fox squirrels (*Sciurus nayaritensis chiricahuae*) are endemic to the Chiricahua Mountains of southeastern Arizona. A paucity of natural history information and uncertain conservation status served as impetus for us to initiate a descriptive ecological study of the species. We examined reproductive and population ecology of Chiricahua fox squirrels intermittently from 1994 to 2003. Chiricahua fox squirrels appear to possess 10 of 13 attributes associated with vulnerability to extinction, including low population densities and reduced reproductive capacity. We underscore potential negative impacts of fire suppression on the species and provide direction for future research and management.*

Introduction

Identifying patterns unique to endangered and threatened species are among the first questions asked in conservation biology. Ecological, behavioral, and distributional characteristics of a species help inform predictions about extinction risk (Purvis et al. 2000a). Numerous empirical studies have demonstrated that particular life-history attributes are associated with species most vulnerable to extinction (Russell et al. 1997). Characteristics of vulnerability include species with restricted ranges (Mace 1994), low population densities (Foufopoulos and Ives 1999), specialized habitat requirements (Purvis et al. 2000), and low rates of population increase (Bennett and Owens 1997). Accordingly, species that possess many traits associated with vulnerability should be primary targets for conservation action.

Chiricahua fox squirrels (*Sciurus nayaritensis chiricahuae*), a subspecies of the Mexican fox squirrel, are endemic to the Chiricahua Mountains of southeastern Arizona (Brown 1984). Chiricahua fox squirrels are large-bodied squirrels (~700 g) that lack sexual dimorphism and occur at low densities (Best 1995). Basic information on the ecology of *S. n. chiricahuae* is restricted to scant field notes of early naturalists (Cahalane 1939) and later compilers (Brown 1984; Hoffmeister 1986). A complete lack of ecological data resulted in Category 2 designation of the species (Drewry 1991), a listing category subsequently abandoned by the United States Fish and Wildlife Service.

Biogeographical isolation, a paucity of natural history information, and uncertain conservation status served as impetus for initiating our ecological study on Chiricahua fox squirrels. Our objectives were to (1) survey the population and (2) describe fecundity of reproductive females to determine if Chiricahua fox squirrels exhibited further characteristics associated with species vulnerable to extinction.

Methods

Study Area

Chiricahua National Monument (elevation 1,573-2,228 m) is located along the northwestern terminus of the Chiricahua Mountains, 55 km southeast of Willcox, Cochise County, Arizona. Towering rhyolite pillars and rocky outcroppings covered with chaparral (*Arctostaphylos pungens*, *Quercus toumeyi*, *Pinus cembroides*) dominate the 5,000 ha preserve. Squirrels are relegated to canyon bottoms composed of pines (*P. engelmanni*, *P. leiophylla, P. ponderosa*), oaks (principally *Q. arizonica*, *Q. emoryi*, *Q. hypoleucoides*, *Q. rugosa*), alligator junipers (*Juniperus deppeana*), and Arizona cypress (*Cupressus arizonica*: Brown 1984; Cahalane 1939; Hoffmeister 1986).

Trapping and Nest Use

We captured squirrels in live-traps (Tomahawk Live Trap Co., Tomahawk, WI, Model 104) baited with peanut butter. Squirrels were transferred to a cloth handling-cone (Koprowski 2002) and uniquely marked with numbered metal ear tags (National Band and Tag Co., Newport, KY, Model 1005-3) and colored washers (National Band and Tag Co., Newport, KY, 1-cm Model 1842). We radiocollared (Wildlife Materials, Inc., Carbondale, IL, Model SOM 2380) a subset of animals and homed-in on (White and Garrott 1990) squirrels at night to determine patterns of nest use.

Reproductive Capacity

We traversed the study area in search of unmarked squirrels and identified lactating females with the aid of binoculars. Enlarged, blackened nipples surrounded by a ring of hairless skin characterized lactating females (Steele and Koprowski 2001). We homed in and/or followed all lactating females to their nests and determined litter size by revisiting nests until young emerged.

Population Survey

A survey of drey (leaf nest) abundance yields a reliable index of population change in tree squirrels (Don 1985). Drey counts are a reasonable indicator of squirrel abundance because > 95% of Chiricahua fox squirrels use dreys as nest sites (unpublished data). We conducted walking surveys throughout

Table 1—Density and litter size of North American *Sciurus*.

Species	Density (animal/ha)	Average litter size	Source
S. aberti	0.3–1.1	3.3	Nash and Seaman 1977
S. arizonensis	NA	3.1	Best and Reidel 1995
S. carolinensis	3.0–21.0	2.5	Koprowski 1994a
S. griseus	0.3–4.3	2.7	Carraway and Verts 1994
S. nayaritensis	0.07–0.1	1.6	Herein
S. niger	1.0–12.0	2.7	Koprowski 1994b

the study area to locate dreys in the forest and scrub canopy in May-August of 1994, 1999, and 2003. We scored dreys based on their physical condition: (1) actively maintained and likely in use; (2) in mild disrepair but potentially in use; (3) in extreme disrepair and not in use. Drey categories 1 and 2 were considered actively in use.

Results

Female Reproductive Performance

Females had (mean ± SD) 1.62 ± 0.51 (range 1-2, $n = 13$) offspring per litter, representing the smallest litter size of all North American tree squirrels (table 1). All young emerged from nests during May-August, indicating that a second reproductive bout did not occur during the late summer or early winter season.

Drey Use and Population Index

On average, squirrels used (mean ± SD) 4.32 ± 3.33 dreys ($n = 20$) and shared at least 22 dreys. Lactating females used tree cavities to raise young but promptly returned (4.5 ± 2.1 days, $n = 2$) to their drey(s) following juvenile dispersal. Female Chiricahua fox squirrels appear to have a similar birthing length (8-12 weeks) as other tree squirrels (Steele and Koprowski 2001). Therefore, drey counts do not overlook lactating females because abandoned nests do not begin to decay until after four months of neglect (Bret S. Pasch, personal observation).

The number of active dreys was 166 in 1994, 126 in 1999, and 108 in 2003, indicating a 35% decrease in active dreys over 9 years. If we assume that squirrels use at least two dreys per year, we estimate the population size to be at 54 individuals in 2003. Approximately 821 ha (~16%) of the Chiricahua National Monument are forested and available to squirrels. Consequently, the population density of Chiricahua fox squirrels (0.07/ha) is lower than all North American tree squirrels (table 1).

Discussion

Examination of current population trends is an essential research priority when studying species at risk. The apparent decline in Chiricahua fox squirrel numbers from 1994 to 2003 therefore warrants attention. Understanding the dynamics of potentially threatening processes is imperative to conserving the species. Tree squirrel populations can vary annually in size, but densities tend to remain constant over the long term. Survivorship and reproduction of tree squirrels is often correlated with tree-seed productivity (Gurnell 1987). Population size decreases significantly following food crop failures and increases following abundant mast years (Koprowski 1991). Because tree seeds constitute the majority of Chiricahua fox squirrels' diet (Koprowski and Corse 2001), we recommend annual surveys of both drey abundance and tree seed productivity. Synthesizing intrinsic risk factors (e.g., low rate of population increase) with extrinsic factors (e.g., food availability) will enable managers to decipher typical population fluctuations against other threatening processes (Beissenger and Westphal 1998).

Measures of female productivity indicate that Chiricahua fox squirrels have small litter sizes and a low frequency of reproduction relative to other congeners. Eastern gray squirrels (*S. carolinensis*) and fox squirrels (*S. niger*) average 2.5-3.0 offspring per litter and potentially produce a second litter in good mast years (Koprowski 1994a,b; Nixon and McClain 1975). The low reproductive potential of Chiricahua fox squirrels translates into a limited ability to recover quickly from disturbance events that decrease population size (Gaston and Blackburn 1995). Therefore, particular care must be taken to maintain mature trees in canyon bottoms to ensure already low squirrel densities do not decrease further.

Island ecosystems are known for endemic species' susceptibility to extinction in the presence of anthropogenic disturbances (Olson 1989). Indeed, the primary threats facing Chiricahua fox squirrels appear to be anthropogenic in nature. Their status as a U.S. Forest Service sensitive species does not prohibit hunting of squirrels for meat and pelt (USDA 1999). Though not popular as a game species, local individuals continue to hunt squirrels on an annual basis (Donna Laing, personal communication). Hunting of Chiricahua fox squirrels could potentially exacerbate population decline by removing females that possess already low reproductive rates.

Decades of fire suppression in a system that experienced a mean fire interval of 15 years prior to European settlement may negatively impact Chiricahua fox squirrels (Swetnam et al. 1989). Squirrels may suffer higher predation within suppressed areas than in prescribed-burned areas, perhaps due to the increased visual obscurity associated with the dense understory where squirrels forage. Unnaturally intense fires characteristic of suppressed forests negatively impact tree squirrels by destroying leaf nests and killing nestlings (Kirkpatrick and Mosby 1981). Conversely, low-intensity fires characteristic of prescribed burns do not damage nests and may stimulate increased cone and mast production (Weigl et al. 1989). Future studies should survey seed production in prescribed-burned areas and determine the mechanism causing increased mortality of squirrels in suppressed areas.

The mountains of the Madrean Archipelago stand as mesic "islands" in a sea of xeric deserts and grasslands that serve as hostile barriers to dispersal. Tree squirrels epitomize island endemism because of their dependence on mature forests and difficulty in colonizing isolated "sky islands" (Brown 1984). Because tree squirrels serve as reliable indicators of forest health due to their dependence on mature trees (Gurnell 1987; Steele and Koprowski 2001), our study has ancillary application to forest management of the Madrean Archipelago. Understanding the ecology of relict populations in Arizona (e.g., Chiricahua fox squirrels, Arizona gray squirrels, Mt. Graham red squirrels) is of value to managers throughout the sky island region. The potential decline of *S. nayaritensis chiricahuae* is one of many ecological studies that should continue on Arizona's tree squirrels if we are to conserve our unique island endemics.

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Habitat and Conservation Status of the Beaver in the Sierra San Luis Sonora, México

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Abstract—*The status of beaver (*Castor canadensis*) in northeastern Sonora, Mexico, is uncertain. We surveyed the Cajon Bonito River to assess the beaver's status and habitat and found five colonies. Limiting factors appear to be pollution due to animal waste, deforestation of riparian trees, and human exploitation. Beavers did not appear to require habitat diversity as much as dense riparian and aquatic vegetation in waters with low organic content. These kinds of studies are imperative to understanding the natural history and ecology of the species in this unique region.*

Introduction

Increased water demands for irrigation, industrial and domestic uses already threaten freshwater resources in many parts of the world where major rivers are dammed, diverted, and overused, leading to the degradation and loss of freshwater habitats. Several species dependent on these freshwater habitats are in danger of disappearing, unless they become protected (Saunders et al. 2002); among these species is the American beaver (*Castor canadensis*). This species is associated with freshwater streams and rivers that have riparian forests of willow and cottonwood trees and plenty of aquatic vegetation (Jenkins and Busher 1979, RIC 1998).

Beavers are abundant and widely distributed across much of North America, but due to landscape changes and habitat fragmentation beaver populations have been decimated in many areas (Kendi et al. 2001). Beavers are considered keystone modifiers or ecosystem engineers, having a profound and long-lasting impact on their environment that is beneficial to a wide variety of wildlife species like fish, river otters, beetles, and aquatic invertebrates (Jenkins and Busher 1979, Melquist and Hornocker 1983, Middleton 1999, Power et al 1996, RIC 1998, Whitham 2001). Therefore in order to keep such an important species, it is imperative to characterize the habitat and to determine the conservation status of the species, including its distribution and abundance (Grigera 2002).

In Mexico, isolated beaver populations have been documented along the U.S.-Mexico border (Leopold 1977, Hoffmeister 1986, RIC 1998). Beavers are protected by federal laws in Mexico and are classified as endangered of extinction (SEMARNAT 2002). However, the knowledge of their status in northeastern Sonora, as in most of Mexico, is not well known.

The populations of beaver in northeastern Sonora are located in the Sky Island region, encompassing southeastern Arizona, southwestern New Mexico, northeastern Sonora and northwestern Chihuahua. This area is biogeographically unique, formed by the crossroads of the Rocky Mountains, the Sierra Madre Occidental, Sonoran and Chihuahuan Deserts. The Sky Island region provides habitat for charismatic species such as mountain lion (*Puma concolor*) and black bear (*Ursus americanus*). In addition, the region functions as a biological corridor for many species such as jaguar (*Panthera onca*), pronghorn (*Antilocarpa americana*, [Imhoft 2003]) and bighorn sheep (*Ovis canadensis*) (data on file with Karla Pelz Serrano and Eduardo Ponce Guevara).

Our objectives were to describe the relative abundance and habitat characteristics of beavers in the Sierra San Luis, Sonora.

Study Area

We concentrated our efforts in the Cajon Bonito River (figure 1). This river system is part of the largest area without fragmentation in northern Mexico (The Wildlands Project 2000). A large portion of the Cajon Bonito is located in private property, where no livestock presence has occurred for the past seven years. Consequently restoration has taken place and good ecological conditions are present, with large populations of fish, reptiles, and amphibians (Robert Minckley pers. comm.). However, upstream the river is diverted for trout aquaculture and used by livestock. We selected 3 sites (fig. 1): (1) Rancho Nuevo Ranch, which has livestock influence, and no beavers, (2) Los Ojos Ranch which has no livestock and no beavers, and (3) El Diablo Ranch, which has no livestock but has beavers.

Methods

Presence and Abundance

To determine the presence of beavers, we surveyed 18.5 kilometers of the Cajon Bonito River, between July and December 2003. Beaver spoor was identified as tracks, fallen trees, and gnawed branches, dams, and food caches (RIC 1998). The geographic location of the spoor was obtained with a handheld GPS unit (Garmin 12XL) and recorded in Universal Transverse Mercator units. Additionally, we

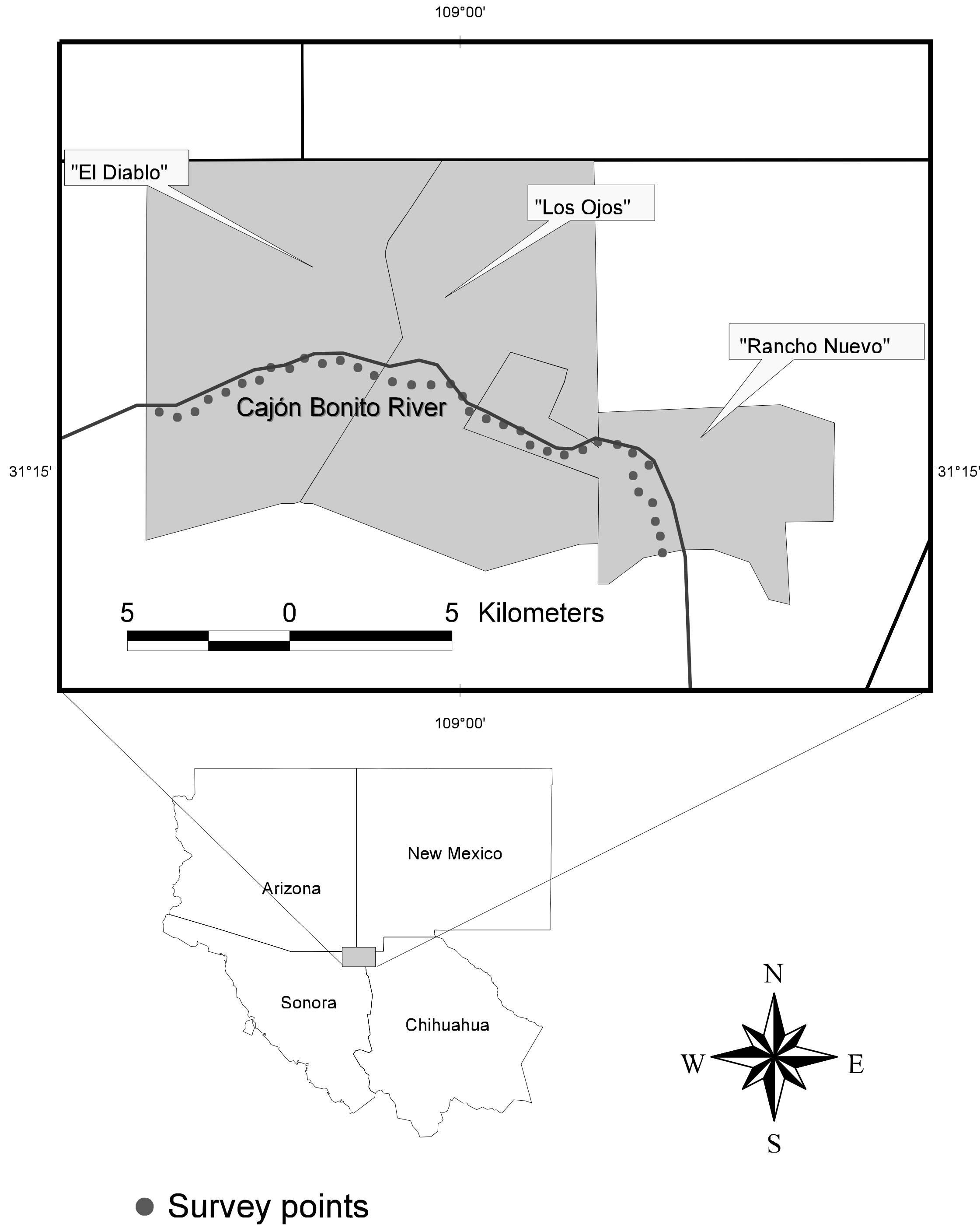

Figure 1—Study area along the Cajon Bonito River within the three ranches. Dots indicate survey points.

performed interviews with neighboring ranchers where we found current beaver activity, to document if these people had previous contact with the species.

We estimated beaver colony size based on the criteria of a fall food cache consisting of branches stored underwater to be used for winter feeding (RIC 1998). Using one fall food cache per colony, we estimated the total number of beavers by multiplying the numbers of colonies in an area by the mean colony size (McTaggart and Nelson 2003, RIC 1998). A typical beaver colony is composed of 2 breeding adults, 1-2 yearlings and 2 kits (RIC 1998). Colony size estimates for selected studies in North America range from 3.4 to 4.6 beavers per colony, including adults and kits (RIC 1998). For this study we used a mean colony size of 4 individuals: 2 breeding adults, 1 yearling, and 1 kit (McTaggart and Nelson 2003, RIC 1998).

Habitat Characterization

The river was described according to riparian vegetation structure and water quality characteristics. To determine the chemical characteristics of water we used a Shallow water test kit (Forestry Suppliers, Inc.). We took a water sample every 0.5 km. Thus in Rancho Nuevo, which has 5.5 km of running water, we took 11 water samples. In Los Ojos and El Diablo,

Table 1—Comparison of the chemical characteristics of the three ranches.

Ranch	O_2 (ppm)	Temperature (ºC)	Turbidity	pH	Width (m)	Depth (cm)
Rancho Nuevo	6.87 ± 0.50 [a]	15 ± 1.68 [a]	0 ± 2.61	7.5 ± 0.39 [a]	2.5 ± 4.84	20 ± 56.5
Los Ojos	7.31 ± 0.42	16 ± 0.61	0 ± 2.40	8 ± 0.26	2.5 ± 0.70	20 ± 34.1
El Diablo	7.4 ± 0.45	15.5 ± 0.68	0 ± 0*	8 ± 0	2.5 ± 1.02	20 ± 55.3

[a] denotes those variables with significant differences between ranches.

we took 13 samples. For each water sample we measured temperature, pH, dissolved oxygen, and water turbidity. The dissolved oxygen was determined by the Winkler method and is given as ppm, and the turbidity is given as Jackson turbidity units (Brower et al. 1998). We also measured the depth and width of the river at each sampling site.

The chemical parameters of all sampling points were compared with an analysis of variance (ANOVA) or Kruskal Wallis ANOVA on ranks, depending on the normality of each variable, in order to test for significant differences. In the case of the ANOVA test, all pairwise multiple comparison procedures were made with the Tukey Test, and in the case of the Kuskal-Wallis, tests were made with Dunn's Method (Zar 1999).

At each site we made three transects of 10 X 50 m along the riverside in order to characterize the riparian vegetation of each ranch. We measured the cover, DBH (diameter at breast high), and height of each tree (>5 cm DBH) within each transect. We calculated density, abundance, importance value, dominance, coverage area, and Simpson and Shannon indexes as measures of diversity (Krebs 1999). We also recorded the presence or absence of aquatic vegetation within transects.

Results

Presence and Abundance

At 6 locations in El Diablo Ranch, we found beaver spoor, including tracks, scats, and food caches for a total of 38 records. The other two ranches lacked beavers. Interviews with residents revealed that all of the Cajón Bonito used to have beavers until a few years ago, and residents reported that they saw a beaver dam in 2003, 3 km upstream from where we found dams in the present study. Of the 38 records of beaver sign in Cajon Bonito, 5 were food caches, indicating 5 different beaver colonies. Multiplying the number of colonies found by a mean colony size of 4, we estimated that the number of individuals present in this population is 20.

Habitat Characterization

We found significant differences in all four water quality variables: dissolved oxygen, temperature, pH, and turbidity (table 1). The most polluted place was Rancho Nuevo, having the highest level of turbidity and the lowest level of dissolved oxygen. Rancho Nuevo also had the lowest pH level, and so was less basic than the other two sites.

In the case of the vegetation structure analysis, we found that the most diverse site was Rancho Nuevo, but it was the least dense and had the least cover (table 2). Los Ojos and El Diablo were not very diverse, but they were dense, had more cover than Rancho Nuevo and had old and young trees (table 2). However, El Diablo had the highest density of willows and cottonwoods. In fact these tree species had the highest importance values of all species of the entire tree community (table 2). The tree species found in the three sites surveyed were the same, but only Rancho Nuevo had *Carya* sp. and *Liquidambar* sp. Sites did vary only in vegetation density and cover.

In all transects of Rancho Nuevo, there was aquatic vegetation, such as duckweed (*Lemmna minor*), horned pondweed (*Zannicchellia pallustris*), and some algae (Clorophyta). These plants are indicators of organic material in the water, and therefore this result is further evidence that Rancho Nuevo had water pollution. In Los Ojos, we recorded horse tail (*Equisetum* sp.), mint (*Mentha* sp.) and some grasses, all of them abundantly. On the other hand, El Diablo presented aquatic vegetation covering most of the water, including algae (Clorophyta and Rodophyta), horse tail, mint, and another aquatic plant from the Lamiaceae family. Los Ojos and El Diablo did not have duckweed.

Table 2—Comparison of vegetation characteristics in the three ranches.

Ranch	H′	λ	Cover (100 m²)	Importance value	Density (ind/m²)	Aquatic plants
Rancho Nuevo	0.63	0.30	1848.07	*Salix* sp. (168.42) *Carya* sp. (153.74)	0.086	*Lemmna minor*, *Zannichellia pallustris* and algae
Los Ojos	0.45	0.42	4523.40	*Salix* sp. (280.12) *Populus fermontii* (160.44)	0.522	*Equisetum* sp. and *Mentha* sp.
El Diablo	0.24	0.66	2347.34	*Populus fermontii* (389.66), *Salix* sp. (183.06)	0.338	*Equisetum* sp. and *Mentha* sp., algae and an aquatic from the family Lamiaceae

Discussion

Beavers were considered a threat to road maintenance in the study area, because trees cut by beavers for dam construction could block the roads and cause flooding. As a result, ranchers began to kill beavers. Now these rodents survive only in remote ranches, without livestock where the habitat is in good ecological condition.

Our estimate of only one colony/km is in accordance with other studies. Rosell and Houde (2001) found 0.83/km in Gvarv River, 0.71/km in Lunde River, and 0.52/km in Saua River in Norway. On the other hand, Lizarralde and Venegas (2001) found introduced beaver colonies at a density of 0.7/km in Tierra del Fuego. Whitham (2001) reported an average density of colonies of 0.8/km along 300 km in Minnesota. Smith (1998) found in the Yellowstone River in Wyoming an average density of beaver colonies of 0.35/km. In Canada, the maximum averaged density of beaver as a whole was estimated at 1.0-1.2 colonies/km (Müller-Schwarze and Sun 2003). This means that the density of colonies in the Cajon Bonito rests within those reported for other North American sites and for an introduced population in South America. However, it is important to highlight the fact that we found only five beaver colonies in the entire Cajon Bonito River, which means that there were only five reproductive pairs; consequently these beavers may confront a problem of genetic variability if there is not enough genetic interchange. According to Withham (2001), the Cajon Bonito should have 60 individuals in its 20 kilometers of running water, if the whole river were suitable for beavers. With this potential density, the population could have a better future.

Rancho Nuevo had the highest levels of pollution, presumably because of the presence of livestock. Animal wastes contain suspended solids, nitrates, and faecal coliform bacteria (Stauffer 1999). Cattle waste cause eutrophication in surface-water as well as increased turbidity and the pH becomes less basic (Stauffer 1999). Los Ojos was more polluted than El Diablo because it received pollutants that flowed downstream from Rancho Nuevo. However, without additional pollutant input, water arrived cleaner in El Diablo. Furthermore beaver ponds probably helped to clean the water.

Apparently, beavers did not depend on the vegetation species diversity of the sites, because beavers were found in the least diverse site. Beavers were in a dense area where the most important plants were those that they eat (*Populus fermontii* and *Salix* sp.). Also, beavers were in a site with more vegetation cover than Rancho Nuevo, which indicates that they need areas with a high density of edible plants and with sufficient cover. Los Ojos was the site with more cover and was denser than the other ranches, probably because it has older trees and it has been without cattle a longer time than El Diablo. Beavers in El Diablo were eating the trees, perhaps contributing to less tree cover at this ranch. However, this feeding may help spread seeds from trees cut by beavers, and so beavers may be helping in the restoration process of riverine systems (Fink 2000). In addition, the least dense site with the least cover was Rancho Nuevo, which also had aquatic vegetation such as *Lemmna minor*, which is an indicator of water polluted with organic material and with poor levels of oxygen (Mathias Dos Santos y Banzatto 2001). On the other hand, El Diablo had vegetation that did not indicate water pollution. Beavers eat pond vegetation during most of the summer (Jenkins and Busher 1979), so places like El Diablo that have many aquatic plants and water quality in good conditions may be seasonally suitable sites for occupation by these mammals. After a period of time, beavers tend to move to other sites; if the upstream part of the river is not in good ecological condition, they are not going to be able to live there.

According to Gallo-Reynoso et al. (2002), beavers in the Bavispe River were more abundant where the riparian vegetation was intact and undisturbed including the presence of cottonwood (*Populus* sp.), and willow (*Salix* sp.), and they were less abundant in areas perturbed by farming, livestock, and human activities. Therefore the removal of natural riparian vegetation and the presence of livestock in the Cajon Bonito River seem to have limited beaver distribution.

There are few published records of beavers from the northeastern watershed of the Sierra Madre Occidental of Mexico (Gallo-Reynoso et al 2002); therefore additional studies about the status of the species are imperative to understanding the natural history of the species in this unique region, and to learn more about their seasonal distribution (Long 2002).

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Ecology and Natural History of the Green Rat Snake at Leslie Canyon National Wildlife Refuge, Cochise County, Arizona

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Abstract—*Green rat snakes (*Senticolis triaspis*) appear to be rare throughout their range, and little is known about their ecology and life history. Using opportunistically captured S. triaspis coupled with captive observations, natural observations, and radio telemetry, we document several natural history and ecological aspects of the species. The only known food items are small mammals; the species only rarely climbs in trees; preferred habitats are steep, rocky east-facing slopes with desertscrub vegetation; and active body temperatures typically are 23.4 - 29.7 °C. The species' conservation will depend on knowing its life-history and ecology, and protecting rocky slopes and mammalian food items.*

Introduction

While the green ratsnake (*Senticolis triaspis*) has a geographic distribution ranging north from Costa Rica through Central America and Mexico, it barely enters the United States in and among several Madrean mountain foothills in southern Arizona and New Mexico. Its apparent restricted geographic range in the United States., secretive habits, and cryptic coloration have led to the perception that it is perhaps an uncommon, arboreal species. Little is known regarding the general population ecology and behavior of this species. Recently, Rodriguez-Robles and De Jesus-Escobar (1999) focused on phylogenetics and the evolution of food habits within the lampropeltine snakes, including *Senticolis*.

Basic life history and ecological information is necessary for appropriate conservation (see, e.g., Wilcove and Eisner 2000); it is therefore difficult to apply conservation measures to species such as *S. triaspis*, for which very little information exists. Degenhardt et al. (1996) review what little is known about the species. Anecdotal information indicates that the species is found in "rocky riparian areas" in New Mexico and Arizona (Degenhardt et al. 1996). Cranston (1989 *in* Degenhardt et al. 1996) provides observational information on behavior, reproduction, and food habits. These accounts suggest that *S. triaspis* is not strongly arboreal as implied by other workers (e.g., Stebbins 2003); that courtship occurs from mid-March to mid-May, and incubation lasts 77-88 d at 26 °C; and limited information indicates that the species feeds on small mammals.

Senticolis triaspis inhabit Leslie Canyon National Wildlife Refuge (LCNWR), in Cochise County, Arizona. Although LCNWR was created specifically to protect native, listed (Federally Endangered and Threatened) fish species, it provides protected areas for many range-restricted, endemic, and otherwise unique species. We used opportunistically captured *S. triaspis*, radio telemetry, and captive and natural observations to examine: food habits, activity periods, behavior, home range size, and habitat use.

Study Area

LCNWR is located in southeast Arizona, overlying the Swisshelm and Pedregosa Mountains at an elevation range of 1,400-1,720 m, and encompasses ~1,100 ha. Vegetation is dominantly (>95%) desertscrub, with both Sonoran and Chihuahuan Desert influences; species include *Opuntia* spp., *Acacia constricta*, *Agave palmeri*, *Nolina microcarpa*, and *Foquierria splendens*. A narrow riparian gallery exists along perennially and seasonally flowing portions of Leslie Creek, occupying <5% of LCNWR; species composition is dominated by *Fraxinus arizonica*, *Juglans arizonica*, and *Salix gooddingii*. Low-lying floodplains are dominated by *Sporobolus muhlenbergii*, interspersed with limited *Prosopis glandulosa* and *Celtis reticulata*. The number of animal taxa that inhabit LCNWR is high despite its small size. Over 40 reptile and amphibian species, >100 avian species, >50 mammalian species, and an unknown, but large number, of invertebrate species occur on the Refuge.

Methods

Capture and Captivity

Senticolis triaspis were captured opportunistically between July 2000 and July 2003. All but one individual (DOR) were returned to LCNWR headquarters for captive maintenance. While captive, daily and seasonal activity patterns were recorded for individuals. Captive *S. triaspis* were presented a variety of food items, all of which occur syntopically with the snake in LCNWR, with the exception of *Mus musculus*. Food items were left in the aquaria with *S. triaspis* until they were consumed, or for 24 h.

Radio Telemetry

Captured *S. triaspis* that were large enough (>100 g) were implanted with Holohil TS-2 temperature variable transmitters in the laboratory using methods described by Reinert (1992); transmitter temperature calibration was conducted in the lab prior to implantation. Individuals were released <50 m from the original capture point (some were captured on the road, necessitating a release point slightly different than, but near, the point of capture), and tracked using a Telonics TR-5 receiver with a 4-element H-antenna. Time, location (UTM, WGS 84 and NAD 27 datums), pulse period (transformed to body temperature), substrate, vegetation, height above ground surface, and visual confirmation were recorded. Body temperature summary statistics were grouped by month and individual, and calculated following Neter et al. (1985).

Habitat mapping was accomplished with DeLorme's X-Map 3.5 (DeLorme 2002) program. Using georeferenced aerial photographs (1:10,000 scale), layers were added to delineate two macrohabitat classes, vegetation, and slope aspect. The classes were further separated into 2 categories. Vegetation was categorized as riparian (dominated by *Fraxinus* and *Juglans*) and desertscrub (dominated by *Opuntia* and *Acacia*) habitats. Topographic contours were used to delineate east versus west aspect categories (local ridges follow a north-south orientation, resulting in dominantly east- or west-facing slopes).

Home ranges (HR) were constructed as outlines of the locality points; minimum convex polygons (MCP), although widely used, were not applied in this case because areas that would have been included were never used by the snakes. The inclusion of these areas from the MCP would bias results and lead to incorrect inference. The HR of each individual was overlaid on vegetation and slope-aspect layers, and the percentage of each category per class within the home ranges was calculated; these percentages established "used" habitats.

To examine macrohabitat preferences, we determined "available" habitat using three models of biologically defined availability (figure 1). We used these models because arbitrary definitions of availability can bias preference assessment and heavily introduce anthropogenic views; the logic of the models is that movement rates and distances must restrict what is actually "available." Model 1 (figure 1a) depicts a hypothetical individual that has a home range with a maximum long axis of length *L*; from release, this individual could theoretically travel any compass direction an equivalent distance. Model

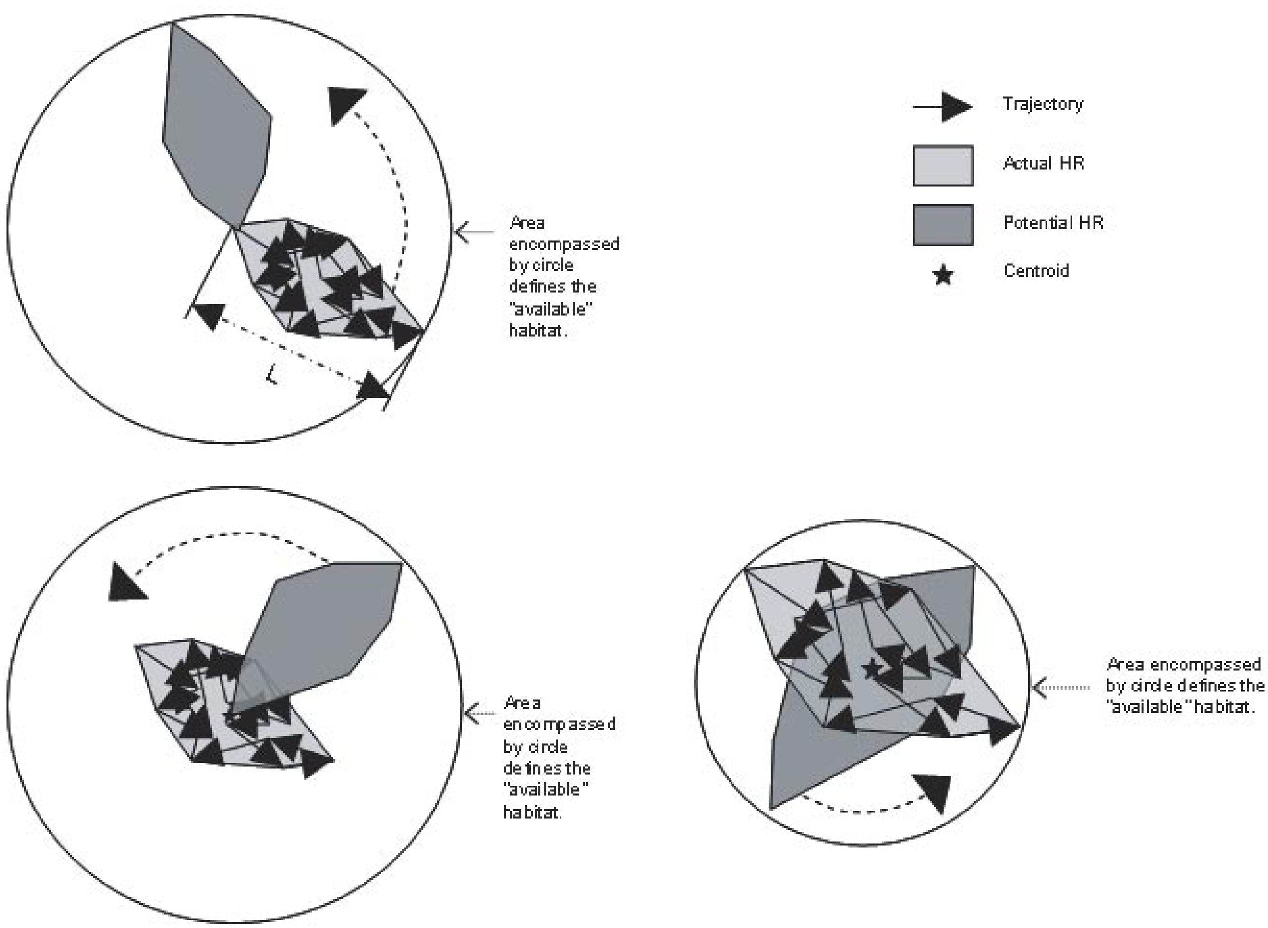

Figure 1—Models of biologically defined availability. a. is Model 1, with an area circumscribed by the radius *L* rotated about the initial release point; b. is Model 2, with an area circumscribed by radius *L* rotated about the observed home range centroid; c. is Model 3, with a radius circumscribed by radius (*L*/2) rotated about the home range centroid.

Table 1—Species consumed or denied by captive *Senticolis triaspis* captured in Leslie Canyon National Wildlife Refuge, Cochise County, AZ.

Species	Accepted	Denied
Peromyscus maniculatus	X	
Peromyscus leucopus	X	
Perognathus baileyi	X	
Perognathus flavus	X	
Baiomys taylori	X	
Mus musculus	X	
Dipodomys ordii	X	
Sceloporus clarkii		X
Urosaurus ornatus		X
Elgaria kingii		X
Aspidoscelis sonorae		X

Table 2—Habitat use and availability according to three models (in figure 1). "Ind" is individual, and all values are given in percent.

		Available		
	Used	a	b	c
Vegetation (%)				
Desertscrub Ind 1	94	92	91	88
Desertscrub Ind 2	93	86	91	95
Riparian Ind 1	6	8	9	12
Riparian Ind 2	7	14	9	5
Aspect (%)				
East Ind 1	90	28	40	47
East Ind 2	95	27	27	97
West Ind 1	10	72	60	53
West Ind 2	5	73	73	3

2 (figure 1b) depicts an "available" area defined by *L* rotated about the home range centroid, under the assumption that the point must remain in any permutation of the observed home range. Model 3 (figure 1c) rotates the home range about the centroid, under the assumption that the centroid must remain the centroid in all permutations. Within each "available" area defined by the models, proportions of each habitat type were calculated. Compositional analysis (Aebischer et al. 1993) was used in part for ranking preference; full ANOVA was not used because of small sample size.

Results

Seven S. *triaspis* were captured in or immediately adjacent to LCNWR; capture dates ranged from April 8 to November 20. Despite the thin, muscular build of the species, similar to that of the syntopic *Masticophis bilineatus*, individuals never attempted to flee when approached: they remained motionless even when clearly visible in a roadway, and resisted capture only once touched.

Senticolis triaspis consumed only endotherms, specifically small mammals; ectotherms were never consumed (table 1). Live mammals were preferred over dead mammals, and food items that were not consumed by *S. triaspis* were ultimately consumed by the control snakes. Feeding trials further suggested that snake body size and food item size are positively correlated. Food items were consumed when presented at any time of day, as well as when the snakes were relatively cool. Captive snakes exhibited diurnal and crepuscular activity, but there was no indication of nocturnal activity. There were two activity peaks, one in the morning and one in the afternoon. Captive mating occurred in spring.

Four *S. triaspis* were implanted with transmitters; of these 4, only 2 individuals (or their transmitters) survived long enough to gather meaningful data. Snakes were diurnal and/or crepuscular depending on season, and did not appear to have prolonged activity periods; nocturnal activity was never documented. Telemetered individuals were found to climb among trees and shrubs only once: an individual climbed for approximately 45min after release, but was never found above the ground again. Movement was evident several times, and in all but the post-release climbing observation and when crossing roads, individuals apparently traveled through interstitial spaces among large rocks. Movement was slow and deliberate when observed. Mean monthly snake body temperatures during through the annual cycle ranged from 13.8-27.8 °C, and active body temperatures documented while snakes were moving through their habitats ranged from 23.4-29.7 °C (July).

HR and *L* estimates for the two individuals were variable (HR = 2.2 versus 0.84 ha; L = 250 versus 140 m), but there was considerable overlap in the home ranges (0.62 ha). Desert scrub and east-facing slopes were predominantly used by both individuals. "Available" habitat proportions varied between the biologically defined models for both individuals, and the changes between models in what was defined as "available" necessarily changed inference of preferences (table 2). Under both Model 1 and Model 2 availability, desertscrub and east-facing slopes were strongly preferred over riparian and west-facing slopes; however, Model 3 availability resulted in ambiguous preference determination (table 3).

Discussion

Natural history and ecological information are important to conserving species, yet little is known about many secretive and range-restricted species such as *S. triaspis*. Feeding experiments supported conclusions in the literature stating that green ratsnakes feed on endotherms, specifically small mammals (e.g., Degenhardt et al. 1996). This finding is consistent with the phylogenetic-constraint hypothesis of food habits presented by Rodriguez-Robles and De Jesus-Escobar (1999), wherein the clade containing *Senticolis* consumes only small mammals.

Radio telemetry data and habitat preference analysis indicated that desertscrub vegetation is strongly preferred over riparian vegetation. However, there is often high spatial autocorrelation in landscape features; in the case of *S. triaspis* in LCNWR, the desertscrub habitat is correlated with very rugged, rocky areas on the sides of the canyon. Based on observations of the species in Central America (J. Malone and J. Meik, personal communication), *S. triaspis* are often found in rocky areas with very different vegetative community structure than that at LCNWR, suggesting that the geologic

Table 3—Average (and standard deviation) of the log-ratio (L-R) differences between used and available habitat categories for two *Senticolis triaspis* radio tracked at Leslie Canyon National Wildlife Refuge. "Effect" indicates affinity (+) or deference (-) for a given habitat category.

	L-R		Effect
	$\bar{x}$	SD	
Vegetation (%)			
Desertscrub			
	a. 0.050	0.040	+
	b. 0.027	0.008	+
	c. 0.022	0.062	-
Riparian			
	a. -0.490	0.287	+
	b. -0.328	0.109	+
	c. -0.178	0.728	-
Aspect (%)			
East			
	a. 1.213	0.064	+
	b. 1.034	0.316	+
	c. 0.314	0.474	-
West			
	a. -2.328	0.500	+
	b. -2.236	0.629	+
	c. -0.578	1.540	-

structure may be more important than the vegetative component. The fact that east-facing slopes appear to be preferred over west-facing slopes may be tied to thermoregulation; the key to refining answers will lie in replication through time and space. The diurnal/crepuscular activity periods, relatively slow movement rates, motionless behavior when approached, and mammalian food preferences implies that *S. triaspis* slowly hunts nocturnally active small mammals in rocky retreats by day—it would not be efficient, given slow movement rates, to actively pursue the prey at night.

Continued research is needed on *S. triaspis*. Our radio telemetry sample size is small, and inferences should be considered preliminary at this point. However, our analysis suggests that a focus on riparian areas may misdirect conservation efforts for the species: rocky hillsides, especially those that are east-facing, may be much more important. If conservation focuses on *S. triaspis* food resources, then efforts to augment or protect lizard populations would also be misdirected given the strict mammalian diet observed.

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GIS and Path Analysis: Examining Associations Between the Birds, the Bees, and Plant Sex in *Echinocereus coccineus* (Cactaceae)

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Abstract—*We tested hypotheses of how pollinators and water resource gradients influence the evolution of dioecy using* Echinocereus coccineus*, a cactus with both hermaphroditic and dioecious populations growing over wide climatic and biotic gradients in the Madrean Archipelago. A GIS database was compiled from herbarium specimens, rainfall data, and hummingbird abundance records. We used structural equation modeling to assess the relative direct and indirect influence of hummingbird abundance and mean annual rainfall on the presence of dioecy. The best fit models contained a direct influence of hummingbird abundance on dioecy; any direct effect of rainfall was negligible. These results support pollinator selection as the major influence on evolution of gender in* Echinocereus coccineus.

Introduction

Most flowering plants require animal pollinators to carry out mating between individuals. However, very few empirical studies have focused on the effect of the behavioral ecology of pollinators on plant mating system evolution. Dioecy is a mating system consisting of separate male and female plants. When it occurs in animal-pollinated species, dioecy may be brought about by a change in pollinators. In many plant families an association between mating system and pollinator specialization has been reported: Species with more specialized pollinators are mostly hermaphroditic, and species with depauperate or small, generalist pollinator fauna tend to be dioecious (Delph 1990; Bawa 1980; but see Renner and Feil 1993). In his review of the evolution of dioecy in flowering plants, for example, Bawa (1980) found examples from four taxonomic groups where, with one exception, all of the hermaphroditic species were bird-pollinated and all of the dioecious species were pollinated by insects. How a shift in pollinator type within one plant species could select for dioecy is not well understood (Renner and Ricklefs 1995). Many authors have proposed that certain types of pollinators produce higher self-fertilization rates when visiting flowers. This higher self-fertilization rate then in turn may select for dioecy to avoid selfing (Bawa 1994; Lloyd 1982; Schultz and Ganders 1996).

The specific genetic conditions that favor evolution of dioecy in plant populations are outlined by Lloyd's outcrossing advantage hypothesis (Lloyd 1975). This hypothesis states that in a hermaphrodite population, if inbreeding depression (relative loss of fitness due to selfing) and selfing rate are both sufficiently high, mutations that eliminate self-fertilization will be selected. Specifically, any completely dominant nuclear mutation that produces a female plant by causing male sterility will increase in a population where loss of fitness in hermaphrodite plants due to self-fertilization is greater than one-half of seed fitness (Lloyd, 1975). Linked modifier mutations in hermaphrodites that produce male plants by causing female sterility can then spread more easily through the population as female frequency increases. Thus, we would expect that if the pollinator assemblage of an outcrossing hermaphrodite population were to change such that selfing increased, and inbreeding depression was high in the population, then this could result in evolution of dioecy if the requisite mutational variation occurs in the population.

Despite its widespread use as an explanation for the evolution of dioecy in animal-pollinated plants, this hypothesis has not been tested empirically. This is probably due to lack of a suitable model species in which populations vary in mating system from purely hermaphrodite to completely dioecious. Most previous studies of dioecy have compared dioecious species to hermaphroditic relatives, and have looked for both biotic and abiotic correlates of dioecy (Bawa 1980). In these systems, however, it is impossible to estimate how interactions with pollinators may have selected for dioecy because it is unknown what the pollinator community composition was at the time when dioecy was initially evolving.

Both pollinator community composition and plant population dynamics respond to changes in resources (Abrams 1995), and interactions among plants, pollinators, and resources can be complex (Schemske and Horvitz 1988; Iriondo et al. 2003). Pollinator distribution and abundance often follow patterns determined by climatic variables. In a study in the mountains of Mexico, Cruden (1972) found that hummingbirds were more effective pollinators at high elevations due to the high incidence of rainfall in these areas. Rainfall gradients could indirectly select for dioecy through their influence on pollinator distribution and abundance (Weller et al.1995; Sakai et al. 1997; Soltis et al. 1996). The mechanism proposed in these systems is that when plants invade drier areas, conditions are no longer favorable for effective pollinators; plants are left with inferior pollinators that may increase the amount of self-fertilization in these populations, and selection favors separation of the sexual functions. An association between rainfall and dioecy has been noted in several studies, but whether it acts directly upon the fitness of the gender morphs or indirectly through its influence on pollinator distributions is still in question. A competing hypothesis proposed by Freeman (1980) states that lack of rainfall produces resource limitation and directly promotes disruptive selection and the resulting niche segregation of male and female plants. Therefore, dioecy could be selected in the absence of any effects of pollinators. This paper describes the first study to jointly test the outcrossing advantage and resource limitation hypotheses within a geographical context in which evolution of dioecy is incipient.

Echinocereus coccineus is an excellent model system to test hypotheses about the effects of pollinator changes and edaphic conditions on the evolution of dioecy. It possesses contemporaneously both hermaphroditic and dioecious populations and possibly gynodioecious populations as well. *Echinocereus coccineus* flowers appear specialized to hummingbirds but are also pollinated by bees. These two floral visitors vary greatly in their pollinating behavior, and based on previous research (Scobell 1999; Scobell 2002; England et al. 2001) we hypothesize that pollination by bees alone will result in a higher selfing rate than that produced when hummingbirds are also present. Distribution and abundance of these pollinator types varies across the geographic range of the plant: both hummingbirds and bees visit flowers in the center of the geographic range, in the areas along the Rocky Mountain/Sierra Madre migration corridor. In the drier, lower altitude areas to the east and west of this range, hummingbirds become rare or absent. Distribution of dioecious populations appears to be associated with areas of low hummingbird abundance, low elevation, and low rainfall (figure 1). Hypotheses we test in this paper include:

- Evolution of dioecy is pollinator-driven: Hummingbirds produce a higher outcrossing rate than bees; therefore, hermaphrodite populations are maintained only in populations with higher hummingbird abundance. In populations lacking hummingbirds, dioecy is selected for by the higher selfing rates bee pollination produces.
- Evolution of dioecy is resource-driven: In arid areas dioecy is selected for due to improved resource allocation of separate male and female plants.
- Evolution of dioecy is driven by a combination of these factors: In the Southwestern United States, both rainfall and pollinator distributions vary with elevation. Pollinators and resources may both be involved in the selection for dioecy in this species.

We used Structural Equation Modeling (SEM) to test these hypotheses. SEM is a statistical technique for solving simultaneous linear equations that combines traditional path analysis with factor analysis (Joreskog and Sorbom 1982). Causal graphs of hypothesized relationships among the data are produced, and then statistically tested, using a chi-square goodness of fit test to select the hypothesis that best describes the data (Shipley 2000).

Several studies have used structural equation modeling (or its predecessor, path analysis) (Wright 1934) to evaluate the direct and indirect influences of pollinators and/or edaphic factors on plant demographics and fitness (Iriondo et al. 2003; Schemske and Horvitz 1984; Mitchell, 1992). Schemske and Horvitz (1984) used path analysis to unravel the complex interactions among pollinators, herbivores, and ant guards and their effects on the number of mature fruits produced by *Calathea ovandensis* (Marantaceae). Iriondo et al. (2003) used structural equation modeling to determine which factors influenced seed production on two different soil types in an endangered plant *Erodium paularense* (Geraniaceae). Mitchell et al. (1992) used path analysis to determine which factors influenced hummingbird approach rate and probes/flower and how much these variables influenced fruit set in *Ipomopsis aggregata* (Polemoniaceae). Each of these studies was able to explore the interactions among the variables and assess their relative influence on the dependent variable (measures of plant fitness) more thoroughly than through linear or multiple regression techniques.

Methods

Study System

Echinocereus coccineus has both hermaphroditic populations (Scobell 1999) and dimorphic populations (Hoffman 1992; Powell 1995) (figure 1). All dimorphic populations that have been tested with hand-pollination crosses between morphs are functionally dioecious (one by Hoffman (1992), one by Powell (1995), and three by Scobell (unpublished data—TCNM, VFNM, and ALTX—figure 1)). We found anecdotal evidence of gynodioecy in three other dimorphic populations observed before and after seed set (Hualupai Mt, AZ (HUAZ), Zion National Park (ZNUT), and Flagstaff, AZ (FLAZ) (figure 1)). In these populations, females are present and some of the hermaphrodite morphs produced seed (1/10 of hermaphrodites in HUAZ, 7/10 in ZNUT, and 9/10 in FLAZ; Scobell, unpublished data). Herein, all dimorphic populations that have been determined experimentally to be dioecious will be termed “dioecious.” All other untested dimorphic populations will be termed “dimorphic.” Further breeding system experiments on northwestern populations of this species are needed to determine the functional mating system of these populations.

Echinocereus coccineus is part of the Triglochidiatus group (Taylor 1985). Members of this group are characterized as cacti that produce large, red, tubular flowers with abundant sucrose-rich nectar. These floral traits are termed hummingbird-syndrome traits (Grant 1967). In previous research, we observed four species of hummingbirds visiting this cactus in the Chiricahua Mountains of southern Arizona (Scobell 2002). The broad-tailed hummingbird (*Selasphorus platycercus*) was the predominant pollinator at all other sites observed, except in the Huachuca Mountains (HUAZ; figure 1) where Anna’s hummingbird (*Calypte anna*) was the sole pollinator (Scobell, unpublished data). However, in a survey of two dioecious populations in central New Mexico, Hoffman (1992)

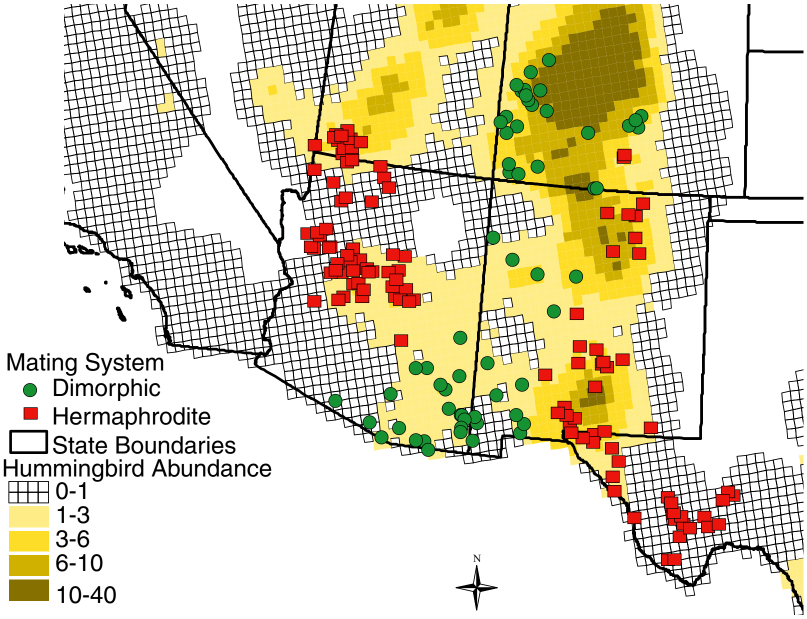

Figure 1—Distribution of dimorphic (dioecious or gynodioecious-red squares) and hermaphroditic (green circles) *E. coccineus* populations in the Southwestern United States superimposed upon a map of hummingbird (broad-tail *Selasphorus platycercus* and black-chinned *Archilochus alexandri*) distribution and abundance obtained from the Audubon Breeding Bird Survey website (http://www.mbr-pwrc.usgs.gov/bbs/bbs.html). Abundance values indicate the average number of hummingbirds seen in 2.5 hours of observation.

found only small halictid bees visiting flowers. Dr. Michael Powell observed that hummingbirds were rare in populations he knew to be dioecious in Texas (A. M. Powell, personal communication).

The hypothesis that variation in pollinator type produces variation in selfing rate rests on the assumption that pollinator types vary in amount of self-pollen they bring to each flower. There are several reasons why we believe this to be the case in this study. Bees require fewer floral visits per foraging bout at *E. coccineus* flowers due to the abundant pollen (approximately 600 stamens; Hoffman 1992) and nectar rewards (35 mg sugar/flower/day, 10x the average hummingbird syndrome flower; Scobell 1999). Most visits by bees recorded in >500 hours of observing pollination of *E. coccineus* are visits within 1 flower or between a few flowers on one plant (Scobell, unpublished data). Only under conditions of severe pollen depletion at the end of flowering do small bees make more trips between plants. Conversely, since the daily energy expenditure of broad-tailed hummingbirds is approximately 23.3 kJ/day, they have to visit >40 flowers per day to meet their energy requirements (Montgomerie and Gass 1981). In his observations on pollination of *Delphinium nelsonii* in Colorado, Waser (1982) found that broad-tailed hummingbirds carried pollen 50-150% longer distances between plants than halictid bees. He estimated that number of plants in the genetic neighborhood (Wright 1969) would increase nearly eight-fold if broad-tailed hummingbirds were the sole pollinator compared to halictid bees (Waser 1982).

Geographic Information System Mapping and Database Compilation

Data on hermaphroditic and dimorphic populations were compiled into a database of over 300 herbarium records. Plants were considered to be from the same population if they were within 1 Km of each other, producing a sample size of 108 populations. All populations were then mapped into a GIS data layer in ArcView 3.3. Populations represented by a herbarium specimen containing female flowers were considered dimorphic. If a flower containing pollen (male or hermaphrodite) was collected within a 30 km radius of a female flower the population of origin of this flower was considered dimorphic as well. These assumptions about the mating system of populations may be overestimating dioecy, but they at least represent populations where selection for dioecy has begun. All herbarium specimen flowers containing pollen that were outside of this 30 km range were considered to come from hermaphroditic populations. These data were coded as 0 = hermaphroditic and 1 = dimorphic. The data layer created by this process was overlain with a data layer of maps of distribution and abundance of broad-tailed and black-chinned hummingbirds. These are the two main species that are present when *E. coccineus* populations are in bloom. These maps are available from the Audubon Society Breeding Bird Survey Database (http://www.mbr-pwrc.usgs.gov/bbs/bbs.html). Mean annual rainfall, in cm, was obtained for each population from the USGS National Atlas Database (http://www.nationalatlas.gov/prismm.html).

Structural Equation Modeling

In order to thoroughly test the hypotheses, associations among the data obtained from the GIS were analyzed using structural equation modeling (SEM). SEM allows for comparison of different causal models (figure 2) using chi-square goodness of fit tests as well as indices such as CFI (Bentler's comparative fit index) and TLI (Tucker-Lewis index). A non-significant chi-square result indicates that the hypothesized model is a good fit to the data (Hayduk 1987). The CFI and TLI fit indices should be over 0.9 as a "rule of thumb" to prevent Type II errors (Bentler and Bonnett 1980). Analyses were carried out with Mplus (Muthen 2002), a free software package that is capable of analyzing a Structural Equation Model that contains categorical dependent variables such as dioecy versus hermaphroditism.

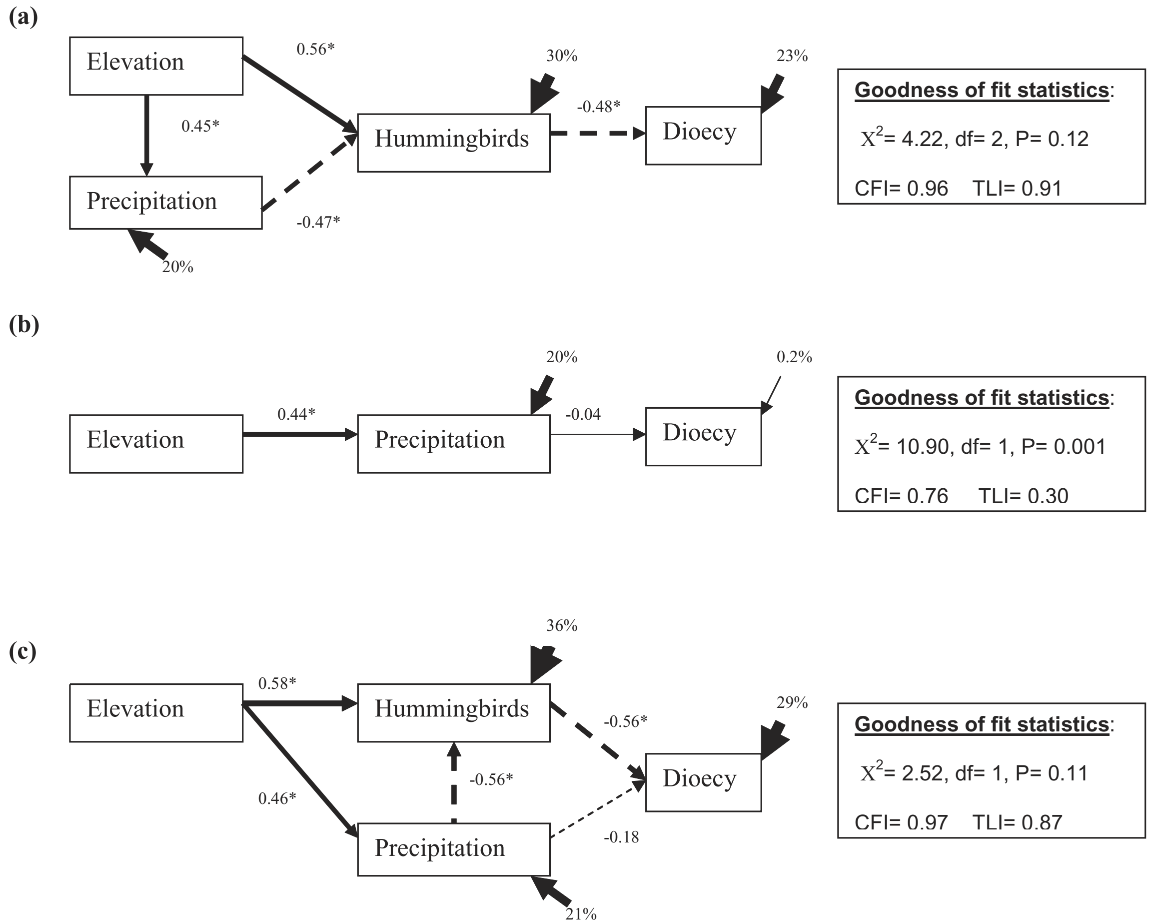

Figure 2—Alternative Structural Models for factors affecting the evolution of dioecy in *E. coccineus*. Numbers indicate value of path coefficients which are the standardized partial regression coefficient for the variables connected by the arrows. Each value represents the independent effect of the variable at the base of the arrow on the variable at the tip of the arrow when all other variables are held constant. Positive paths are shown with solid arrows, negative paths with dashed arrows. Arrow widths are proportional to magnitude of the path coefficients. Asterisks denote paths that are significantly different from zero. Arrows not originating in a variable indicate the amount of variation not explained by the variables in the model. (a) Hypothesis 1: Evolution of dioecy is pollinator-driven. (b) Hypothesis 2: Evolution of dioecy is resource-driven. (c) Hypothesis 3: Evolution of dioecy is driven by both pollinators and resources.

Results

The alternative causal models presented below (figure 2) represent three possible scenarios for how elevation, precipitation, and hummingbird abundance may be directly and indirectly influencing the evolution of dioecy in *E. coccineus*. In the first model (figure 2a) we are testing the hypothesis that only hummingbird abundance is directly affecting the evolution of dioecy in this species. Hummingbird abundance is directly affected by elevation and precipitation, which only indirectly influence the evolution of dioecy. This model is consistent with our data, and has the strongest support out of the three models ($\chi^2 = 4.22$, df = 2, P = 0.11, CFI = 0.962, TLI = 0.906). The negative value for the effect of hummingbirds on dioecy is consistent with the hypothesis that dioecy is associated with areas of lower hummingbird abundance. Elevation is only weakly influencing precipitation and hummingbird abundance. Surprisingly, precipitation is negatively affecting hummingbird abundance, which seems to contrast with the results of Cruden (1972). Possible reasons for this negative correlation will be covered in the discussion.

When this model is compared to the second model (figure 2b), it can be seen that a model with precipitation as the only direct cause of dioecy has a much poorer fit to the data ($\chi^2 = 10.90$, df = 1, P = 0.001, CFI = 0.832, TLI = 0.159). The significant chi-square value makes it clear that this model does not fit the data. The value of the path coefficient from precipitation to dioecy is also not significantly different from zero. This indicates that precipitation is a poor predictor of dioecy in this species.

The third possibility, that rainfall and hummingbirds are both directly influencing the evolution of dioecy, is supported by the data ($\chi^2 = 2.52$, df = 1, P = 0.11, CFI = 0.974, TLI = 0.871), but the path from precipitation to dioecy is not significantly different from zero (95% CI = –0.11 to 0.069). This indicates that the direct effect of precipitation on the occurrence of dioecy is negligible if it exists at all.

All three models have large amounts of the variation in dioecy left unexplained. Future work on this system will use exploratory SEM (Shipley 1997) to determine if including variables such as aspect, temperature, and geologic substrate would improve the explanatory power of these models.

Discussion

There are many advantages to using structural equation models to answer questions about causal relationships between interacting variables. If properly applied, this technique can be used to choose the model that best fits the data by comparing the differences in the model's chi-square statistics (Hayduk 1987). This is not the same thing as proving causality or stating that the selected model is the only causal model that explains the data, but causal models that do not explain the data can be rejected. This is an improvement over conventional path analysis. Using this technique, models can not be statistically tested but can be compared based only on the amount of the variation left unexplained by each model (Sokal and Rolf 1995).

In our case, we can reject model (b) (figure 2b), the hypothesis that rainfall is directly affecting the evolution of dioecy, based on the lack of fit of the model to the data. In this system it appears that a model that includes only direct influence of rainfall as a predictor of dioecy does not adequately explain the distribution of dioecious populations. The effect of rainfall on the presence of dioecious populations is not significantly different from zero. Rejection of this model suggests that Freeman's resource allocation hypothesis for the evolution of dioecy is incorrect for *E. coccineus* (Freeman et al. 1980).

It is interesting to compare models (a) and (c) which were both found to be consistent with the patterns in our data. In both models there is a strong negative effect of hummingbird abundance on the presence of dioecious populations. In other words, dioecious populations are more likely to be found in areas with low hummingbird abundance. When precipitation is included in the model as a direct effect, it has a very small effect (that is not significantly different from zero) in relation to hummingbird abundance. Even though the trend is as predicted by Freeman et al. (1980) with a negative association between precipitation and dioecy, the effect is negligible compared to the effect of hummingbirds.

The strong negative relationship between annual precipitation and hummingbird abundance is at first confusing, considering that both hummingbird abundance and precipitation are shown to increase slightly with elevation, and the GIS shows the highest abundance of hummingbirds at the highest elevations. However, since the data for rainfall and hummingbird abundance were gathered only in places where the cactus populations exist, the natural history of the cactus changes the distribution of the data. These cacti prefer to grow on the drier southeastern slopes of the Sky Islands. Therefore data were not gathered in this study for areas with precipitation levels higher than the tolerance level of this cactus. This leaves out areas that have both high precipitation and high hummingbird abundance.

The findings of these models support the hypothesis that pollinator behavior may be selecting for the evolution of dioecy in this system. To test this hypothesis further, experiments where plants were caged to produce bee pollinated and hummingbird + bee pollinated treatment groups were carried out in six populations in 2000-2003. Microsatellite data will be used to determine if bees produce higher selfing rates than hummingbirds.

The combination of GIS and SEM in this paper in conjunction with the incipient evolution of dioecy has allowed the first combined test of both the inbreeding avoidance hypothesis and the resource allocation hypothesis for the evolution of dioecy. Future work will focus on the effects of hummingbird pollination on gene flow within and between populations of *E. coccineus* across the Madrean Archipelago. The results of this research may have implications for the conservation of many plant species that depend on hummingbirds for pollination.

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Black Bear Abundance, Habitat Use, and Food Habits in the Sierra San Luis, Sonora, México

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Abstract—*We studied black bears to determine habitat use, food habits, and abundance between April 2002 and November 2003 in the Sierra San Luis, Sonora. We utilized transects to determine spoor presence, camera traps for abundance, and scat analysis. During 2002, bears fed principally on plant material, and for 2003 on animal matter, namely livestock. Habitat use differed between years and seasons. In general terms, we recorded black bears more frequently during 2002 than 2003, attributing this change to a lack of resources, fruits, and water in our study area.*

Introduction

Black bear populations in Mexico have been severely affected by many adverse factors such as habitat loss, poaching, and illegal trade among others. Consequently the species is classified as "endangered of extinction" by Mexican laws (SEMARNAT 2002). Species distribution is poorly known in Mexico, only having verified records for the Mexican states of Sonora, Chihuahua, Coahuila, Nuevo León, Zacatecas, and Durango. The bear's historical distribution is thought to have been reduced by 20% (SEMARNAP 1999). To date, black bears in Mexico have only been studied to detail in Coahuila (Doan-Crider 1995). This lack of information prevents the formulation of sound management decisions concerning the conservation of black bears in Mexico. The main objectives of this study are to determine food habits, habitat use, and abundance of Mexican black bears in the Sierra de San Luis, Sonora.

Study Area

During the 2002-2003 period we studied black bears at El Pinito ranch (68.8 km^2), located in the Sierra San Luis, Sonora, between 108° 56' 46'' N latitude and 31° 11' 49'' W longitude (figure 1). The area according to the Mexican national forestry inventory is covered by pine forests, pine-oak forests, pine-oak forests with second growth, open low forest, grasslands, and chaparral (Palacio-Prieto et al. 2000). The second year of the study (2003) was characterized by the El Niño phenomenon, exacerbating the already harsh drought conditions of the area.

Methods

We used wildlife and human-made trails in El Pinito to set up transects of 3 km length between April 2002 and early December 2003 to detect patterns of habitat use and food habits by black bears. We walked these trails every other week, looking for spoor (i.e., footprints and scats). We complemented habitat use data with camera traps (Camtracker™) placed along the trails, nine in 2002 and six in 2003. We used commercial sardines to attract black bears. Camera traps were checked every three weeks, to replace the batteries and review if any photo was taken. Survey periods were divided into three biologically meaningful seasons: dry (April 20 to July 5, 2002, and April 2 to July 31, 2003), wet (July 6 to October 9, 2002, and August 1 to October 8, 2003) and dry-II (October 10 to November 23 in 2002 and 2003). We covered approximately 156.35 km^2 in 2002 and 187.22 km^2 in 2003.

Food Habits

Black bear diets were determined by examining scats collected from the different trails during the two-year study period. As scats were collected, date and location were recorded. All droppings were washed, air dried, and analyzed in the laboratory. The scats were separated by year and season of collection. Food items were sorted and identified to the smaller taxonomic category. The relative frequency and the consumed biomass were determined for each food item for the two years and the three seasons within a year using the following methods.

Relative frequency (RF) was calculated using $FR = fi / F \times 100$ where: fi = number of scats where an item appears and F = number of total frequencies of all items in all scats (Martínez, 1994; Hidalgo, 1998). Biomass consumed (BC) was calculated using $BC = (RFi \times CF) / \Sigma (RFi \times CF) \times 100$ where RFi = relative frequency of the item; CF = the correction factor of the item. The following correction factors were used according to Hewitt and Robins (1996): leaves, sprouts, and flowers = 0.26; roots and fruits = 0.93; hard mast = 1.5; insects = 1.1; small mammals and birds = 4; hair = 15; and bones and skin = 1.5.

We used Jaccard's similarity index to determine how similar the diets between years and seasons were, $CC_J = c/ s_1 + s_2 - c$ where s_1 and s_2 is the total number of items per year or season and c is the number of shared items (Brower et al. 1998).

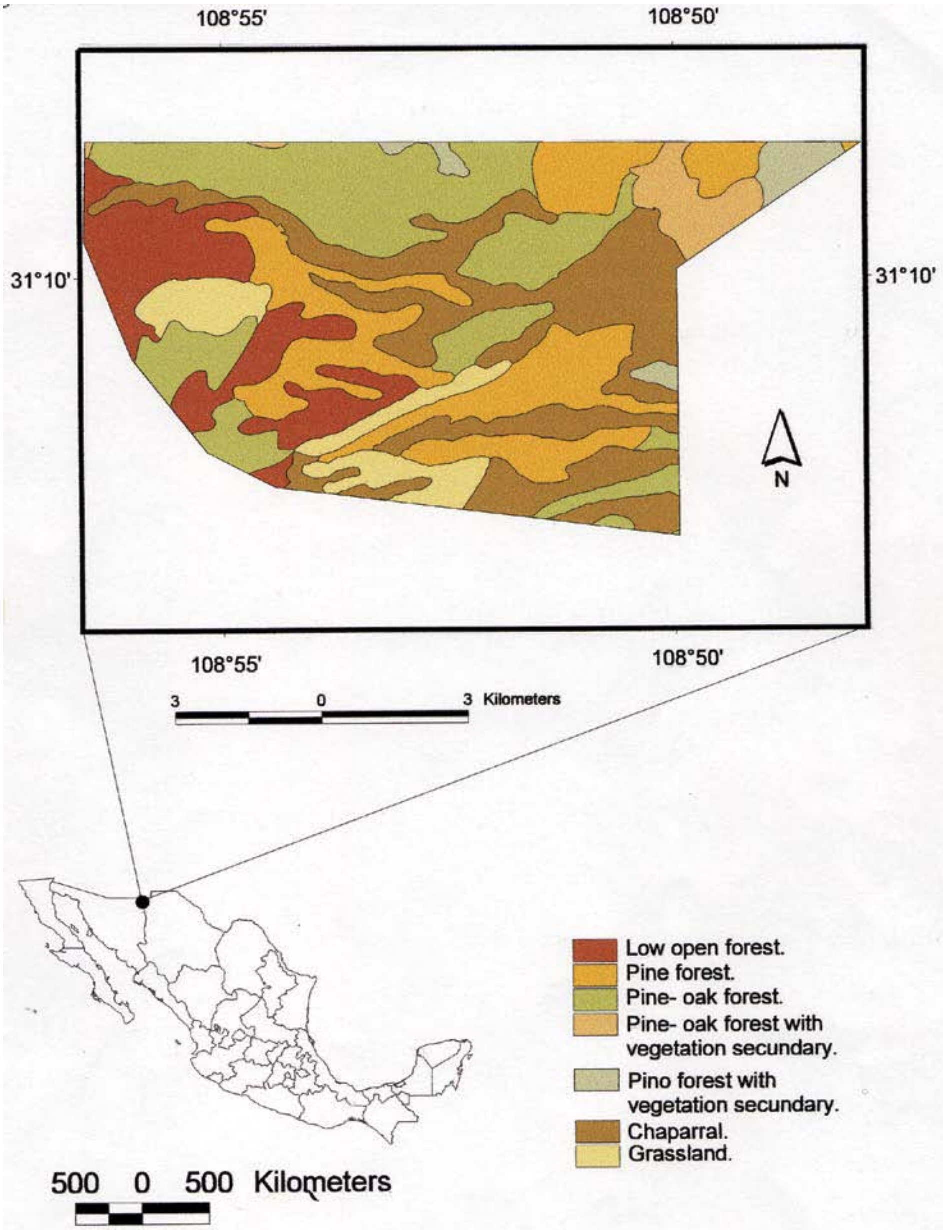

Figure 1—Vegetation types in the El Pinito ranch located in the Sierra San Luis Sonora, Mexico.

Habitat Use

For the habitat selection we combined spoor (scats and footprints) and photographic data gathered for the two years (and three different seasons) to determine use of different vegetation types. These data were plotted using ArcView v.3.2 (ESRI 1999) creating a Geographic Information System (GIS). We used the National Forestry Inventory classification layer to determine which plant associations were used each year and season. In order to determine significant differences between years we used Chi-square analysis and Bonferroni intervals to determine preference, no preference, or use as expected by chance (Byers et al. 1984).

Abundance and Density

We obtained two measures of abundance using camera trap data (24 hrs) within the seasons and the two years. The first method uses the number of days of all cameras until the first photo is taken; for this data we use the equation $Y= 133.89\ x^{-0.971}$ (Carbone et al. 2001) where Y is the number of trap days until the first photo was taken and X is the number of individuals in 100 km^2. The relative abundance was calculated as the number of total photographic records taken within a season divided by the total number of camera trap days times 100.

Results

Food Habits

During 2002 we analyzed a total of 180 scats (66 dry, 65 wet, and 49 dry-II), with a total of 24 prey items (12 animal items and 12 plant material), and 47 scats for 2003 (32 dry, 13 wet and 4 dry-II) for a total of 16 prey items (8 plants and 8 animals).

Table 1—Food items and the consumed biomass estimated for the study period.

	Total		Dry		Wet		Dry-II	
Food items	**2002**	**2003**	**2002**	**2003**	**2002**	**2003**	**2002**	**2003**
Arctostaphylos pungens	27.1	2.1	39.3	2.8	25.3		11.3	
Juniperus deppeana	34.0	22.8	10.9	18.6	32.9	42.0	71.2	20.0
Dasylirion wheeleri	2.8	0.9	5.7	1.0	1.7	0.6	0.3	
Herb	1.8		1.7		1.8		1.8	
Quercus sp	8.2	1.7	6.9	2.2	10.7		6.1	
Yucca bacata	2.2	0.3	1.8	0.5	0.6		5.6	
Nolina bigelovii	0.4	0.8	0.7	0.9	0.3	0.6		
Opuntia		2.4		0.5		8.0		8.3
Pinus sp	0.3		0.7		0.2			
Prunus persica	0.9	0.3		0.5	2.2			
Seed 1	0.2		1.8					
Seed 2	0.7		0.6					
Seed 3	0.2		0.6					
Odocoileus virginianus	4.3	11.1	7.9	7.4	2.7		1.5	66.8
Bos taurus	1.4	50.0	4.0	59.6		32.3		
Conepatus mesoleucus	0.4		1.0					
Spilogale putorius	0.4		1.0					
Birds	1.9				4.7			
Opilionids	0.5		0.7		0.7			
Diplocentrus peloncillensis	1.8	0.4	0.7	0.5	3.3		1.1	
Formicidae	5.2	1.6	7.3	1.6	6.5	2.4		
Vespidae	2.6	0.4	3.6		3.3	2.4		
Apidae	0.3		0.7					
Orthoptera	1.3		0.7		2.0		1.1	
Coleoptera	1.0	0.8	1.5		1.3	4.7		
Homoptera		4.1		3.8		4.7		4.9
Molusca		0.4				2.4		
N/ period	24	16	22	13	17	10	9	4

For 2002, black bear diets were composed by vegetational items through the consumption of manzanita (*Arctostaphylos pungens*) and junipers (*Juniperus* sp.) representing 61.1% of the total BC. In contrast, consumption of manzanita and juniper in 2003 was drastically reduced by 92.6% and 33% respectively. Bears were more carnivorous by increasing the use of livestock by 97.3% and up to 61.1% in white-tailed deer, with these two species composing more than 60% of the total BC during that year. In addition, we report the consumption of scorpions (*Diplocentrus peloncillencis*), an item that has never been reported as having been eaten by bears. Jaccard's index was 0.48 confirming changes in the composition of the items used by black bears.

Dry Season

During 2002, the main items consumed by black bears were manzanita, junipers, white-tailed deer, and ants representing 65.4% of the total BC. In contrast, in 2003 bears fed mostly on livestock and white-tailed deer, adding up to 66.9% of the total BC for that season (table 1). During the dry season, the similarity index was 0.4.

Wet Season

For 2002, the most important prey items were junipers and manzanita representing 58.2% of the biomass, whereas during 2003 junipers and livestock accounted for 74% of the BC (table 1). For this season, the similarity index was 0.28 showing a very different diet for both years.

Dry-II Season

We found the least diverse diet for both years during this season (table 1). During 2002, junipers and manzanita accounted for 82.5% while in 2003, white-tailed deer accounted for 66.8% of the diet. The similarity index for this season was only 0.18 showing a dramatic change between prey items used by black bears in the different years.

Habitat Use

We obtained a total of 916 records (730 for 2002 and 186 for 2003). For 2003 we found a higher habitat use of oak-pine forest ($0.250 > P < 0.384$), pine forest with second growth ($0.054 > P < 0.139$), and grasslands ($0.063 > P < 0.152$) than

Table 2—Use of the communities in the study period where (+) = significantly higher use in 2003 compared to 2002; (-) = significantly lower use in 2003 compared to 2002; and (=) = proportional use in both years.

	General			Dry season			Wet season			After wet season		
Community	2002	2003	Use	2002	2003	Use	2002	2003	Use	2002	2003	Use
Low open forest	28.82	15.05	-	27.01	13.61	-	34.5	21.88	=	21.96	14.29	=
Pine forest	16.12	12.09	=	14.98	5.44	-	14.7	40.63	+	19.06	42.86	=
Pine forest with secondary vegetation	0	9.68	+	0	10.68	+	0	0	-	0	28.57	=
Pine-oak forest	14.98	31.72	+	10.92	40.14	+	11.5	0	-	23.36	0	-
Pine-oak forest with secondary vegetation	4.56	2.69	=	3.45	1.36	-	7.99	9.38	=	0.47	0	-
Chaparral	31.81	17.20	-	39.66	14.97	-	30.03	28.13	=	28.04	14.29	=
Grassland	3.71	10.75	+	4.02	13.61	+	1.28	0	-	3.71	0	-

in 2002. Open low forest and chaparral were less used in 2003 than in 2002 (table 2). During the dry season, we recorded an increase in the use of pine-oak forest, pine forest with second growth, and grasslands compared to 2002, where black bears used the other communities less than expected (table 2). For the wet season there was significant increase in the use of pine forest; as expected, bears used open low forest, chaparral, and pine-oak with second growth (table 2). For the 2003 dry-II season, black bears avoided pine-oak forest, pine-oak with second growth, and grasslands and used the remaining communities as expected (table 2).

Abundance and Density

We obtained a total of 134 photographs (96 in 2002 and 38 in 2003). For both years, we recorded a higher relative abundance during the dry season than either the wet season or the dry-II season (figure 2). The difference in abundance can be related to densities estimated per sampling period. For 2002, we determined a density of 6.9 (± 7) individuals/100 km^2, with a minimum density during the wet season (2.64 ind/100 km^2) and an intermediate density during the dry-II season (6.0 ind/100 km^2) and the highest density during the dry season (8.91 ind./100 km^2). For 2003, the overall density was lower with 4.15 (± 6.12) individuals/100 km^2, and no individuals recorded during the dry-II (figure 3).

Discussion

We found ample differences in black bear behavior during the two years of field work. During 2002 we found bears using a higher diversity of food items, concentrating on plant matter similar to that reported by other authors (i.e., Maehr and Brady, 1984; Leopold, 1985; Hellgren, 1993; Stubblefield, 1993; Beecham and Rohlman, 1994; Doan-Crider, 1995). Manzanita was gradually replaced by junipers in 2002 as the result of their respective fruiting period (USDA Forest Service 2003; Orth, 1995). Sotol is an important water source used in stressful months and appeared most frequently in scats from the dry period (Bolger, 1994; Hellgren, 1993). For 2003, junipers were used throughout the seasons. The low consumption of plant material was apparently related to low or no available resources produced during this year, due to El Niño, which exacerbated

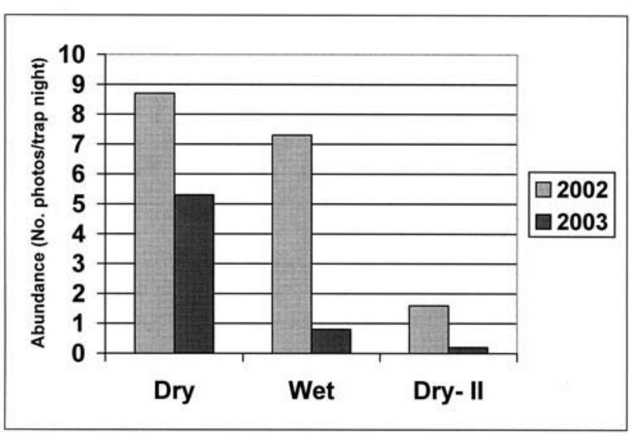

Figure 2—Black bear relative abundance index within different seasons.

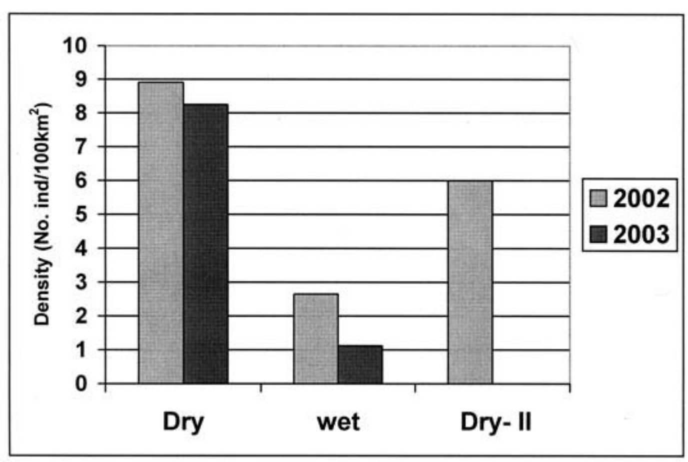

Figure 3—Black bear density estimates for the different sampling seasons.

drought (data on file, ranch owners of the region, Alfredo Varela and Manuel Gómez,). This drought was the probable cause of a higher ingestion of livestock, without a further distinction of scavenging or hunting. Doan-Crider (2002) noted a similar behavior during a year of low production of fruits. Finally, it is important to mention the presence of scorpions (*Diplocentrus peloncillensis*), as this is the first time it has been recorded as part of the diet of black bears.

We recorded changes in the utilization of habitat types by black bears during the two years, mainly attributed to fruit productivity and water availability, factors that are critical for black bear survival (Beecham and Rohlman, 1994, Hellgren, 1993). The most important category in terms of food production was the chaparral (LeCount, 1983; Stubblefield, 1993; Doan-Crider, 1995). Habitat use in the dry season of 2003 could be related to the presence of habitats adjacent to livestock production areas, concordant with an increase in livestock use. Similarly Beecham and Rohlman (1994) mention that black bears travel to new areas looking for complementary sources of energy. Pine forests were avoided in 2002, but they were highly used during 2003, probably related to water available in this habitat as there was no other source throughout the ranch. This factor has been characterized as a determining factor for bear productivity in other areas (Lyons et al. 2003).

A combination of low food productivity and drought apparently was reflected in the abundance and density having a reduction of 30% in relation to the first year of the study. Nevertheless our densities can be considered as relatively low compared to similar areas, such as Coahuila (Doan-Crider 1995, 72.46 ind/100 km^2) or Arizona (96-200 ind/100 km^2, LeCount 1982 and 1990).

Conclusions

During 2002 the prevailing environmental conditions of the study area favored a high diversity diet, coupled with a higher density and abundance of black bears in the study area. During 2003, distinct climatic conditions modified black bear behavior in terms of habitat use and they became more carnivorous with a dispersed distribution to complement the lack of food and water resources.

Importantly, there were many complaints from ranchers about livestock depredation by black bears during 2002, when livestock ingestion was minimal. Although cattle consumption was significantly higher during 2003, ranchers filed no depredation complaints. Eradicating bears to solve a depredation problem is a misguided solution. It is necessary to determine real depredation rates and determine livestock mortality causes. We believe that increasing water sources for black bears in the prime habitat will reduce the number of bear-livestock incidents by dispersing black bears into neighboring areas.

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Fire

Effects of Fire on Sonoran Desert Plant Communities

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Abstract—*The number of fires has increased during the past 45 years in the Sonoran Desert within the Tonto National Forest of central Arizona. The positive trend in the number of fires was consistent with an increase in the population of Maricopa County and an increase in traffic along major Sonoran Desert highways in the Tonto National Forest. The number of hectares burned did not change with increased population in Maricopa County or increased traffic along Sonoran Desert highways. However, number of hectares burned was influenced by the occurrence of two and three consecutive winters' precipitation. Overall plant density decreased as canopy cover increased on a time-since-fire (tsf) gradient. Native species most impacted by fires were saguaro (*Carnegiea gigantea*) and foothill paloverde (*Cercidium microphyllum*).*

Introduction

Native Sonoran Desert plants lack fire-adapted characteristics, and their discontinuous spacing indicates that recurring fires were not significant in the long-term ecological history of the Sonoran Desert (Rogers 1986; Smith and others 1997). However, the changing fire regime in the Arizona Upland Subdivision of the Sonoran Desert has been an increasing concern during the past three decades. Increased fire occurrence could alter Sonoran Desert vegetation by removing several species, including the indigenous saguaro (*Carnegiea gigantea*) from plant communities (Cave and Patten 1984; Rogers and Steele 1980; Rogers 1985; Smith and others 1997; Wilson and others 2000). The spatial and temporal variation of fire in the Sonoran Desert appears to be highly sensitive to changes in climatic and anthropogenic activities. Climate and human activities influence fire regimes through their effects on fuel condition and fire ignition (DeBano and others 1998; Veblen et al. 2000). Precipitation and temperature govern the amount of vegetation that is produced and the moisture content of the fuels. Human activities often provide an ignition source to the fuels. The objective of this study is to determine which anthropogenic and climatic factors significantly influence the number of fires and number of hectares burned annually in the Sonoran Desert ecosystem, and determine the recovery of Sonoran Desert plant species on a time-since-fire (tsf) gradient.

Methods

Study Area

The study area consists of the Sonoran Desert ecosystem on the Tonto National Forest (TNF) in central Arizona. The study area is typical of the Arizona Upland Subdivision (Shreve 1951), characterized by: saguaro, foothill palo verde (*Cercidium microphyllum*), creosote bush (*Larrea tridentada*), catclaw acacia (*Acacia greggii*), white thorn acacia (*Acacia Constricta*), mesquite (*Prosopis* spp.), bursage (*Ambrosia deltoidea*) and brittle bush (*Encelia farinosa*).

It generally extends from Phoenix north to Sunflower, and from the east side of Roosevelt Lake to Interstate Highway 17 on the west. Mean annual precipitation, during the past 45 years was 368 ± 19 mm of which 34% fell during winter (December-February), 18% during the spring (March, April and May), 22% during the summer (June-August), and 26% during the fall.

The number of fires and hectares burned were extracted from the Forest's individual fire reports. Population of Maricopa County and annual 24-hour traffic on State Highways 87 and 60 were used as anthropogenic factors that potentially affect the number of fires and hectares burned. The climatic factors consisted of seasonal and annual precipitation in the study area from 1953 through 2000 extracted from the National Oceanic Atmospheric Administration (NOAA) Climate Data Center records. The monthly totals from the Bartlett Lake, Stewart Mountain, and Roosevelt Lake Weather Stations were averaged to represent the Sonoran Desert moisture regime on the Tonto National Forest. Individual seasonal precipitation, combinations of seasons, and combinations of years of precipitation were used as variables affecting number of fires and number of hectares burned.

The anthropogenic and climatic factors were used as independent variables in a stepwise regression analysis to determine their power to influence the number of fires and hectares burned.

Table 1—A description of the study sites.

Study site	Year burned	Fire age category time-since-fire (tsf)	Time of year burned	Hectares burned
River Fire	1995	<5 years	July	3,845
Vista Fire	1993	5–15 years	May	36
Bush Highway Fire	1976, 1983, 1993, 1994	Repeat burns	May and June	40-200
Massacre Fire	1983	15–20 years	July	1,335
Siphon Fire	1979	20–25 years	June	283

Five previously burned sites were selected for determining the effects of fire on Sonoran plant communities. These were compared with adjacent unburned sites. The burned sites represent a stratum of time-since-fire of less than five years, five to ten years, ten to fifteen years, fifteen to twenty years, and twenty to twenty-five years (table 1). One site had repeated fires between 1976 and 1994.

A random-systematic design (Barbour ant others 1999) was used to compare plant height, cover, and density between burned and control plots in the five burn sites. Five 100 m X 100 m (one hectare) homogeneous macro-plots were located within the burned area of each study site, and in adjacent control areas. Within each macro-plot, four randomly located 100 m transects were established. Canopy cover was measured by the line intercept method, in which the length of the intercept of canopy was measured for each species (Cox 1996). The height of each plant that intersected the line was recorded. The same 100 m line was used to form the center of a 2 m X 100 m belt transect. Density was estimated by counting the number trees, shrubs and perennial plants in the belt transects. The number of saguaro was counted within each 100 m X 100 m macro plot.

Results and Discussion

Climatic and Anthropogenic Influences on Sonoran Desert Fire Regimes

The annual number of fires increased sharply from 1955 through the early 1980s and stabilized somewhat from 1990 through 2000 (figure 1). The relationship between both human population and traffic, and the number of fires in the Sonoran Desert, was significant (P = <0.05); however, these factors were not significantly (P = <0.05) related to the number of hectares burned.

There was a significant increase (P = 0.05) in numbers of fires with increased annual precipitation, winter precipitation, two consecutive winters precipitation, three consecutive winters precipitation, and spring precipitation. However, summer precipitation, fall precipitation, and consecutive summer and winter precipitation did not have a significant relationship to the number of fires. Summer precipitation appears to have an inverse relationship to the number of fires, but the relationship was not significant.

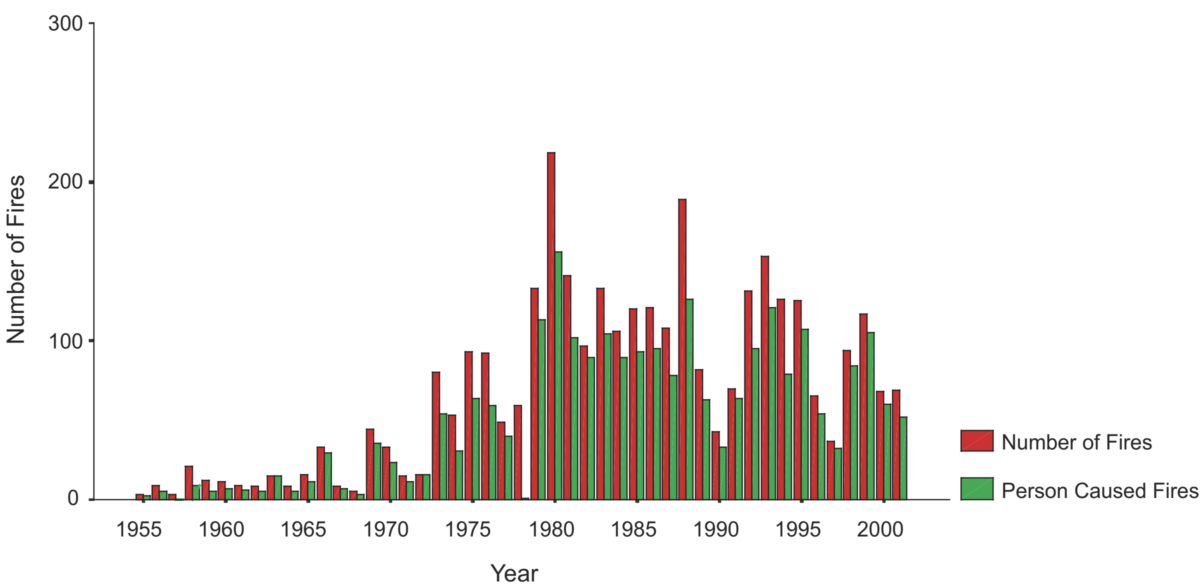

Figure 1—Total fires and person caused fires in the Sonoran Desert on the Tonto National Forest from 1955-2000.

The number of hectares burned increased with an increase in two and three consecutive winters' precipitation, and consecutive winter and spring precipitation; however, the number of hectares burned were not affected by the increase in population of Maricopa County or the increase in traffic on SH 87 and 60. The strongest variables for predicting the number of fires were "traffic" and "three consecutive winters' precipitation," while three consecutive winters precipitation was the strongest variable for predicting the numbers of hectares burned.

This study shows an interaction between the heavy anthropogenic activities, and arid early summer preceded by one to three consecutive wet winters. These conditions yield a vigorous fire season in late spring-early summer. The summer monsoons sharply reduce the incidence of fire in the Sonoran Desert by increasing fuel moisture and unfavorable fire conditions such as increased relative humidity.

Effects of Fire on Sonoran Desert Plant Communities on a Time Since Fire Gradient

The number of plant species decreased as time fire increased. However, canopy cover increased along the tsf gradient. The similarity of total canopy cover between the burned and control plots increased with time (figure 2). Canopy cover on the burned plots was 24% of the control plots on the River Fire (5 tsf) whereas the similarity of canopy cover between burned and controlled plots was 75% on the Siphon Fire (21 tsf). With this model one could predict that total ground cover would recover after approximately 28 years.

Saguaro and foothill paloverde were noticeably removed by fire from the burned plots in all but the Siphon Fire, which showed no significant difference in density of saguaro and a

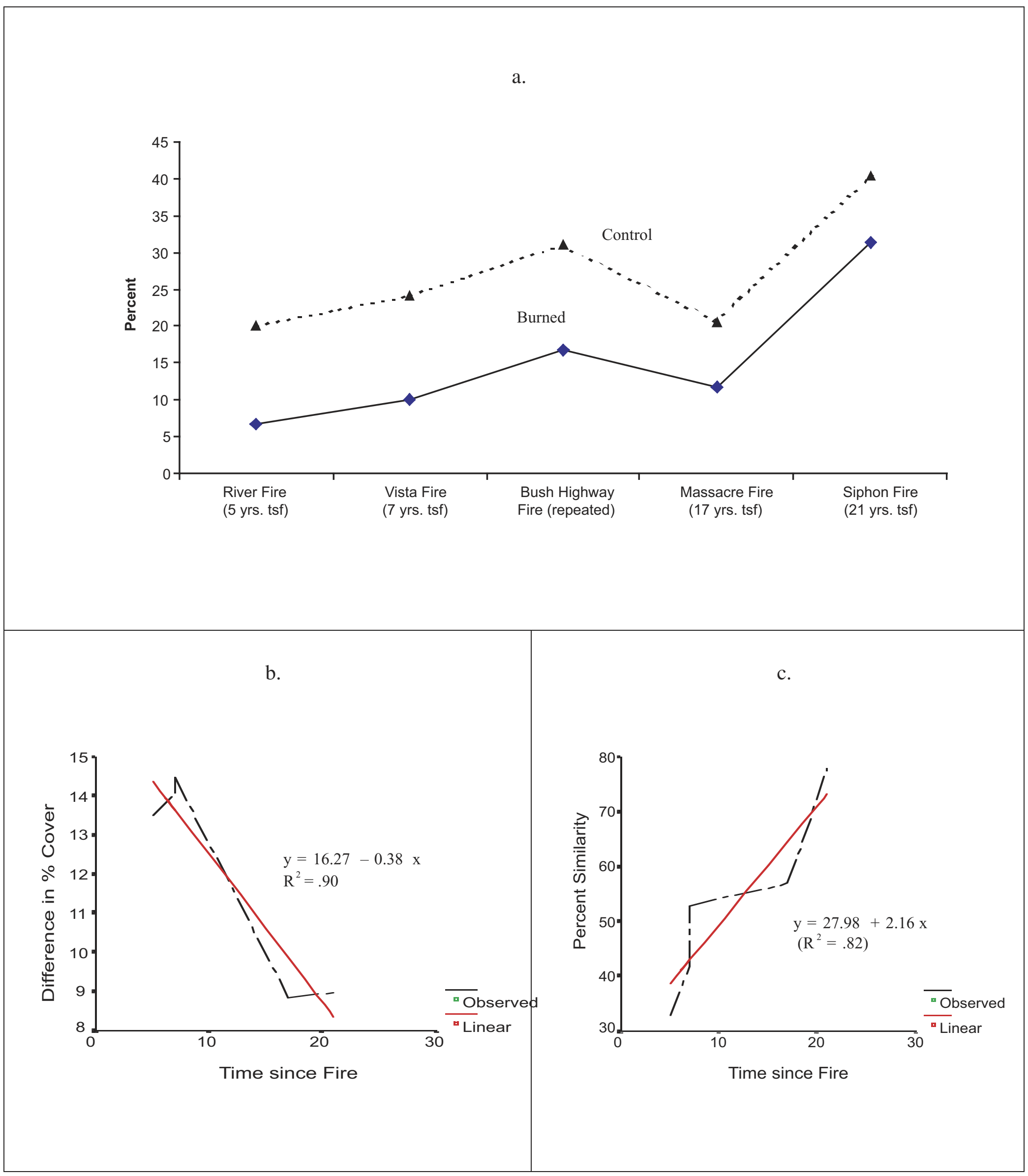

Figure 2—Canopy cover response to tsf. a. shows the canopy cover of burned and control plots; b. shows the difference in canopy cover between control and burned plots on a tsf gradient; c. shows the similarity between the burned and control plots on a tsf gradient.

small significant increase in density of foothill paloverde. It is difficult to conclude that saguaro has recovered on the Siphon Fire, since the pre-fire density is unknown and the recovery after fire is rare. However, 32 % of the saguaro in burned plots were <0.6 m in height. It takes 30 to 40 years for the saguaro to reach 1 m in height (Steenbergh and Lowe 1983; Pierson and Turner 1998). Therefore, plants that are 0.6 m should be 18 to 24 years old, within the time since the Siphon fire event. The 32% of the saguaro that were <0.6 m in height included plants that were a few centimeters up 0.6 m in height. Therefore, it is concluded that there was at least some recovery of saguaro on the Siphon Fire.

The Bush Highway Fire (repeated) appears to be the site most influenced by fire because of the loss of native Sonoran Desert vegetation. The highly significant increase in density and/or canopy cover of purple three-awn (*Aristida purpurea*) and senna (*Cassia Armata*), and the decrease in native species such as saguaro, foothill paloverde, white ratany (*Krameria grayi*), creosote bush (*Larrea tridentada*), and wolfberry (*Lycium berlandieri*) indicates that shrubs and nurse trees are being replaced with lower growing plants.

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Madrean Pine-Oak Forest in Arizona: Altered Fire Regimes, Altered Communities

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Abstract—*In Madrean pine-oak forests in the Chiricahua Mountains, surface fire favors pines, which exhibit high top-survival, but resprouting allows oaks to rebound during inter-fire periods. These patterns plus age structure and radial growth data suggest that frequent presettlement surface fire maintained open stands, promoted a high pine:oak ratio, and excluded less fire resistant species—patterns reversed by a century of reduced fire. Recent anomalous stand-replacing crown fires have further transformed some stands: most oaks resprouted but pine establishment was sparse, exacerbated by a protracted drought. This synthesis argues for the careful and flexible use of fire to restore more open pine-oak stands.*

Introduction

Prior to Euro-American settlement, lightning fires shaped much of the forest land of the Western United States and Northern Mexico, including the Madrean Archipelago (Fulé and Covington 1996; Marshall 1962; Swetnam and others 2001). Reduction in fire frequency, beginning in the mid-19th century in the United States and more recently in Mexico, has radically changed the structure, composition, and processes of many of these forests (Allen and others 2002; Covington and Moore 1994; Fulé and Covington 1996; Rodriguez-Trejo and Fulé 2003; Swetnam and others 1999, 2001). This context is essential for understanding most aspects of the evolution, ecology, and conservation of the Madrean Archipelago ecoregion.

The purpose of this paper is to synthesize past research on fire-driven dynamics of Madrean pine-oak forests in the Chiricahua Mountains in southeastern Arizona. As in most pine and oak dominated forests in this region, frequent surface fires characterized the presettlement fire regime (Swetnam and others 1989, 1992, 2001). I will, accordingly, first address the intrinsic differences in response to these fires between the pines and the oaks in the Chiricahuas. Understanding these contrasting responses is central to any general conceptual model of the fire-driven dynamics, anthropogenic changes, and restoration of Madrean pine-oak communities. Second, I will examine the impacts of a century of fire exclusion on stand structure, the ratio of pines to oaks, and the presence of fire sensitive species. One of the effects of fire exclusion in pine-oak communities in the Madrean Archipelago has been increased fuel loads, which has led to stand-replacing fires generally outside the range of natural variability for these systems (Fulé and others 2000; Swetnam and others 1999, 2001; see Moore and others 1999). My final goal, then, is to summarize my recent research on the transforming community effects of crown fires, as well as the exacerbating influence of coinciding drought.

Study Site and Fire History

The Chiricahua Mountains are located in southeastern Arizona in Cochise County, U.S.A. (31° 52' N, 109° 15' W), in the northern part of the Madrean Archipelago. The mountains extend southeast to northwest for about 80 km and rise from about 1,100 to 3,000 m altitude. The climate is semi-arid, with two wet seasons, one in July-September, when more than 50 percent of total precipitation falls, and the second December-March. A pronounced dry season usually occurs between the final winter storms in March or April and the onset of the rainy season in July (Sellers and others 1985).

The Chiricahuas support a wide diversity of desert, Petran, and Madrean communities (Barton 1994; Brown 1982). This study focused on Madrean pine-oak forest (Mexican oak-pine woodland subtype #3; Brown 1982), the most abundant community type between 1,650-2,050 m. The major tree species are *Pinus leiophylla* (Chihuahua pine), *P. engelmannii* (Apache pine), *P. arizonica* (Arizona pine; *P. ponderosa* var. *arizonica*), *Quercus hypoleucoides* (silverleaf oak), *Q. arizonica* (Arizona white oak), and *Q. emoryi* (Emory oak).

A three-century fire history of Rhyolite Canyon in the Chiricahua Mountains (Swetnam and others 1989, 1992; see also Barton and others 2001) revealed a fire regime characterized by frequent (every 5-15 years), low-severity surface fires, similar to results for other Madrean pine-oak forests (Fulé and Covington 1996; Swetnam and others 2001). Fires were often synchronous, suggesting extensive fires the length of the canyon. This inferred synchrony was interrupted, possibly as a result of flood events (Swetnam and others 1991), from 1801-1851, when fires ceased in most of middle Rhyolite but continued in lower Rhyolite. Fire frequency declined drastically beginning in the 1870s, probably as a result initially of intensive livestock grazing and then fire suppression (Bahre 1995; Swetnam and others 2001).

Methods

This paper synthesizes data from five different sources. Details for each of these can be found in the references provided.

1. Population age structures were constructed for pines and *Quercus hypoleucoides* in lower Rhyolite Canyon (Barton 1999; Barton and others 2001), and for pines and *Pseudotsuga menziesii* in Cave Creek Canyon (see Barton 1994 for site details). Increment cores were prepared and cross-dated using standard dendrochronology practices. Seedling growth was used to estimate age at coring height where appropriate.
2. To examine the relationship between tree radial growth and fire, ring widths were measured to the nearest 0.001 mm for 77 *P. arizonica* trees from Rhyolite Canyon that germinated before 1860 (Barton and others 2001).
3. I quantified the responses of two pines (*P. leiophylla* and *P. engelmannii*) and four oaks (*Q. hypoleucoides*, *Q. arizonica*, *Q. emoryi*, and *Q. rugosa*) to recent low-severity fires (Barton 1999). In each fire, which had occurred during the previous 10 years, data were collected along belt transects on top-kill, resprouting, and seedling establishment. Using this retrospective approach, I calculated stand data for each species for pre-fire, immediate post-fire, and actual sample period 3-10 years after fire.
4. I collected similar data for *P. leiophylla*, *P. engelmannii*, and *Q. hypoleucoides* for two stand-replacing crown fires. Sampling was carried out in 1999 in the 10,330-ha 1994 Rattlesnake Fire and in 1992 in the 23-ha 1983 Methodist Fire (Barton 2002). Data were collected along belt transects, in areas of complete top-kill, on resprouting, height of resprouts, and number and height of seedlings.
5. The Rattlesnake Fire was resampled in 2003 for resprouts and seedlings in 16 plots in each of three types of burned areas: "interior," >75 m inside the perimeter of the area in which all canopy trees were top-killed (crown fire perimeter); "edge," 5-30 m inside the crown fire perimeter; and "periphery," 5-100 m outside the crown fire perimeter. The expected relative soil moisture of these 48 sample plots was assessed using the Topographic Relief Moisture Index (TRMI; Parker 1982) to examine its potential role in pine establishment patterns.

Results and Discussion

Presettlement Madrean Pine and Oak Dynamics

Pines and oaks exhibited contrasting responses to low-severity fires characteristic of the presettlement fire regime. Pines were fire resistant, with high levels of top-survival, whereas oaks were fire resilient, with lower top-survival but prolific resprouting (table 1). *Pinus leiophylla* also resprouted after top-kill but at much lower levels than for oaks. As a result of these responses, low-severity fire favors pines in the short-term, but resprouting allows oaks to increase relative to pines during inter-fire periods (Barton 1999; see Fulé and others 1996, 1997).

Age structures reveal, similarly, that pine individuals persisted through many fires, whereas *Q. hypoleucoides* stems arose in a narrower window of time after the last series of frequent fires in 1850-1870 (figure 1). Although pines survived fire well, their establishment was closely tied to periods of relatively low fire frequency (figure 1). In fact, number of pine stems for a given decade is negatively correlated with number of subsequent fires but not correlated with number of past fires (Barton 1999; Barton and others 2001). These results suggest that regeneration of these pines requires, in addition to other factors, fire-free periods sufficient to allow growth to a height that provides resistance to subsequent fires.

These studies taken together (see also Fulé and others 1996, 1997; Rodriguez-Trejo and Fulé 2003), then, suggest a presetttlement Madrean pine-oak forest in which occasional pulses of pines arose, many of which persisted in open stands for centuries through frequent surface fires. Oaks also probably persisted for long periods of time, but many of them were forced to resprout repeatedly after top-kill from these fires, which maintained them at relatively low cover levels. Other important but less common tree species in these communities also appear to follow the resprouting strategy of oaks (e.g., *Arbutus arizonica*; Barton, in press).

Table 1—Oak and pine top-survival, resprouting, and seedling establishment after low-severity and high-severity fires[a].

Fire name	Fire severity	Top-survival		Resprouting		Seedlings	
		Oaks	Pines	Oaks	Pines[b]	Oaks	Pines
		pct. (n)	pct. (n)	pct. (n)	pct. (n)	#ha^{-1}	#ha^{-1}
Rhyolite III	Low	53.2 (124)	84.9 (33)	44.8 (58)	0.0 (5)	9680	5900
Rhyolite T	Low	39.6 (265)	61.1 (36)	56.2 (160)	0.0 (8)	1400	950
Methodist 1	Low	11.0 (154)	50.4 (141)	59.1 (137)	11.6 (43)	2140	640
Methodist 2	Low	18.8 (218)	63.7 (55)	43.5 (177)	12.5 (16)	980	480
Animas	Low	30.5 (128)	69.5 (95)	38.2 (89)	6.9 (29)	2690	30
Rattlesnake	High	0.0 (355)	0.0 (217)	90.1 (355)	23.2 (164)	150	77
Methodist	High	0.0 (63)	0.0 (55)	92.0 (63)	13.3 (15)	30	70

[a]Sampling carried out 3-10 years post-fire in belt transects; for details on methods and data for individual oak, pine, and other species, see Barton (1999, 2002).
[b]*Pinus leiophylla* included only; *P. engelmannii* does not resprout.

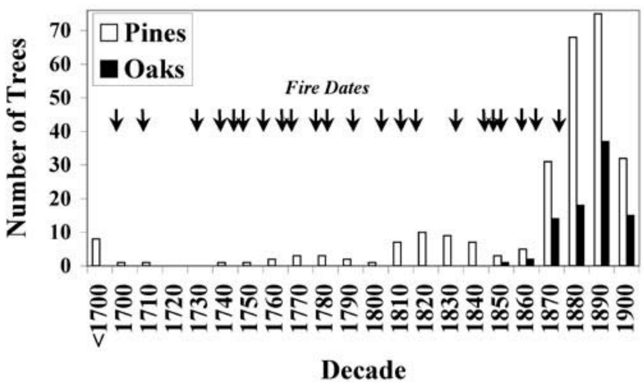

Figure 1—Age structure of pines (*Pinus engelmannii* and *P. leiophylla* combined) and oaks (*Quercus hypoleucoides*) in Rhyolite Canyon in relation to fire dates. Fire dates are from Swetnam and others (1989, 1992; see Barton and others 2001).

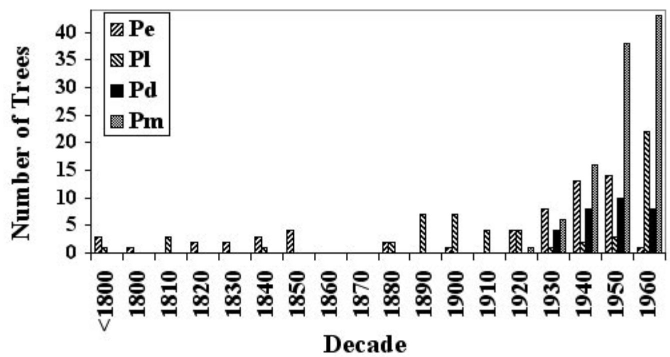

Figure 2—Age structure evidence of recent invasion of *Pseudotsuga menziesii* (Pm) and *Pinus discolor* (Pd) in a stand of *P. engelmannii* (Pe), *P. leiophylla* (Pl), and *Quercus hypoleucoides* (data not shown) in Cave Creek Canyon. All stems at least 2 m tall were cored in 1.75 ha (Pm), 0.5 ha (Pd), 0.3 ha (Pe), and 1 ha (Pl).

Community Response to Reduced Fire Frequency

Reduction in fire frequency has resulted in major changes in the structure and composition of Madrean pine-oak forests in the Chiricahuas. Age structures reveal large increases in the density of all species beginning in the late 1800s, coincident with the reduction in fire frequency (figure 1; see also Fulé and others 1996, 1997; Rodriguez-Trejo and Fulé 2003). This suggests again that frequent presettlement fires maintained stands with more widely spaced trees than today (see also Mills 2002).

P. arizonica radial growth declined in the 20th century in association with fire reduction and increased stand density (Barton and others 2001). Superposed epoch analysis demonstrated that presettlement fires did not generally lead to growth releases (Barton and others 2001). However, as in the 20th century, radial growth was significantly reduced during the 50-year fire hiatus in middle Rhyolite, an effect not recorded in lower Rhyolite where fires continued unabated (Barton and others 2001). Apparently, stands were generally so open during presettlement times that growth was stimulated through fire-caused thinning only after an unusually long inter-fire period.

Both age structures and responses to low-severity fires suggest that the ratio of pines to oaks was higher during presettlement times than today. Furthermore, frequent fire appeared to exclude *P. discolor* and *Pseudotsuga menziesii*, species with fire-sensitive juveniles, which have recently invaded some pine-oak sites (figure 2). Interestingly, *P. menziesii* is a relatively shade tolerant species invading from moister, generally higher elevation sites, whereas *P. discolor* is a large-seeded, relatively shade tolerant pinyon (Barton 1993), invading from drier, generally lower elevation sites (see also Mills 2002).

Community Response to Anomalous Crown Fires and the Exacerbating Influence of Drought

In areas subject to complete top-kill (table 1), most oaks resprouted. *P. leiophylla* exhibited low levels of resprouting, which nonetheless could be an important source of pine recruitment. Seedlings were rare for all three species, much lower than after low-severity fires (table 1). Oak seedlings and resprouts were significantly taller than those of pines (Barton 2002). Several years after high-severity fire, then, fast-growing oak resprouts had formed a dense, coalescing canopy over sparse pine seedlings and resprouts. These results suggest that anomalous crown fires can transform complex Madrean pine-oak forests into more homogenous oak woodlands, perhaps for decades if not centuries (see also Fulé and others 2000).

Resampling in Rattlesnake Fire nine years post-fire revealed continued very low seedling densities, no higher than for five years post-fire and an order of magnitude lower than for before the fire (1988; table 2). The especially low establishment levels for interior parts of the crown fire might suggest unfavorable conditions created by severe fire effects. However, three types of data suggest that curtailed establishment is at least exacerbated by an extended dry period. First, precipitation in the eight years before the 1988 was substantially higher than for the eight years after the fire (2003; figure 3). Second, values for the Topographic Relative Moisture Index differed significantly among fire areas in the same order as seedling abundance: periphery > edge > interior ($P = 0.01$; table 2). In fact, the number of pine seedlings in a plot was positively related to this index of soil moisture ($P = 0.0002$; figure 4). Finally, *P. engelmannii*, a species with abundant seedlings in 1988, had almost no seedlings as of 2003. This species is substantially less drought tolerant than *P. leiophylla* (Barton 1993), and its near absence in these sites, which are near its lower (drier) elevational boundary, is likely a result of drought.

Restoration of Madrean Pine-Oak Forest

This synthesis reveals major changes in Madrean pine-oak forests resulting from a reduction in surface fires. Increases in stand density, the ratio of pines:oaks, and the abundance of fire intolerant species are direct effects that are likely to continue.

Table 2—Number of pine sprouts and seedlings before (1988), five years after (1999), and nine years after (2003) the Rattlesnake Fire. Topographic Relief Moisture Index (TRMI) is also given for the three types of areas sampled in 2003.

	Periphery[a] (2003)	Edge[a] (2003)	Interior[a] (2003)	I & E[b] (1999)	Pre-Fire[c] (1988)
	mean/ha (SE)	**mean/ha (SE)**	**mean/ha (SE)**	**mean/ha (SE)**	**mean/ha (SE)**
P. leiophylla sprouts	50.0 (16.1)	67.5 (14.5)	17.5 (6.3)	93.3 (19.9)	NA[c]
P. leiophylla seedlings	187.5 (48.4)	110.0 (30.4)	17.5 (8.9)	60.0 (30.6)	1002.5 (278.5)
P. engelmannii seedlings	7.5 (4.0)	12.5 (6.0)	2.5 (2.5)	16.7 (6.0)	677.5 (129.5)
# of Plots	16	16	16	12	10
TRMI[d]	36.3 (1.5)	29.9 (1.4)	19.1 (1.1)		

[a] Interior: >75 m inside perimeter of the area in which all canopy trees were top-killed by the fire (crown fire perimeter); Edge: 5-30 m inside the crown fire perimeter; Periphery: 5-100 m outside the crown fire perimeter.
[b] I&E: Interior and Edge; Periphery were not sampled in 1999.
[c] Since no recent fire had occurred, juvenile plants of sprout and seedling origin were not distinguished. For details, see Barton (1993, 1994).
[d] Larger values indicate higher expected soil moisture availability. Means are significantly different: $F_{2,45} = 5.1$, $P = 0.01$.

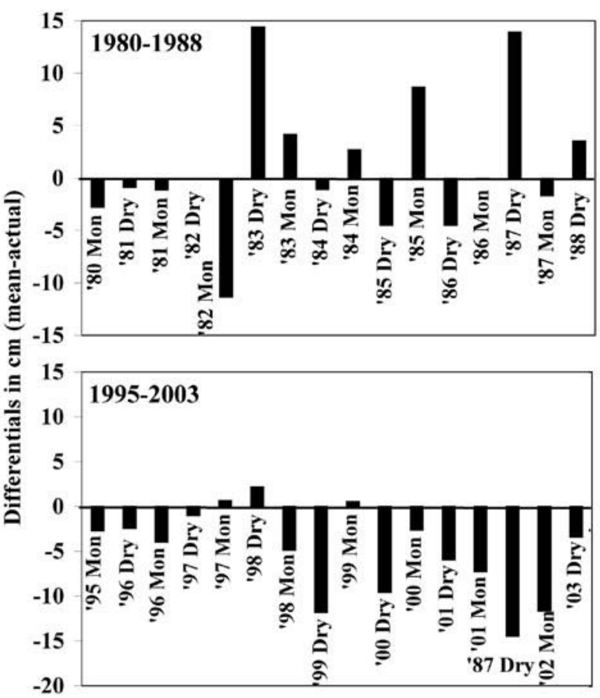

Figure 3—Precipitation records for 1980-1988 and 1995-2003 for the National Weather Station Portal 4 SW—within four km of the Rattlesnake Fire study area. Data are provided for two periods each year: July-October ("monsoon") and the rest of the year ("dry"). For each period, recorded precipitation is subtracted from the long-term mean (1965-1994) for that portion of the year.

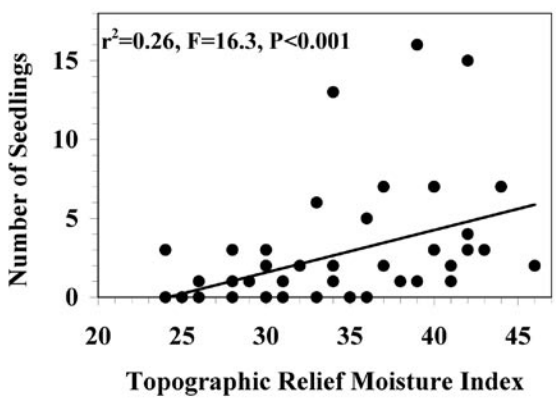

Figure 4—Regression of number of seedlings (in 250-m^2 plots) of *Pinus leiophylla* against Topographic Relative Moisture Index, which estimates expected moisture availability. Statistical results are for regression of log (x + 1) transformed data (to correct non-normality of residuals).

Anomalous crown fires, however, pose an increasing and equally serious threat by drastically reducing the abundance of pines. The results discussed here suggest that the impacts of such fires might depend strongly on their timing, especially relative to drought.

This synthesis argues for the use of fire to restore more open pine-oak stands, bearing in mind the following caveats. Madrean pine-oak forest varies tremendously in pine and oak composition over its range from the borderlands to far south in the Sierra Madre Occidental (Rodriguez-Trejo and Fulé 2003). Presettlement fire regimes also exhibited substantial variation over time and among mountain ranges (Swetnam and others 2001). Finally, burning areas with dense oak thickets without igniting crown fires might be a serious challenge for fire managers (C. Baisan, personal communication). These caveats suggest the need for a variety of careful and flexible restoration approaches (see Allen and others 2002; Rodriguez-Trejo and Fulé 2003).

Acknowledgments

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Greater Huachuca Mountains Fire Management Group

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Abstract—*The Greater Huachuca Mountains Fire Management Group is developing a fire management plan for 500,000 acres in southeast Arizona. Partner land managers include Arizona State Parks, Arizona State Lands, Audubon Research Ranch, Coronado National Forest, Coronado National Memorial, Fort Huachuca, The Nature Conservancy, San Pedro Riparian National Conservation Area, and private ranches. The plan will guide cross-jurisdiction collaborations on wildland fire use, prescribed burns, suppression, and non-fire fuels reduction around developed and other sensitive areas. Group members have outlined the plan and assigned major tasks to themselves. This paper serves as a spring 2004 progress report on the group's activities.*

Introduction

The Greater Huachuca Mountains Fire Management Group (FMG) brings together public and private partners from the San Pedro River on the east through the Patagonia Mountains on the west (figure 1). The chief goal of the group is to jointly manage fire activities over the 500,000-acre area. Collaboration among landowners in the planning area began in 1996. The benefits of managing for fire on a broad landscape scale such as the greater Huachuca area are numerous. Foremost are:

- Increased public and fire crew safety
- Widespread improvement in ecosystem function
- Economical execution of fire activities

The collaboration also focuses on efficient communication about fire, responsible protection of sensitive resources, and border issues. In addition to land managers, participants from University of Arizona have come to the table—parties with fire-related projects in the planning area (Department of Geography, Institute for the Study of Planet Earth, School of Natural Resources, and USGS Sonoran Desert Research Station). Other cooperators include local fire departments, Arizona Department of Game and Fish, Immigration and Naturalization Service, and U.S. Fish and Wildlife Service (USFWS). Collaborators are also soliciting Mexican partners. The FMG intends to continue working together on regular updates of this plan.

Historically, fire burned frequently in the grasslands and woodlands of southeastern Arizona. Fire history studies in the vegetation types present in the Huachuca group planning area have detected fire return intervals of roughly 4–20 years before the suppression era began (Abbott 1998; Danzer 1998; Kaib et al. 1996; Swetnam and Baisan 1996). Regular fire keeps shrubs out of grasslands, thins forests to remove fire-intolerant trees, increases streamflows, and renews wildlife habitat. Fire also prevents fire. Burning can minimize potential for wildfires by reducing overall quantities of fuels and breaking up contiguous vegetation. To facilitate more fire on the landscape and treatment of hazardous fuels, FMG partners are developing a fire management plan (FMP) to guide collaborations on fire program activities and allow projects to cross political boundaries. To achieve even a conservative (longer versus shorter) desired fire return interval of 20 years across the vegetation communities of the planning area, the group needs to think big and be ready to treat 25,000 acres per year.

Group Dynamics

There is no mandate holding the Huachuca FMG together other than policies that encourage cross-jurisdictional cooperation on fire. Individual representatives are serving with the blessing of the organizations they represent, for the most part unsupported by funds earmarked for this activity. How does such a group stay together? In a review of literature on cooperative planning as it might apply to fire management, Stapp (2003) found five factors that promote effective collaboration:

- Shared, vested purpose or goal that is not achievable by individual group members
- Willingness of each party to contribute to the collective effort
- Continuity of participation that allows group members to get to know, respect, and like one another
- Flexibility on the part of organizations represented that allows innovative pursuits
- Credible, strong leadership

After an initial pulse of activity in 1996, the FMG remained relatively dormant until the large wildland fires in the spring of 2002 affected the Sierra Vista Ranger District of the Coronado National Forest, Fort Huachuca, the Audubon Research Ranch, the Babocomari Ranch, and other private lands in the planning

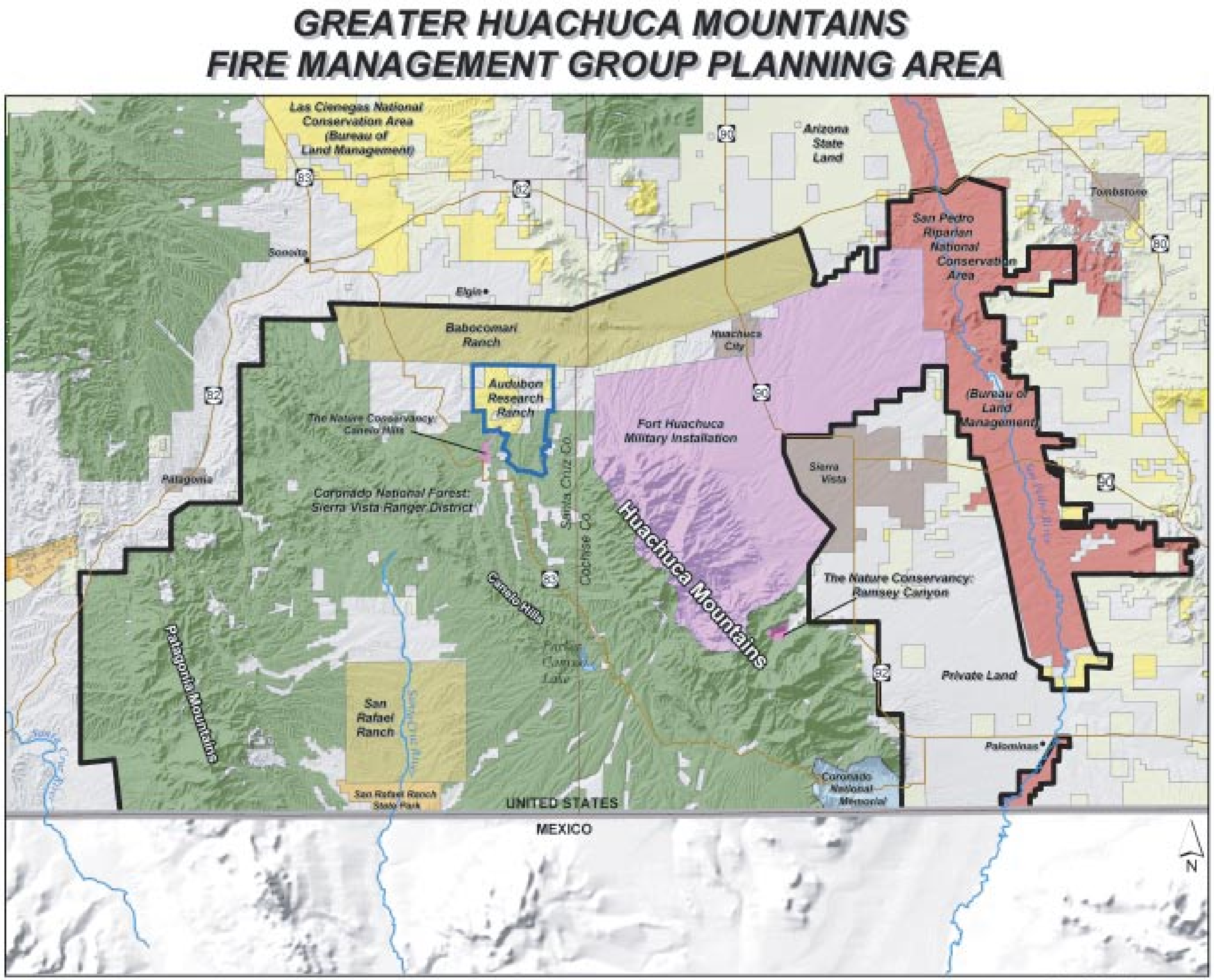

Figure 1—Greater Huachuca Mountains Fire Management Group planning area.

area. In the fall of 2002 Nature Conservancy spearheaded a FMG restart. The reformed group is overtly paying attention to the above factors and the challenges of (1) maintaining the alliance and (2) making genuine progress on the FMP. We have also come to appreciate ourselves as our best resource. Group field exercises contribute needed new data and provide opportunities for members of this diverse group to become better acquainted. As of spring 2004, four partners have acquired funding from their agencies that is covering small amounts of their time as well as buying student help and local outreach assistance. We recognize that completing this cooperative fire plan will strengthen the FMG's ability to attract funding for fuels projects in the region.

Progress Report

The contents of the greater Huachuca plan embody material that applies to all land manager partners. Together the group is defining for the planning area:

- Ecological mapping units
- Fire ecology and history
- Regional environmental issues
- Protection guidelines for listed species, sensitive cultural resources, and unique sites
- International border considerations
- Fire management units
- Inventory of regional operational resources
- 10-year plan for fuels treatments
- Outreach program

Federal managers and other members of the group are required to write their own FMPs according to internal standards. Use of the shared information in this plan is meant to reduce the effort required to produce those individual partner plans. Members adopt this plan then append it to their own documents or vice versa. The following sections review progress on the plan as of spring 2004.

Mapping Units

We are looking at the planning area landscape in three different ways: ecological mapping, fire management units (FMUs), and special treatment zones. Ecological mapping delineates natural units where fire regime, fire behavior, and desired effects of fire are relatively uniform. A separate paper in these proceedings (Laing et al. 2004) explains 12 ecological mapping units developed for the FMG area. These units have been defined as a composite of slope, geology, landforms, vegetation, soils, precipitation and temperature, elevation, and hydrologic characteristics. They serve as the framework for developing ecological goals for fire program activities and are recognizable as distinct by area land and fire managers. Members of the FMG have received training in fire regime condition class (FRCC) assessment and are evaluating vegetation of each ecological mapping unit. FRCC is a calculated departure from natural fire regime that has been promoted nationally as a tool to help standardize discussion of wildfire risk and prioritize the distribution of fuels treatment funds. The FMP fire ecology discussion will lump these 12 types into a more manageable list of structural vegetation types: desertscrub, grassland, Madrean woodland, mixed conifers, and riparian.

At a second level, FMUs denote areas where particular fire management strategies are permitted. Land use, condition, and neighbors will determine applicability of (1) wildland fire use (allowing natural ignitions to burn); (2) appropriate management response (suppression); (3) prescribed fire; and (4) non-fire fuels treatments. The third level of organization identifies special treatment zones, where particular needs within an ecological mapping unit or fire management unit dictate fire activities. Presence of special status species, riparian areas, sensitive cultural resources, or residential development could necessitate deviation from ecological mapping or fire management unit goals. A session with cultural resources experts from the group's four Federal agencies identified rock art and flammable structures eligible for listing on the National Register as the area's most fire-sensitive and culturally significant resources.

Regional Environmental Issues

The FMG scoped regional environmental issues to provide a shared basis for NEPA analysis. We narrowed down an extensive list of possible areas of concern to the following:

- Life and property: Fire is an effective tool for reducing fuels, but it is also a threat to people and developed areas. Juxtaposition of wilderness and wildland-urban interface complicates fire management.
- Community economics and land use: Property values can be reduced by adjacent burned landscapes, but owners who apply firewise measures can increase values. Local tourist-based businesses may experience temporary declines if visitation drops due to fire-related concerns, but businesses may also benefit from providing supplies and services for fire operations. Fire can improve forage for wildlife and livestock.
- Border concerns: Proximity to the international border brings danger to and from illegal immigrants and drug operatives in fire project areas and limits use of tactical tools; it also brings opportunities to cooperate with Mexican resource managers on fire projects, particularly training and suppression activities.
- Sensitive species: Fire could directly kill or injure listed, rare, or charismatic plants and animals, but fire also promotes reproduction in fire-adapted plants and renews wildlife habitat. Negative short-term effects lead to long-term gain, in many cases.
- Exotic species: Fire may aid invasion and spread of some exotic species but may also prove to be a control tool for others.
- Cultural resources: Historic structures, landscapes, and artifacts may incur fire damage, while fire may help reduce surrounding hazard fuels and maintain the historic scene.
- Watershed integrity: Fire can remove vegetation from slopes and cause increased erosion and downstream sedimentation until plants regrow. Removing vegetation also changes soil moisture regimes and flows in springs and streams. Fire can

Table 1—Federally listed species within the Fire Management Group Planning Area.

Species	Status	FMG-area habitat
Species that may travel through the area but are likely not to be affected by fire activities		
Jaguar (*Panthera onca*)	E	Madrean woodland
Species that occur in wet places immune from direct effects of fire but susceptible to post-fire sedimentation		
Canelo ladies tresses (*Spiranthes delitescens*)	E	Cienegas in the Canelo Hills
Huachuca water umbel (*Lilaeopsis schaffneriana* ssp. *recurva*)	E	Wetlands throughout planning area; 4,000-6,500 ft
Gila topminnow (*Poeciliopsis occidentalis occidentalis*)	T	Small streams, springs, cienegas below 4,500 ft with aquatic vegetation and debris for cover; Santa Cruz drainage
Chiricahua leopard frog (*Rana chiricahuensis*)	T	Canyons with perennial water and stock tanks; 3,300-9,000 ft
Spikedace (*Meda fulgida*)	T	San Pedro River
Sonoran tiger salamander (*Ambystoma tigrinum stebbensi*)	E	South end of Canelo Hills; 4,000-6,300 ft
Huachuca springsnail (*Pyrgulopsis thompsoni*)	C	Possibly in wetlands throughout planning area; 4,500-7,200 ft
Loach minnow (*Tiaroga cobitis*)	T	San Pedro
Gila chub (*Gila intermedia*)	PE	Smaller streams, cienegas, impoundments on west side of Huachucas; 2,000-3,500 ft
Species that would be affected if riparian habitat burned		
Southwestern willow flycatcher (*Empidonax traillii extimus*)	E	San Pedro River
Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*)	C	San Pedro River and possibly riparian woodlands throughout area
Bald eagle (*Haliaeetis leucocephalus*)	T	Seen at Parker Canyon Lake
Species requiring careful project-by-project consideration		
Lesser long-nosed bat (*Leptonycteris curasoae yerbabuenae*)	E	Cave/mine roosts, *Agave palmeri* foraging areas
Mexican spotted owl (*Strix occidentalis lucida*)	T	Closed-canopy, uneven-aged forest stands and canyons, 4,100 to 9,000 ft
Pima pineapple cactus (*Coryphantha scheeri* var. *robustispina*)	E	Far west side of planning area

E = Endangered: Species is in danger of extinction throughout all or a significant portion of its range. (PE = Proposed endangered.)
T = Threatened: Species is likely to become endangered within the foreseeable future.
C = Candidate species: USFWS has sufficient information on their biological status and threats to propose them as endangered or threatened under the Endangered Species Act, but development of a listing regulation is precluded by other higher priority listing activities.

also cause short-term changes in soil and water chemistry. Long-term, fire will decrease woody vegetation and increase herbaceous vegetation which should result in decreased water run-off and soil erosion and increased infiltration (diffuse aquifer recharge).

- Plant communities: Fire may change the character of unique habitats within the planning area, but fire may also return plant communities to historic species compositions and structures. Widespread, high-intensity fires can lead to destructive vegetation type conversion.
- Recreation and wilderness: Fire activities may temporarily interfere with recreational use of planning area lands, but long-term fuels reduction and ecological benefits ultimately can make recreation safer and more enjoyable. Fire operations can disrupt wilderness values, but presence and effects of fire help maintain the integrity of wilderness.
- Aesthetics: During fire operations equipment noise and smoke disturb visitors and nearby residents. Burnt landscapes are unattractive to many people, but education about the benefits of fire can help build tolerance and even appreciation.

Special Status Species

Managing fire in the greater Huachuca area requires paying attention to numerous Federally listed species as well as those protected by other agencies. Table 1 is a list of the species protected by the Endangered Species Act that the FMG must consider across its 500,000-acre planning area. The FMG is working with USFWS to develop consistent fire program conservation measures for these species. We are using the approach developed for the FMP—creating a blanket report on these species that forms the basis of compliance documents. As we define a set of specific projects, we will be working further with USFWS on a programmatic consultation that covers all the partners. Special treatment zones, mentioned above in the mapping discussion, have been proposed for Mexican spotted owl protected activity centers and riparian and wetland areas that are habitat for many species appearing in table 1.

Regional Operational Resources

The FMG has compiled a list of the fire management resources present in the region. The inventory covers vehicles, miscellaneous equipment, and personnel and certifications for four Federal agencies, six local fire districts, two non-profit organizations, and the State of Arizona.

Challenges

As we complete the FMP, moving from writing to taking action is the biggest challenge facing the Greater Huachuca Mountains FMG. We will also need to take the plan to the public, and each agency will face integrating its practices with the direction of the group. At present, the group remains committed to executing projects that require collaboration to succeed—that cannot be carried out by parties acting alone.

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We thank all the members of the Greater Huachuca Mountain Fire Management Group for their hard work. The success of the group is particularly dependent on the people who, along with the authors, have their names assigned to the FMP outline: Barbara Alberti, Shelley Danzer, Cori Dolan, James Feldmann, Mark Fredlake, Bill Gillespie, Dave Gori, Steve Gunzel, Kevin Harper, Jim Hessil, Sara Jensen, Linda Kennedy, Larry Laing, Jaylene Lineback, Wayne Lackner, Keith Lombardo, Barbara Morehouse, Alix Rogstadt, Sherry Tune, Joan Vasey, Carly Voight, Bill Wilcox, and Brian Wooldridge.

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No Positive Feedback Between Fire and a Nonnative Perennial Grass

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Abstract—*Semi-desert grasslands flank the "Sky Island" mountains in southern Arizona and Northern Mexico. Many of these grasslands are dominated by nonnative grasses, which potentially alter native biotic communities. One specific concern is the potential for a predicted feedback between nonnative grasses and fire. In a large-scale experiment in southern Arizona we investigated the interaction between fire season and Lehmann lovegrass, a perennial bunchgrass from Southern Africa. We observed a slightly increasing proportion of Lehmann lovegrass over time. However, this trend is not linked to fire regime. Biomass on most plots has not recovered two to three years after fire.*

Introduction

Nonnative grasses alter fire regimes in a variety of systems (D'Antonio and Vitousek 1992). Among the three requirements for fire (fuel, oxygen, and heat), introduced grasses may alter the fine fuel component; more specifically they can change fuel continuity, abundance, or composition and in turn alter the size, frequency, and intensity of fire. For example, in the eastern Sonoran Desert where fires had not occurred because of lack of fine fuels, invasion of buffle grass (*Cenchrus ciliarus*), red brome (*Bromus rubens*), and fountain grass (*Pennisetum setaceum*) destroyed native plant communities where fire-sensitive species exist (e.g., Schmid and Roger 1988). On some sites in the Great Basin, cheat grass (*Bromus tectorum*) stands have replaced sagebrush communities by increasing fire frequency and size thus preventing recovery of fire-sensitive sagebrush (Whisenant 1990). In these areas where fire had about a 30-year return interval a majority of grassland plant species resprouted after fire or established quickly from the seed bank and were gradually replaced by species that are less fire tolerant. Thus, nonnative grasses that recover quickly and exclude native species may increase fire frequency. In addition, nonnative grasses may increase fire intensity in fire-adapted systems. An African grass, *Melinis multiflora*, introduced into the Brazilian savanna produces resinous biomass that can burn in 95% relative humidity and prevents regrowth of native species (Klink and Moreira 2002). In these ways, nonnative grasses may alter fire regimes, including fire spread, frequency, and intensity. These changes may induce a positive feedback whereby the nonnative grass is benefited by and influences fire regimes to the detriment of the native plant communities (D'Antonio and Vitousek 1992).

Prior to Anglo settlement, fire in semi-desert grasslands occurred with a mean frequency of about 10 years (McPherson 1995). Unlike wetter grasslands such as the tallgrass prairie, semi-desert grasslands are constrained by erratic precipitation and produce relatively little fine fuel. Additionally, semi-desert grasslands support a discontinuous fuel source because the communities are dominated by perennial bunchgrasses that are widely spaced. The influence of nonnative grasses on fire regimes in this system depends on site characteristics. Upland sites support a discontinuous fine fuel layer of bunchgrasses because soils typically are shallower and precipitation tends to run off. Bottomlands have deeper soils than uplands and water tends to collect in these areas, thereby supporting considerable biomass. Historically, fires likely could spread through these areas more frequently than on uplands because bottomlands were covered by a continuous fine fuel source and often had sufficient soil water to allow grasses to recover quickly. As a result, nonnative grasses are expected to have a greater influence on fire frequency and intensity on uplands than on bottomland sites.

In southeastern Arizona, Lehmann lovegrass (*Eragrostis lehmanninana*), a nonnative perennial grass, was introduced in the 1930s for livestock forage and erosion control. Lehmann lovegrass may have a positive feedback with fire because it produces more biomass than many native grasses (Cox et al. 1990b) such as *Aristida purpurea* and *Hilaria belangeri* and its germination is enhanced by fire (Ruyle et al. 1988). Lehmann lovegrass originated in a fire-dominated system in Southern Africa and now covers a large portion of the American Southwest. Upland sites with shallow soils appear to be heavily dominated by Lehmann lovegrass, whereas bottomlands are occupied by native species with higher biomass, for example, Sacaton (*Sporobolus wrightii*) (personal observation). The germination and growth characteristics of Lehmann lovegrass may influence fire regimes. In dry summers, Lehmann lovegrass can produce about four times as much green biomass as native species (Cox et al. 1990b). Accumulation of old-dead standing biomass from perennial grasses may be significant when summers are dry and termites (*Gnathamitermes perplexus*) are relatively inactive (Cox 1984). Following fire, Lehmann lovegrass rapidly establishes from the seed bank (Biedenbender and Roundy 1996; Ruyle et al. 1988; Sumrall et al. 1991) Additionally, under well-watered conditions this nonnative grass can double its biomass in less than one week, whereas native grasses may require up to four weeks and when drought conditions were imposed, its maximum relative growth rate did not decline (Fernandez and Reynolds 2000). Thus, Lehmann lovegrass and fire appear to be part of a positive feedback cycle whereby large amounts of biomass contribute to a fine fuel source that promotes fire, and rapid germination and recovery following fire encourages rapid fire-return intervals. In this study we investigated the effect of fire season on relative biomass of Lehmann lovegrass to evaluate this apparent positive-feedback cycle. We expected that if a positive feedback exists then Lehmann lovegrass would be enhanced by fire at the expense of native plant biomass. We also expected that spring fires would harm native plants more than summer fires, the timing with which native species evolved, thus providing an opportunity for Lehmann lovegrass to increase.

Methods

Study Sites

Our experiment was established in grasslands and mesquite (*Prosopis velutina*) savannas at the base of the Huachuca Mountains (31º 34' N, 110º 26' W) of southern Arizona. Elevations range from 1,420 to 1,645 meters, and about two-thirds of the average annual precipitation of 440 mm falls between July-October and 20% falls between December-March (NOAA 1992). The region is characterized by a hot, dry period between late March and early July prior to the onset of seasonal "monsoons." The most recent fires at our sites occurred 11 to 24 years ago. Few livestock have grazed at Fort Huachuca Military Reservation since the late 1800s, and livestock have been excluded since 1950.

Experimental Design

Our experiment has a full-factorial treatment structure. Extant plant community (described below) is the whole-plot factor (levels: native, mixed, Lehmann), and burn season is the sub-plot treatment (spring fire, summer fire, no fire).

Plot Selection and Allocation

In the summer of 1999, we chose 18 sites at FHMR, 6 within each of 3 types of grassland communities, representing a continuum of plant invasion. Nonnative sites are grasslands dominated by Lehmann lovegrass (*Eragrostis lehmanniana*), a nonnative perennial grass. Native sites are grasslands dominated by native perennial caespitose grasses including *Aristida* spp., *Bothriochloa barbinodis*, *Bouteloua* spp., *Digitaria californica*, *Eragrostis intermedia*, and *Panicum* spp. Mixed sites are grasslands composed of a mix of nonnative and native species. Within each site we established 3 permanent 1-ha plots, each of which received 1 of 3 prescribed-fire treatments: no fire, spring fire, summer fire. We treated plots in 9 of 18 sites in each of 2 years, 2001 and 2002. We used a total of 3 replicates per community type (n = 3) per treatment (n = 3) in a given year (n = 2).

In September and April we collected biomass of plants rooted in 25, 1 m x 0.5 m quadrats on each plot from 1999 to 2004. All vegetation was clipped at ground level (except perennial grasses, 2.5 cm) and separated into species. Samples were oven-dried at 65 ºC for 48 hours. Data were analyzed in JMP (SAS Institute) using repeated-measures with biomass over time as the dependent variable and plant community type and treatment as independent variables. The experiment was a nested design with site nested within plant community (native, mix, nonnative) as the whole-plot factor and fire treatment as the sub-plot factor. In this paper we only present results of the proportion of Lehmann lovegrass at peak standing biomass (September sampling) on "Nonnative" and "Mixed" plots.

Results

The relative proportion of Lehmann lovegrass was not influenced by fire regime (table 1, MANOVA, $P > 0.1353$). There was a significant interaction between change in biomass over time and vegetation type (i.e., degree of dominance by nonnative grass) (table 1, MANOVA, $P < 0.0009$). On "Nonnative" plots (i.e., dominated by Lehmann lovegrass) treated in summer 2001, the proportion of Lehmann lovegrass declined during the first two growing seasons, but by the third growing season no differences persisted (figure 1a). There is an apparent overall increase in the proportion of Lehmann lovegrass over time, particularly in 2003 on "Nonnative" plots (figure 1). There was no change in proportion over time on "Mixed" plots (i.e., with an equal mix of Lehmann lovegrass and native grasses) treated in 2001; however, the variability in proportion across replicates increased in 2003 (figure 2a). Likewise, there was no change in the proportion of Lehmann lovegrass in response to fire on "Mixed" plots treated in 2002; there was an apparent increase in the proportion of Lehmann lovegrass in 2003, a particularly dry year (figure 2b).

Discussion

Other studies have examined the response of Lehmann lovegrass to fire. Cox et al. (1990a) examined the effect of fire treatments (winter, spring, summer, fall, and no fire) in communities dominated by Lehmann lovegrass on the Santa Rita Experimental Range, Arizona, and found biomass reduced for at least two years post-fire. However, in that study no pre-fire data or data on native perennial grasses are available for comparison of the relative proportions of native and nonnative grasses. Bock and Bock (1992) compared canopy cover of native grasslands and grasslands planted with Lehmann and Boer lovegrass prior to and after a wildfire burned one plot among the pair of native/nonnative sites. They found no change in the proportion of native grasses within nonnative sites or nonnative grasses found at native sites. An analysis of long-term trends in plant communities at the Buenos Aires National Wildlife Refuge also showed no relationship between fire and Lehmann lovegrass (unpublished data). Data described in this paper also indicate that in the 2-3 years following fire this nonnative grass did not increase, relative to native plant biomass, providing no evidence of a positive feedback. These results contrast with

Table 1—Proportion of Lehmann lovegrass biomass as influenced by vegetation type and fire season in grasslands of the Huachuca Mountains, Arizona. The analysis was a repeated-measures analysis of variance (MANOVA) with proportion of Lehmann lovegrass over time as the response variable and the independent variables are as follows: Vegetation Type (i.e., degree of dominance by Lehmann lovegrass) is the whole-plot factor, Fire Treatment is the sub-plot factor, and Site is nested within Vegetation Type. The entire experiment was replicated and the replicates are designated as 2001 and 2002.

	Year	F	Numerator DF	Denominator DF	P
Time	2001	32.7919	4	9	<0.0001
	2002	71.5554	3	10	<0.0001
Time*Veg Type	2001	5.8466	8	18	0.0009
	2002	4.6708	6	20	0.0040
Time*Treatment	2001	1.7193	8	18	0.1616
	2002	1.8744	6	20	0.1353
Time*Site[Veg]	2001	1.1901	24	32.607	0.3175
	2002	1.4900	18	28.77	0.1625
Time*VegType*Treatment	2001	1.1979	16	28.133	0.3275
	2002	0.8749	12	26.749	0.5805

a review of other studies that investigated feedbacks between fire and nonnative grass (D'Antonio and Vitousek 1992). In the short span of our study, fire did not accelerate dominance by the nonnative, Lehmann lovegrass.

Our study is the first large-scale experiment to explore the effects of fire season on plant communities across a gradient of invasion by Lehmann lovegrass. In the current paper, we examined the change in proportion of Lehmann lovegrass on plots containing greater than 40% biomass of this nonnative (i.e., Nonnative and Mixed sites). If a positive feedback exists between fire and Lehmann lovegrass we would expect the proportion of nonnative biomass to increase over time on burned plots. Specifically, we expected that fire on plots with an equal mix of the nonnative and native grasses would result in an increase in the proportion of Lehmann lovegrass. We also expected that site characteristics would influence the proportion of Lehmann lovegrass after fire. We found evidence of a slight change in the proportion of Lehmann lovegrass on some

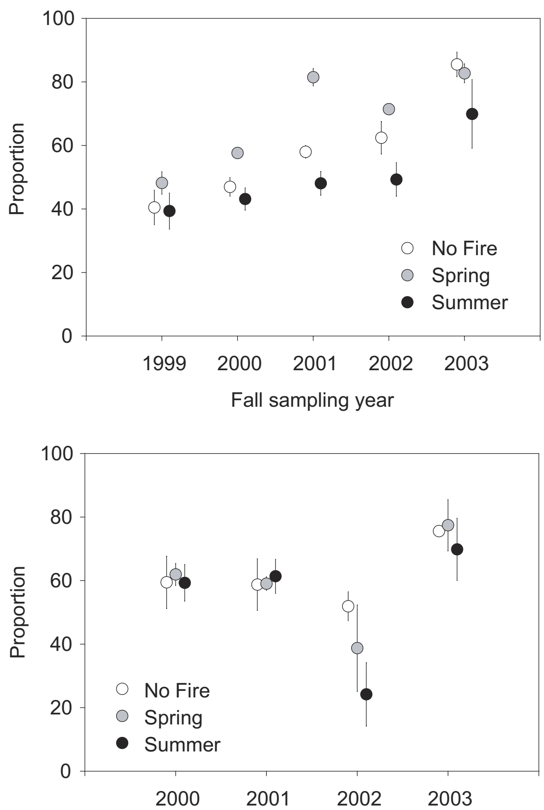

Figure 1—Proportion of Lehmann lovegrass (*Eragrostis lehmanniana*) on "Nonnative" plots dominated by Lehmann lovegrass burned in 2001 (figure 1a) and on plots burned in 2002 (figure 1b) in semi-desert grasslands at the base of the Huachuca Mountains, Arizona.

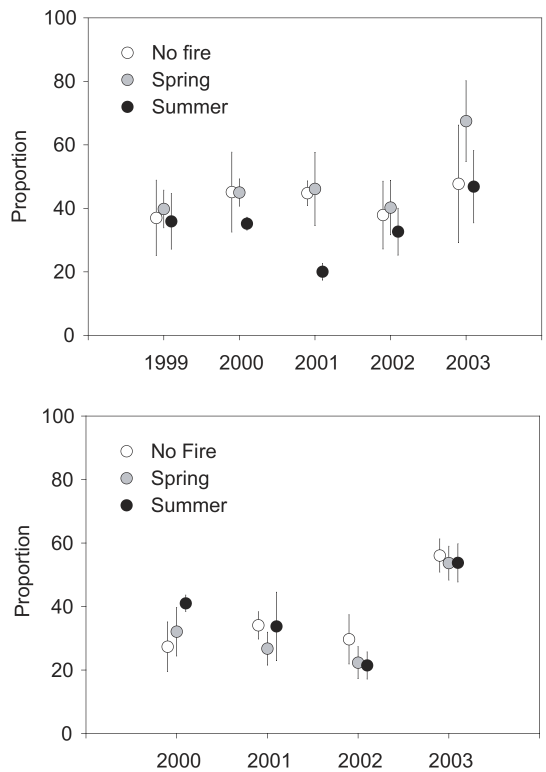

Figure 2—Proportion of Lehmann lovegrass (*Eragrostis lehmanniana*) on "Mixed" plots comprised of approximately equal abundance of Lehmann lovegrass and native grasses burned in 2001 (figure 2a) and on plots burned in 2002 (figure 2b) in semi-desert grasslands at the base of the Huachuca Mountains, Arizona.

plots (figure 1a) but the biological significance of this trend is unclear. However, the biomass on burned plots has not returned to pre-fire levels (unpublished data) so the relative proportions of native and nonnative grasses, especially in relation to site, may change as plants continue to grow.

Even if the proportion of Lehmann lovegrass to native plants is not altered by fire, scientists and land managers should continue to monitor its status and be cautious when incorporating fire into these systems. The data presented in the current paper explicate the interaction between nonnative grass and fire at very limited spatial and temporal scales. Effects of spring fires are largely unknown, especially for the many ecosystem functions and unnoticed species that are rarely monitored. A more appropriate management strategy would involve introduction of fires during the season with which native species evolved: early summer coincident with dry-lightning storms preceeding the "monsoon" rains. Native species have developed adaptations to fires that occur at a particular frequency, season, and extent, and reintroduction of the fire regimes with which these species evolved should assume high priority for those interested in maintaining high levels of biological diversity.

Reintroduction of ecological processes such as fire should be a relatively efficient and comprehensive strategy for retaining native species in extant ecosystems, albeit with two caveats about contemporary fires: (1) Contemporary fires often are unlike the fires with which species evolved and communities developed. A century of fire suppression, particularly in concert with the introduction of nonnative species such as Lehmann lovegrass, has changed the mix of species and wildland fuels in many of these systems. Lehmann lovegrass currently represents 30-90% of the total biomass in these grasslands and appears to be increasing over time. Fires in these "new" systems may favor a few nonnative species to a greater extent than they favor diverse native species, thus reducing biological diversity. (2) Anthropogenic activities have fragmented landscapes, and this fragmentation has blocked routes of dispersal. Former metapopulations no longer exist as recolonization sources for small, isolated populations, which may amplify adverse biodiversity effects of fires. Because of changes in species composition, fuel loads, and metapopulation dynamics, contemporary fires may extinguish small, isolated populations of many species in Southwestern ecosystems.

Another challenge to land managers in semi-desert grasslands is the inherent variability in these systems. Because erratic precipitation limits growth in semi-desert grasslands, fire effects can vary substantially as a function of weather conditions both before and after fire. For example, fires set during drought may require long recovery periods, create conditions that favor certain species over others, and result in increased erosion due to low vegetative cover. Some managers may develop plans several years in advance to receive funding and approval (e.g., 10 years) and not consider the importance of flexibility in setting the time for prescribed fire. Often, they are unable to adapt their proposed activities at the most appropriate time, without risking losing the funding. Scientists can contribute to management of these "new" communities by exploring which factors contribute to changes in variability of plant community composition and by identifying thresholds for recovery of native grasslands.

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An On-line Interface for Integrated Modeling of Wildfire, Climate, and Society for Strategic Planning for the Sky Islands

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Abstract—*The demand for strategic planning tools that account for climate and human influences on wildfire hazard is growing. In response, the University of Arizona, through an EPA STAR Grant has undertaken interdisciplinary research to characterize the human and climate dimensions of wildfire. The resulting Fire-Climate-Society (FCS-1) prototype model developed for Sky Islands in southeastern Arizona (Catalina/Rincons, Huachucas, Chiricahuas) addresses both the biophysical elements of wildfire probability and the human elements of values-at-risk. An online, spatially explicit application will allow users to choose climate-based scenarios, weight model components through a multi-criteria decision process, and then create spatially explicit maps for dynamic strategic planning.*

Introduction

Natural resources and environmental quality are considered at risk across 190 million acres (77 million ha) of United States forests and rangeland due to wildfire. Altered wildfire regimes jeopardize the sustainability of these ecosystems, particularly in the Southwest. On average, 433,000 acres (175,000 ha) burned annually in Arizona and New Mexico between 1992 and 2003 (Southwest Coordination Center 2004), over seven times the annual rate over most of the past century (Swetnam and Betancourt 1998). The severity of these fires has increased in recent years, posing an increasing threat to human life and property, and to ecosystems more adapted to low severity fires. Climate factors (Swetnam and Betancourt 1998) and human activity (Cardille and others 2001) can be precursors to increased fire activity at a variety of temporal and spatial scales. Increases in tree density and basal area over the past century have led to significantly greater fuel loads indicative of entirely different fire regimes than in the past (Covington and Moore 1994). Ponderosa pine forests have become vegetation- and fuel-dense and are at risk of stand-replacing ecosystem change through historically uncharacteristic high-intensity wildfires (Covington and others 2001). What once were anomalous crown fires can have radical, long-term impacts on species composition and structure of Madrean oak-pine communities common in Southwestern sky islands (Barton 2002). Severe fires impact the soils—volatilization and mineralization of nutrients, changes in hydrologic functioning, and accelerated erosion and leaching (Neary and others 1999). Population expansion into previously open spaces has exacerbated the problem by placing people and their property at risk, particularly in the Southwestern United States where population increased 1,500% between 1900 and 1990, compared to 225% for the nation as a whole (Chourre and Wright 1997).

Demographic trends and changing fire regimes require modifications in fuel management strategies based on spatially explicit and temporally dynamic risk assessments (Conrad and others 2001). Strategic wildfire planning would be improved greatly by a decision support system that incorporates the long-term influences of climate in fire probability analysis and the assessment of values at risk of damage or loss. The importance of different values depend on the perspective of the individual, thus integration with fire probability in an overall risk assessment is difficult if not impracticable (Hardy and others 2001). Addressing these challenges is the focus of Wildfire Alternatives (WALTER; http://walter.arizona.edu), a U.S. EPA Science to Achieve Results (EPA STAR) grant project being conducted by a multidisciplinary research team at the University of Arizona. The objective of WALTER research and development is to enhance the ability of wildfire managers to improve the health and sustainability of fire-prone ecosystems through a web-based, spatially dynamic decision support system that is capable of integrating assessments of fire probability and values at risk (Morehouse and others 2000). WALTER research has culminated in a prototype strategic planning model called Fire-Climate-Society (FCS-1) that will enable decision makers to construct risk assessment maps under alternative climate scenarios and varying perspectives of values at risk for three sky islands in southeastern Arizona (Catalina/Rincons, Huachucas, Chiricahuas) and the Jemez Mountains, New Mexico. FCS-1 risk assessments are constructed with a 1 km^2 minimum mapping unit, the finest resolution at which spatially distributed climate information can be reasonably integrated. This paper reviews the inputs to the FCS-1 fire probability and values at risk sub-models, their integration through a multi-criteria decision method, and the applications logic and architecture behind an interface permitting FCS-1 to be run interactively on-line.

FCS-1 Model Components

FCS-1 is made up of both a fire probability and values at risk sub-models (figure 1).

Fire Probability

FCS-1's fire probability sub-model is made up of five components: Fuel Moisture Stress Index, Fire Return Interval Departure, Large Fire Ignition Probability, Lightning Probability, and Human Factors of Fire Ignitions. The Fuel Moisture Stress Index (FMSI) is central to how climate scenarios are built into FCS-1 (e.g., fuel moisture conditions that result after a wet winter followed by a dry spring and summer). FMSI is a measure of moisture stress in vegetation relative to a given time of year. It is predicated on a correlation analysis of the interactions between antecedent climate and wildfire variability (Crimmins and Comrie 2004) and the relationship between chlorophyll content, live fuel moisture condition, and a time-series analysis of bi-weekly fire season Normalized Difference Vegetation Index (NDVI) (e.g., Nemani and Running 1989) derived from the NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery between 1989 and 2004. In order to measure the temporally relative stress that is distinctive to a given pixel, "raw" NDVI values are transformed into negative z scores (Yool 2001). The negative z score is calculated by:

$$-(x_i - \mu)/\sigma$$

where x_i is the NDVI value of a pixel for a given date, μ is the mean value for the pixel's NDVI time series, and σ is the standard deviation for the pixel's NDVI time series. This standardization of the current pixel relative to the time series provides us with a value for relative fuel moisture stress that is comparable between pixels (Taunton and Yool 2004). Climate measures showing strongest correlation with FMSI were air temperatures coincident with the fire season and precipitation the winter prior to the fire season. This study has employed an extensive investigation of climate correlations to determine the inception and length of fire season (highly variable in complex sky island terrain) so that FMS can be averaged over the fire season for each pixel for each year to produce a fire season summary FMSI for each year.

Fire Return Interval Departure (FRID) is a measure of how long it has been since this area has experienced a fire in relation to how frequently it would be expected to burn in a natural state (Keifer and others 2000). From maps of where and when fires have occurred in the past, average fire return intervals for each

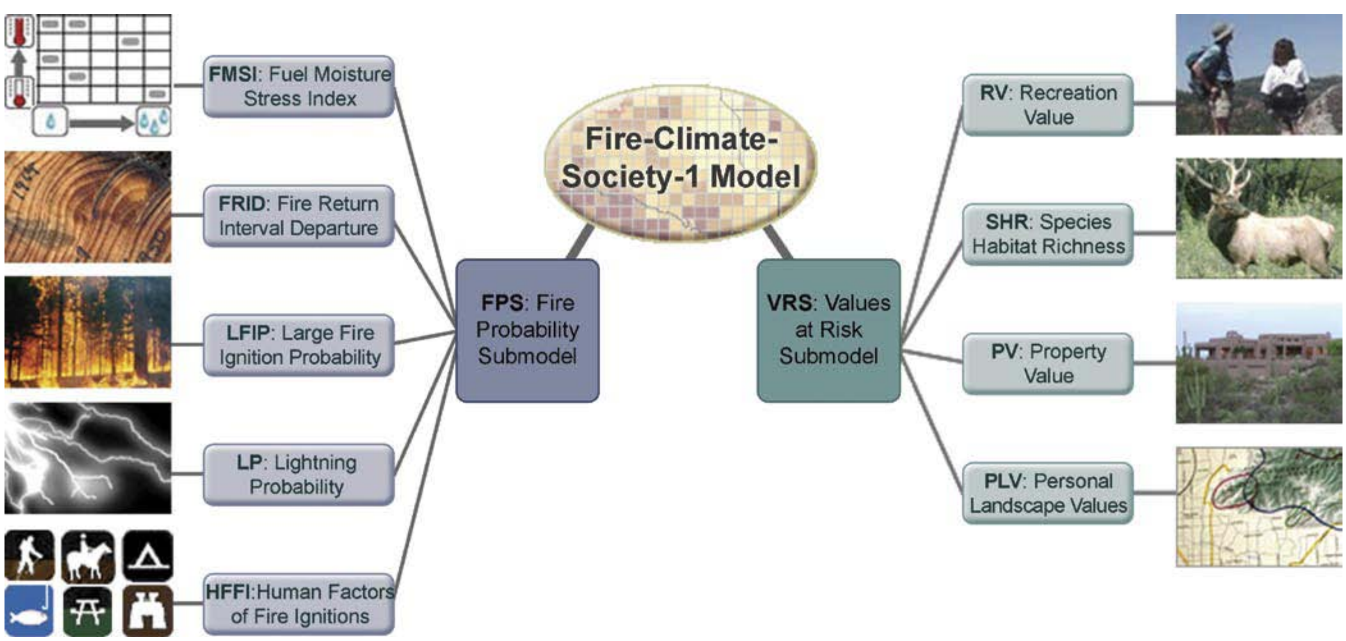


Figure 1—FCS-1 model components.

vegetation type class can be determined. Using the time that has elapsed since the last fire, a derived index can be calculated for each map pixel to quantify the departure of an area from its average fire return interval. The equation for FRID is:

FRID index = (Years since last fire - Natural Fire Return Interval) / Natural Fire Return Interval.

Large Fire Ignition Probability (LFIP) represents the chance an ignition will grow into a "project" fire. Based on a cumulative fire size probability analysis, fires that reach 250 acres (101 ha) in size have a 45% chance of expanding to 1,000 acres (404 ha), and once achieved, a 30% chance of growing into a major wildfire of 5,000 acres (2,023 ha) or more increases substantially once a fire reaches 250 acres in size (Neuenschwander and others 2000). Only 5% of all fires on the Coronado National Forest, for example, reached 250 acres between 1986 and 1999, but they account for 95% of the total area burned. Because different vegetation types produce different fire behavior, a vegetation type is assigned to each fire ignition in FCS-1. The vegetation types were obtained from gap analysis vegetation maps (Halvorson and others 2001).

The total ignitions for each vegetation type are then standardized into a density map based on the total area in each class. Lightning Probability (LP) is based on the density of lightning strikes per 247 acres (100 ha) per year in each research venue data acquired between 1989 and 1999 from the National Lightning Detection Network™ (Cummins and others 1998). Annual data proved sufficient because the relative probabilities of a lightning strike in one location versus another remained consistent year to year. Human Factors of Fire Ignitions (HFFI) is based on the spatial relationship between human activities and the location of human caused ignition. A logistic regression analysis revealed human ignitions were spatially associated with proximity to roads, location of campgrounds and picnic areas, and proximity to urban areas. Human ignitions also tended to occur more frequently in non-forested vegetation types.

Values at Risk

The FCS-1 values at risk sub-model is composed of four components: Recreation Value, Species Habitat Richness, Property Value, and Personal Landscape Value (Johnson and others 2003). Recreation Value (RV) is based on a proximity analysis of major recreation activities in each venue as determined through data obtained from public land agencies such as the Forest Service's National Visitor Use Monitoring Program (English and others 2002). Maps were created for the top ten recreation activities in each venue (i.e., campgrounds, hiking trails, roads, picnic areas, lakes, historical sites, and visitor centers). Viewsheds were created by calculating Euclidean distance grids and visibility surface grids from features of interest based on the assumption that visual amenity makes up part of recreation value. These were then weighted by the proportion of visitors who participated in each activity and then summed for an overall assessment of recreation values at risk. Species Habitat Richness (SHR) was designed to be a proxy for the diversity of fauna since landscape-scale species diversity maps are not available for the WALTER study sites. SHR is a spatially explicit sum of the GAP-model habitats (Halvorson and others 2001) for mammals, amphibians, reptiles, and birds. Property Value (PV) uses maps of property value created from tabular housing data joined to census block-level data, and total housing value was assigned proportionally based on area of intersection with the 1 km^2 project grid. Personal Landscape Value (PLV) addresses the personal perceptions of risk that concerned groups and individuals assign to areas at risk of wildfire (Johnson and others 2003). This model component is based on participatory map-based interviews at each of the WALTER venues. A purposive sample of 30 stakeholders was chosen to capture the breadth of viewpoints including representatives from agency personnel, home associations, and environmental advocacy groups.

Weighting and Integration

Each of the components of FCS-1 provides information on either fire probability or values at risk, and yet none can stand alone as an integrated risk assessment. Stakeholder feedback from the outset of FCS-1 development emphasized the need for an operational model that could integrate risk assessment elements through expert knowledge of local conditions. Of concern was the reality that stakeholders with different priorities would place differing levels of importance on the FCS-1 model components and sub-models. This is evident particularly when trying to integrate human and biophysical characteristics of the model.

One method for addressing this is assignment of weights through expert opinion. Where there are multiple criteria and interrelated choices, however, weighting decisions become complex. Saaty (1980) developed a method to decompose and synthesize this complexity through the Analytical Hierarchy Process (AHP), reducing decisions into a series of one-on-one comparisons. The problem FCS-1 is trying to address—strategic fire planning—is structured first into a hierarchy with criteria (the sub-model components) and alternatives (the 1-km^2 map cells) (Johnson and others 2003). Next, the relative importance of each sub-model component versus the next component is scored on an integer scale of 1-9 by each individual stakeholder. These same steps are used to compare the relative importance of the two sub-models. These comparisons are essentially a ratio of relative importance or preference. The set of preference scores are then synthesized through a matrix averaging (eigenvector) method (Saaty 1980) in order to assign weights to the criteria. Linear combination of the weighted sub-model components creates the "fire probability" map and a "values at risk" map. A linear combination of the sub-models creates the final FCS-1 risk assessment. Figure 2 provides an example of the model output.

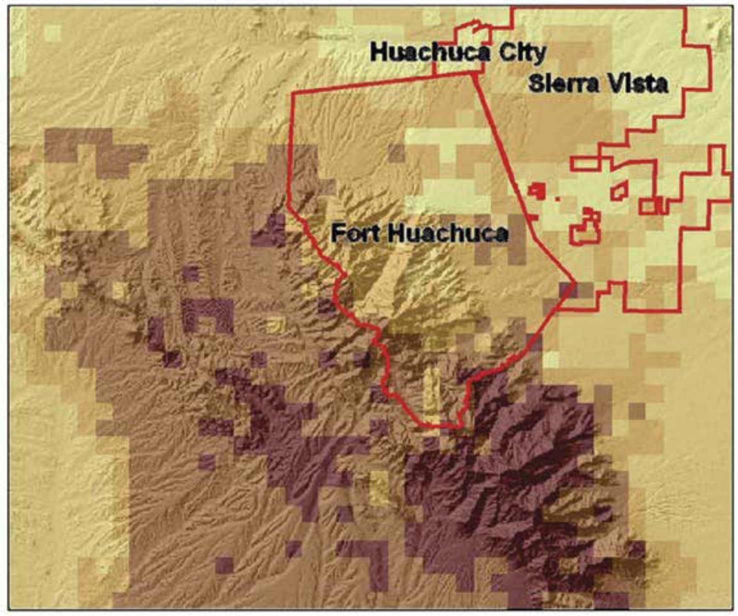
This modeling approach integrates the preferences of a group of people in order to visualize their combined preferences. Feedback from the stakeholders who evaluated FCS-1 emphasized how the combination of AHP and interactive maps illustrated the complex relationships inherent to wildfire risk assessment.

Fire Probability: .457

FMSI	.294
FRID	.254
LFIP	.150
LP	.106
HFFI	.196

Values at Risk: .543

RV	.251
SHR	.118
PV	.327
PLV	.304



FCS-1= (AHP weight) * ((AHP weight) *FMSI)+((AHP weight) * FRID)+((AHP weight) * LFIP)+((AHP weight)*LP)+((AHP weight) *HFFI))
+ (AHP weight) * ((AHP weight) *RV)+((AHP weight) *SHR)+((AHP weight) * PV)+((AHP weight) * PLV))

Figure 2—Example AHP output, where darker areas have higher risk.

FCS-1 On-line Application

We designed the WALTER Web site to serve a wide range of stakeholders interested in the climate and human dimensions of wildfire. Our objective has been to create a Web-based decision support tool that will enable decision makers to construct fire risk maps under a selected set of alternative climate scenarios (e.g., a wet winter followed by a dry spring). Transferring FCS-1 from the desktop to the web involves the use of relational database and Internet map server technology. Web programming will feature map algebra to calculate cell attributes on-the-fly so user-specified parameters can be passed on and used in the FCS-1 model. In keeping with the WALTER objectives of technology transfer geared to a wide range of stakeholder interests and backgrounds, the web-based version of FCS-1 is being framed in a decision flow structure, ensuring comprehension at each decision step to guide users, much the way a "wizard" guides users of desktop software.

The first decision step involves a FCS-1 model overview as visualized in figure 1. Explanations of each model component and the science behind their creation will be linked to each respective graphic. Next, users will be able to select one of the four WALTER study sites from a map or a list. All FCS-1 model components will then be displayed as interactive maps (zoom, query, etc., available) for that site (again, with links to the underlying science). The third step is generation of the climate scenario based on FMSI fire season summaries grouped in a matrix based on the temperature coincident with that season and precipitation from the season before. This matrix, the underlying FMSI maps, and graphical representations of the climate summaries will guide the user in choosing a scenario that match climate-influenced fuel moisture conditions of interest. This choice then initializes the AHP—either through the selection of a set of weights obtained by experts who have stored their results in the database, or the execution of a personal model (following the steps detailed in the previous section).

Pairwise comparisons will be facilitated by graphic representation (interactive maps of each combination of variables) and a series of radio buttons (1-9 for both criteria) to record user preferences. The final step, AHP synthesis, will result in a report page that will include a fully interactive map of the final risk assessment, spatially linked maps of the sub-models along with all nine input variables and their corresponding weights. Our ultimate plans are to develop a query tool that will deliver the relative importance each input map value and corresponding AHP weight contributes to each map cell.

Though the WALTER project databases are currently only available for the four study sites under investigation, we intend to develop regional databases that apply the tool applicable over larger areas. We will then distribute the model components to those groups who wish to develop their own databases.

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Changes in Forest Species Composition and Structure After Stand-Replacing Wildfire in Mountains of Southeastern Arizona

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Abstract—*A wildfire in the Chiricahua Mountains of southeastern Arizona apparently altered the long-term structure of the forest. The pre-fire canopy forest, which had not burned for 100 years, was an even mixture of Arizona pines and Rocky Mountain Douglas-firs. A decade later the new forest was numerically dominated by quaking aspen seedlings in clumps separated by persistent gaps. Douglas-firs were positively associated with aspens but Arizona pines were not. The new forest was more open, diverse, and patchy than the one it replaced. Extensive stand-replacing fires in the Mountain West may produce forests with long-term desirable resource properties.*

Introduction

Very large, stand replacement forest fires are becoming increasingly common in the coniferous forests of the Western United States (Zimmerman 2003). Since such fires destroy all of the above ground portions of trees and other vegetation, the forest that regenerates may develop a different structure and species composition than that which existed before the fire. Seed banks and soil properties are examples of variables affected by intense fire that could subsequently alter the course of succession. This is a report on the first decade of regeneration of trees following such a wildfire that occurred in southeastern Arizona in 1994, apparently altering the long-term structure of the forest.

Study Area

The Chiricahua Mountains are located in extreme southeastern Arizona, near the borders of New Mexico and the Republic of Mexico. The range is approximately 65 km long and 32 km wide, with a maximum elevation of 2,975 m. The primary study area contained three species of trees, Arizona pine (*Pinus ponderosa* var. *arizonica*), Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), and quaking aspen (*Populus tremuloides*). The study area was located at elevations of 2,700 to 2,900 m, UTM grid coordinates 3528500N 662100E, immediately north of the Chiricahua Wilderness within the Coronado National Forest in Cochise County. Slope in the sampling area varied from 0–8%, with an easterly aspect.

Rattlesnake Fire

In June and July of 1994 a fire ignited by lightning burned approximately 11,000 ha of forested land in the upper elevations of the Chiricahua Mountains. This was the first large fire that had burned these mountains since the late 19th Century (Bahre 1991). The fire burned at varying intensities through almost all the coniferous and aspen forest of the mountain range. It was propelled by erratic winds, steep terrain, and it burned through fuel types ranging from Madrean oak woodlands to Englemann spruce. Within the perimeter of the fire almost all forested areas burned. In some watersheds all trees were killed and the soil was destroyed by heat so intense that boulders shattered and cylindrical holes more than a meter deep were left where trees were burned below the surface of the ground. In other areas, however, very light surface fires consumed only small-diameter fuels and lightly scorched the bases of trees.

Sampling Methods

In the summers of 1998 and 1999 perpendicular belt transects were established on a gently sloping plateau where most trees had been killed by the Rattlesnake Fire (figure 1). These sampling belts were 4 m wide, with lengths of 255 and 300 m, with a total sampling area of 2,204 m^2 that crossed an area of 7.75 ha. The location and height of all tree seedlings and resprouts within the belts were recorded annually between 1999 and 2003, using the center lines of the sampling belts to define orthogonal coordinates. In 1998 the composition of the pre-fire forest was measured from 21 points at 15 m intervals along a line defined by the center of the 300 m belt using the point-quarter method (Cottam and Curtis 1956). Tree densities were calculated using the mean distance from the sampling point to the tree as the mean distance between trees. At that time all snags of canopy trees present before the fire were still standing, and the species and dbh of both dead and living tree stems greater than 10 cm in diameter were sampled.

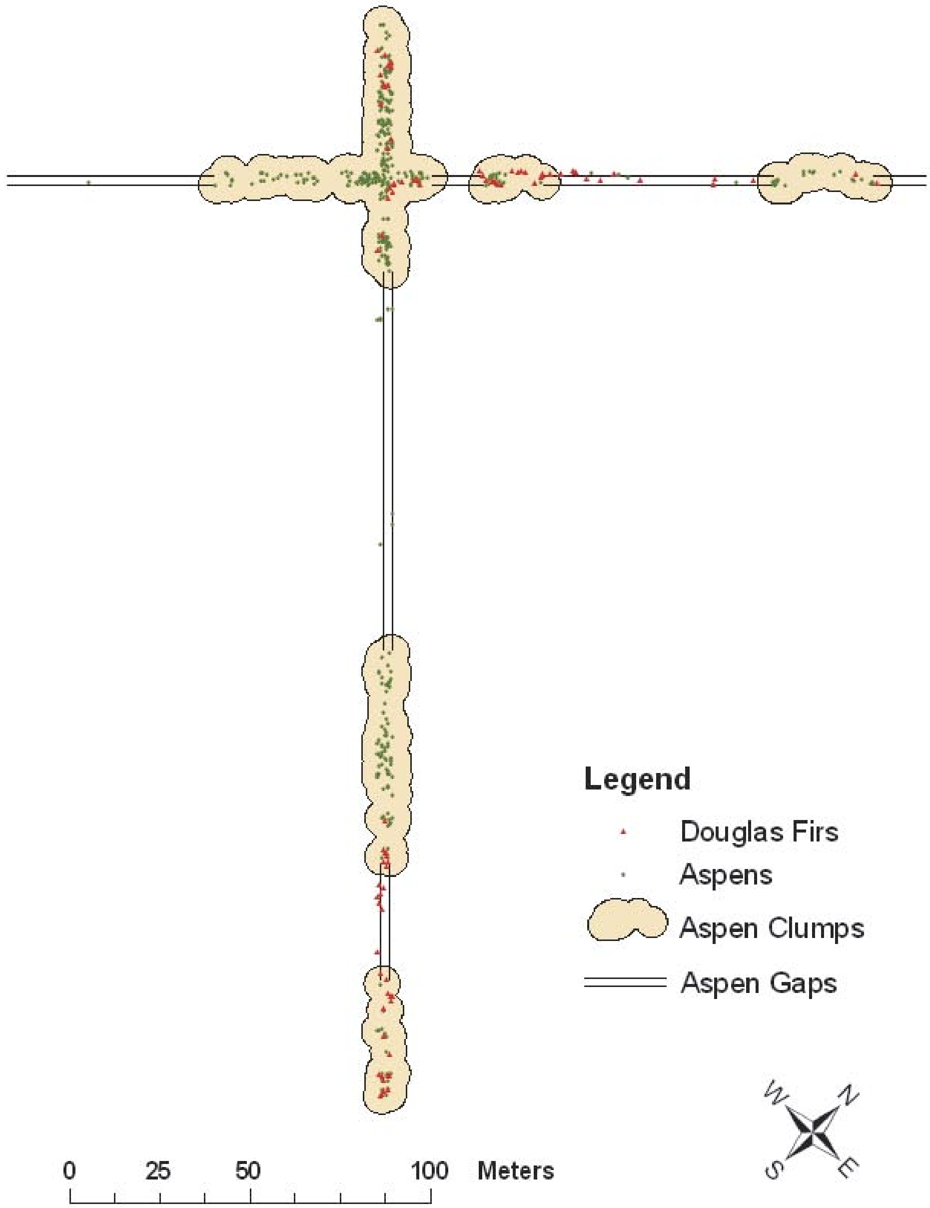

Figure 1—Aspen clumps and gaps in 2003, and distribution of Rocky Mountain Douglas-fir.

Results and Discussion

Pre-fire Forest Composition

Prior to the fire the portion of the study area along the 300 m transect contained nearly equal numbers of similarly sized Rocky Mountain Douglas-fir (DF) and Arizona pine (AP) in a combined density of 701 trees per ha, and combined basal area of 57.25 m^2 per ha. No other species of trees were found. DF had a mean dbh of 31 cm (SD = 15.5) and AP had a mean dbh of 27 cm (SD = 12.3). The two species of conifers were evenly mixed, with relative frequencies of 49% (DF) and 51% (AP). The estimated height of pre-fire canopy trees was 16–18 m, based on measurements in 1998 of trees in the study area that survived the fire. Prior to the fire the study area had a tree density typical of Southwestern forests that have been free of fire for most of the 20th century (Dahms and Geils 1997; Friederici 2003). Twenty-six percent of the AP sampled survived the fire, all in an area where the fire did burn the tree crowns. The fire killed all sampled DF, although there were some that survived nearby. There was no evidence of quaking aspen canopy trees found anywhere on or near the sampling belts or within the surrounding area of 7.75 ha, although snags or living aspens existed within 100 m of the ends of the belts. Canopy cover in places with living AP was 71%.

The Regenerating Forest

Aspens numerically dominated the post-fire forest community, accounting for four-fifths of all tree seedlings. In 1999 an analysis of the root systems of 27 randomly selected aspens excavated 1–10 m from the edges of the belt transects revealed that all these plants were seedlings, not suckers arising from established aspen roots (Quinn and Wu 2001). Aspen snags were present near the study area, but none were close enough to the area sampled to support aspen root systems within the study area.

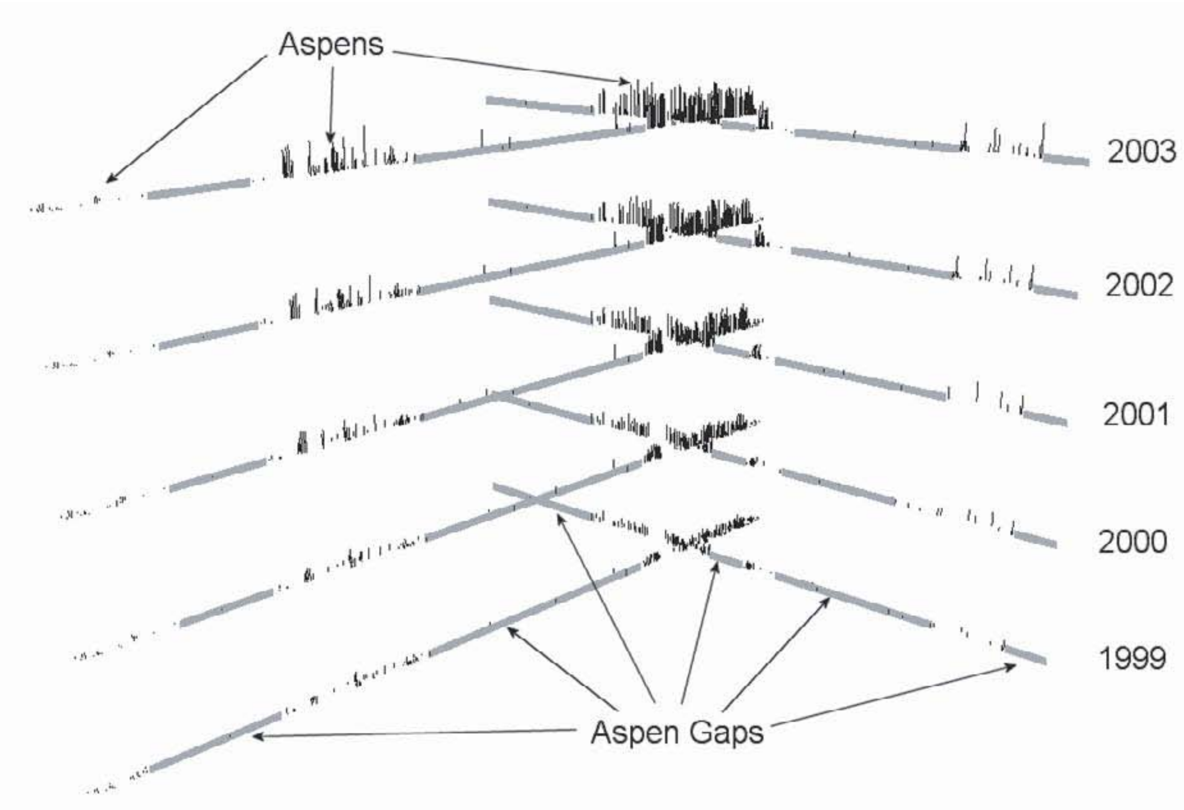

Figure 2—Distribution of aspen gaps from 1999 to 2003. Lengths of vertical lines are proportional to heights of aspen trees.

GIS mapping of tree seedlings revealed that aspens occurred in clumps separated by pronounced gaps, and this pattern of gaps persisted through the period of the study (figures 1, 2). The gaps and clumps were defined by using the buffer function of GIS. A buffer with a radius of 5 meters was generated around each of the live aspen trees. If the buffers overlapped, the boundaries between them were eliminated to create a single polygon. These polygons were defined as clumps if they contained 5 or more aspens. The area between two clumps along the belt transects was defined as a gap. The gap length was measured from the last tree in one clump to the first tree in the next clump or to the end of the sample belt. Based on this method, all gaps were at least 10 meters long and contained no clusters of 5 or more trees. Forty-nine to 55% of the sampling belts were gaps that persisted for the duration of the study (figure 2).

Rocky Mountain Douglas-fir and Arizona pines, the two tree species of conifers present before the fire, returned to the study area as seedlings. Both species grew at much lower densities than aspens, and their numbers within aspen clumps and in the overall study area increased slowly and unevenly with time (table 1). Unlike the aspens, which have light seeds that can be dispersed over long distances by the wind, the relatively heavy seeds of DF and AP can only be passively dispersed over distances of approximately 40 m (AP) to a few hundred meters (DF) as they fall from seed trees (Howard 2003; Steinberg 2002). Consequently, the seedlings of both species tended to be situated near areas where canopy seed trees survived the fire.

The DF seedlings are concentrated in and around the aspen clumps (figure 1). Following the method of McAuliffe (1988) the association between DF and aspens was tested by generating a number of randomly placed points within the belts equal to the number of DF seedlings, measuring the distance from each point to the nearest aspen, and then comparing those values to the actual distances between all DF seedlings present in 2003 and the nearest aspen. The mean distance between DF and nearest aspen was 2.14 m (SD = 2.87, $n = 89$), while the comparable value for the random array was 3.92 m (SD = 4.61), which is significantly greater ($t = 3.09$, $P = 0.002$). The association between DF and aspens may be explained by the presence of shade provided by the rapidly growing QA, over half of which by 2003 were more than a meter tall (figure 2). Those DF that grew outside of the aspen clumps were located beneath or near canopy trees that survived the fire. Since DF germinates and grows best in shade (Steinberg 2002), the aspens and surviving canopy trees provided a framework of shade for the establishment of DF seedlings.

The number of AP was relatively small in the areas sampled (table 1), and unlike DF they were not concentrated in or around the aspen clumps. Applying the same test of association between AP and aspen as compared with AP and random points showed a lack of a significant difference between the means at the 5% level of significance ($t = 1.54$, $P = 0.129$, $n = 34$).

If the easily dispersed seeds of aspen trees had been randomly scattered across the study area since the fire it remains to be explained why seedlings were not more evenly distributed. Aspen tree gaps along the belt transects constituted 52% of

Table 1—Tree density by species 1999 - 2003 (trees per ha).

	Aspen		Arizona pine		Douglas-fir	
	In clumps	Study area	In clumps	Study area	In clumps	Study area
1999	3,516	1,620	61	45	447	277
2000	3,071	1,624	170	118	518	331
2001	3,349	1,633	261	177	714	445
2002	3,745	1,856	171	118	599	377
2003	4,078	2,010	209	154	675	408

the area sampled in 2003 (figures 1, 2). A likely explanation, which may apply to the distribution of DF as well, is the uneven amount of available soil moisture during the summer growing season. The monsoon rains of July and August are irregular in onset and quantity. The first half of the growing season, May and June, has relatively little to no rainfall (table 2). The soil is quite thin over the study area, as indicated by exposed rhyolite bedrock in many places. Limited summer precipitation and thin soil could easily create an irregular pattern of relatively xeric and mesic microsites, and aspens and DF are intolerant of dry sites (Anderson 2001; Steinberg 2002).

One vegetation pattern suggests that the distribution of aspen-DF tree clumps may be governed by sufficient soil moisture. Scouler willow (*Salix scouleriana*) is a large shrub that grows well after stand replacement fires. This species requires moderately moist sites as compared to typical upland forest sites of the Southwest (Anderson 2001). The willows were abundant in patches across the sample area, and these willow patches fell almost entirely within the aspen/DF clumps. The test of association comparing distances between willows and aspens, and between willows and random points showed that willows are strongly associated with aspens ($t = 1.99$, $P < 0.001$, $n = 73$). Its presence within these clumps suggests that these are locations where moderate soil moisture has been reliably available, satisfying the requirements of both aspens and willows.

The forest that was regenerating in the study area was markedly different than that which grew there prior to the fire. It was dominated numerically by aspens (table1), which colonized the area as seedlings, while DF and AP were less numerous. The aspens occurred in clumps separated by gaps containing relatively few tree seedlings of any species (figures 1, 2). DF became established within and around most of these clumps, while AP lacked association with the clumps. In 2003 AP was too uncommon to break up the gaps by colonization, probably because of the inability of its seeds to disperse over long distances from scattered seed trees. Over the study period the distribution pattern of all 3 tree species remained stable while tree densities increased slowly (table 1). The stand replacement fire created the beginnings of a forest that was more open, diverse, and patchy than the one it replaced. The Southwestern ponderosa pine forests of the 19th century were also broken by frequent openings (Mast 2003), so in this respect the new forest may become structurally similar to forests of the past.

Over a time span of a century or more the relative abundance and spatial arrangement of the 3 tree species present will undoubtedly change as aspens thin and die in undisturbed places and are replaced by DF. AP may eventually close

Table 2—Mean monthly precipitation at a weather station 4 km from study site (N = 39).

Month	May	June	July	August
Mean	12.7	25.4	111.2	94.7
S.D.	23.4	33.5	45.7	43.4

existing forest gaps as seeds incrementally reach suitable sites, especially during years with abundant seed crops. At the same time scale future fires of lower intensity and lesser extent, in this region of frequent summer lightning, may create new gaps and opportunities for regeneration. These events could maintain the forest as a heterogeneous mixture of vegetation types and structures in response to a more complex, fine-grained disturbance regime.

At the study site dry pine species of lower elevations mingle with firs and aspens of higher elevations, so that individual fire responses of three species of trees can create a shifting mosaic of forest types that depends on variations in the disturbance regime and microsite characteristics from point to point. Mixtures of tree species such as these with different responses to fire and microclimate are resilient to localized disruptions because collectively they possess several options of physiology and life history that are potentially available for regeneration. A particular species may temporarily become more or less abundant with each revolution of the fire cycle, but it is unlikely that any species will be eliminated by fire alone across its natural range on an entire landscape.

The Rattlesnake Fire, which burned most of the coniferous forest over an entire mountain range, may have set in motion events that will establish a forest that exhibits desirable properties not present before the fire, such as better overall wildlife habitat, greater species richness of plants, and a lessened propensity for extensive and uncontrollable wildfires. Under these conditions, where fuel accumulations are maintained at low to moderate levels by frequent ground fires, it may be safe and desirable to allow some fires of moderate intensity and size to burn without human intervention. Admittedly this is a more plausible scenario for a wilderness area on public land, with no structures or permanent residents, than it would be in populated areas with multiple land uses and goals. Nonetheless there are extensive parts of the Mountain West with remote forests that may fit this model once they have experienced large stand replacing fires. The extensive forest fires that have become so common in the Mountain West may not always mark an unfortunate sea change in ecological processes and management goals, producing nothing but long term resource losses.

Acknowledgments

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Proposed Wildland Fire Amendment to the Coronado National Forest Land and Resource Management Plan

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***Abstract**—The Coronado National Forest proposed amending its 1986 Land and Resource Management Plan to conform to the 2001 Federal Wildland Fire Management Policy. This Policy emphasizes fire's essential role in maintaining natural ecosystems and allows a broader range of management options for wildland fires. Under the current Forest Plan, fires must be suppressed in areas outside of congressionally designated Wildernesses, Wilderness Study Areas, and Research Natural Areas. The proposed amendment would allow fire managers' discretionary use of a spectrum of fire management alternatives, from suppression to managing natural ignitions to achieve resource benefits throughout the Forest.*

History of the Forest Service's Wildland Fire Policy

Forest Service wildland fire policy began with the 1905 *Use Book*, which provided regulations and management instructions for the National Forest Reserves. The first objective contained in the *Use Book* states, "Forest reserves are for the purpose of preserving a perpetual supply of timber…" The fire protection section further defines the need to protect the forest reserves from fire, which was "…insurance against the destruction of property, timber resources, and water supply by fire." Additionally, the *Use Book* explained how citizen fire brigades, composed of the local residents and permit holders, were organized to fight fires on forest reserves, and that firefighting was the priority for forest reserve employees over all other duties during fire season.

The year 1910 marked a significant event in wildland fire history when five million acres of National Forest land burned and eighty-five firefighters lost their lives (Pyne 1982). These fires helped shape the thinking that wildland fire was a destructive force and needed to be suppressed. Also, it became evident that citizen fire brigades alone could not control and extinguish such conflagrations.

Support for suppression of all wildland fires gained momentum with the 1935 10 a.m. Policy, which stated that all wildland fires would be controlled by 10 a.m. the next day. The Forest Service adhered to this policy for over forty years until it was replaced in 1979 (Pyne 1982). During the 1940s Smokey Bear was introduced as a symbol in prevention of forest fires and became a national icon with his famous slogan, "Remember, only you can prevent forest fires."

Starting in the 1970s, the Forest Service reconsidered its position on management of wildland fire. The 10 a.m. Policy was revised in 1979, which allowed an *appropriate* suppression response to wildland fires. This policy required a timely suppression response for each fire ignition with appropriate forces based on cost efficiency (Servis and Hurley 1990). Suppression strategies ranged from direct control with minimum acreage burned, to more indirect methods of containment and confinement, which often allowed large areas to burn. Also at this time, the emerging science of fire ecology was providing new information about fire's role in shaping many ecosystems on National Forest System land (Pyne 1982).

The Federal Wildland Fire Management Policy

The unintended effects of decades of fire suppression on National Forest System land and other Federal land became increasingly evident in the 1990s. During the 1994 wildland fire season millions of acres burned and thirty-four firefighters were killed. One of the most significant fires of 1994 was the South Canyon Fire in Colorado in which fourteen Forest Service and Bureau of Land Management (BLM) firefighters died. After the investigation of the fatalities, the Director of the BLM and the Chief of the Forest Service chartered an Interagency Management Review Team (Review Team) to develop a report that further addressed the concerns identified in the investigation. Their report stated that "The single-agency focus and contrasting approaches of the various [fire management planning] systems has precluded effective interagency planning…Fuels management, especially through the reintroduction of fire as an integral part of natural resource management, must be a high priority of the Departments of the Interior and Agriculture."

After the Review Team's report was published, the Secretaries of Agriculture and the Interior formed an interagency working group to address the Team's recommendations and the challenges of wildland fire management, and also to create a standardized interagency wildland fire policy for all Federal land management agencies (USDA and USDI 1995). The working group developed a report to provide the foundation for interagency wildland fire management, which resulted in the 1995 Federal Wildland Fire Management Policy and Program Review, commonly known as the Federal Fire Policy. The Federal Fire Policy included the following nine guiding principles to ensure consistency among Federal land management agencies (USDA and USDI 1995):

- "Firefighter and public safety is the first priority in every fire management activity.
- The role of wildland fire as an essential ecological process and natural change agent will be incorporated into the planning process.
- Fire management plans, programs, and activities support land and resource management plans and their implementation.
- Sound risk management is a foundation for all fire management activities.
- Fire management programs and activities are economically viable, and based upon values to be protected, costs, and land and resource management objectives.
- Fire management plans and activities are based upon the best available science.
- Fire management plans and activities incorporate public health and environmental quality considerations.
- Federal, State, Tribal, and local interagency coordination and cooperation are essential.
- Standardization of policies and procedures among federal agencies is an ongoing objective."

Further, the Federal Fire Policy included recommendations necessary for the Federal agencies to achieve collaborative implementation of this policy. These recommendations included the need for planning and the development of Fire Management Plans for all areas with burnable vegetation. A fire management plan must be consistent with firefighter and public safety, values to be protected, and Land and Resource Management Plan direction. Additionally, it must address all fire management occurrences and include a full range of fire management actions (USDA and USDI 1995).

On May 4, 2000, the Cerro Grande Prescribed Burn was ignited at Bandelier National Monument in New Mexico, but exceeded its prescription and became a wildland fire. The Cerro Grande Fire burned 18,000 acres and destroyed 235 homes (National Interagency Fire Center, Fire Investigation Team 2000). The investigation report concluded that Federal agencies had not completed all the necessary work to fully comply with the Federal Fire Policy.

The 2000 wildfire season led the Secretaries of Agriculture and the Interior to direct the working group who had prepared the Federal Fire Policy to conduct a review of the Policy. The Secretaries asked that special attention be given to the implementation status of the Federal Fire Policy and issues raised by the Cerro Grande Investigation Report. The working group reached the following conclusions (USDA and USDI 2001):

- "The Federal Fire Policy is still generally sound and appropriate.
- As a result of fire exclusion, the condition of fire-adapted ecosystems continues to deteriorate; the fire hazard situation in these areas is worse than previously understood.
- The fire hazard in the Wildland Urban Interface is more complex and extensive than understood in 1995.
- Changes and additions to the 1995 Federal Fire Policy are needed to address important issues of ecosystem sustainability, science, education, and communication, and to provide adequate program evaluation.
- Implementation of the 1995 Federal Fire Policy has been incomplete, particularly in the quality of planning and in interagency and interdisciplinary matters.
- Emphasis on program management, implementation, oversight, leadership, and evaluation at senior levels of all federal agencies is critical for successful implementation of the 2001 Federal Wildland Fire Management Policy."

Thus, the review and update report of the 1995 Federal Wildland Fire Management Policy resulted in the 2001 Federal Wildland Fire Management Policy.

The Coronado National Forest Proposed Wildland Fire Amendment

The decrease in wildland fire had a destabilizing influence in many fire-adapted ecosystems, including much of the land managed by the Coronado National Forest (Forest). A lack of natural fire influences over the past century changed the character of the vegetative communities on the Forest. The natural role of fire was virtually eliminated from many vegetative communities, and the unnatural accumulation of fuels and increase in plant density left many areas at risk for uncharacteristic fire behavior. As a result, wildland fires became larger and more severe than historical fires.

Wildland fire threatens public and private land, particularly where vegetation patterns have been altered by development, land-use practices, and aggressive fire suppression. Obviously, potentially serious ecological deterioration is possible where fuel loads and tree density have become extremely high. On the Forest, these conditions clearly contributed to the severity of the recent Bullock and Aspen Fires in the Santa Catalina Mountains, and these uncharacteristic conditions elsewhere have set the stage for future large destructive fires.

In 2002 the Forest Service amended the Forest Service Handbook 5109.19, Chapter 50—Fire Management Planning, to provide direction for restoring fire-adapted ecosystems and described the format for preparing a fire management plan. The Handbook states, "Fire management plans should address as extensive as possible a range of potential wildland fire occurrences and should include the full range of fire management actions in a manner consistent with Forest land and resource management plans…Where the land and resource management plan does not support a full range of fire programs options, amending the Forest land and resource management plan may be considered by the Forest Supervisor to reflect a broader wildland fire management program."

In December 2002, the Coronado National Forest proposed an amendment to its Land and Resource Management Plan (LRMP) to align it with the Federal Wildland Fire Management Policy. Appropriate use of wildland fire on a landscape scale is needed to (1) reduce hazardous fuels and avoid catastrophic fires, and (2) sustain wildland ecosystems. Providing for wildland fire use also broadens management discretion in the use of naturally occurring fires to meet resource management objectives already identified by the Forest LRMP. Under the proposed amendment, changes would be made to fire management direction throughout the LRMP.

The Coronado National Forest LRMP divides the Forest into the following two Fire Management Suppression Zones with differing responses:

> "Fire Management Zone 1: The appropriate suppression response in this zone will be predicated upon preventing fires from reaching or damaging high value resources and improvements.
>
> Fire Management Zone 2: The appropriate suppression response in this zone will be predicated upon responses that will suppress wildfires at the least cost with acceptable damage to improvements."

The Coronado National Forest 2003 Fire Management Plan divides the Forest into two Fire Management Units (FMUs), based on the current LRMP direction. The two FMUs are Wildland Fire Use and Wildland Fire Suppression (USDA Forest Service 2003). The Wildland Fire Use FMU includes the following areas: Wilderness, research natural areas, and Wilderness study areas. These areas allow a full range of wildland fire responses, from aggressive initial attack to managing for resource benefits. The Wildland Fire Suppression FMU includes all other areas of the Forest, where suppression is the only appropriate management response (USDA Forest Service 2003). The delineation of Fire Management Suppression Zones would no longer exist under the proposed amendment.

Amending the LRMP would benefit the Forest in the following ways:

- Allow fire to assume a more natural role as an essential ecological process and natural change agent across a greater extent of the landscape.
- Improve habitat for native species.
- Sensitize fire managers to a more complete spectrum of resource issues.
- Provide authority for managers to implement wildland fire use in areas currently designated as wildland fire suppression.
- Educate the public about the role of fire in the ecosystem.
- Assure alignment of Forest fire management policies with Federal fire management policy.

The incorporation of this amendment into the LRMP does not suggest that a wildland fire use strategy will be implemented for every natural ignition. Wildland fire use would not be the appropriate management response under the following circumstances:

- Where threat to life, property, or resources cannot be mitigated.
- Where potential effects on cultural and natural resources are outside the range of acceptable effects.
- Where factors such as time of season, fire danger, fire size, and potential fire complexity are unacceptable to the Agency Administrator.
- Other proximate fire activity that limits or precludes successful management of the fire.
- Other Agency Administrator issues that preclude wildland fire use.

The appropriate management response for each wildland fire will vary across the Forest and will include the full spectrum of options from aggressive initial attack to managing fires. Wildland fire use, appropriately applied, is intended to restore fire's natural role in maintaining a healthy, diverse, and resilient ecosystem, resistant to natural disturbances.

Conclusion

The frequent occurrence of fires with uncharacteristic fire behavior over the last decade has led to a significant shift in Federal wildland fire policy. The Coronado National Forest's Proposed Wildland Fire Amendment demonstrates how the Forest has incorporated a science-based approach to wildland fire management. The integration of this amendment into the Forest's LRMP will move management practices toward restoring natural ecosystems altered by past wildland fire management policies.

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Global Climate Change

Shifts in the Potential Distribution of Sky Island Plant Communities in Response to Climate Change

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***Abstract**—To examine potential responses of sky island ecosystem pattern to projected climate changes, we used topographic and climatic data to develop a predictive model of plant community distribution in Saguaro National Park East, AZ. Increasing temperatures led to an upslope movement of communities and increased the area of desert scrub at the expense of montane conifer forest while increasing precipitation led to the opposite response as growth constraints imposed by arid conditions were lessened. Specific combinations of temperature and precipitation change created more or less extreme changes, with relatively little change in community area or spatial pattern occurring even in some cases where both climate variables increased. While simple, this model illustrates the complicated nature of sky island community responses to climate change and underscores the need for applications of more complex biogeographic models and targeted, field-based inventory and monitoring of plant communities.*

Introduction

Over the course of the last two decades, scientists have used a range of experimental, statistical, and mathematical techniques to explore the potential effects of projected climate changes on ecosystem pattern and function. One common prediction is that warmer temperatures resulting from increasing atmospheric concentrations of carbon dioxide and other greenhouse gases will lead to a widespread reorganization of species and community patterns (e.g., Shafer et al. 2001; Iverson and Prasad 2002). Mountains have been cited as areas where the effects of climate change may be especially noticeable because steep, elevationally structured gradients in temperature and precipitation lead to a rapid turnover of plant communities and relatively distinct community zones (Kupfer and Cairns 1996). In few places are such distinct vegetation patterns as evident as in the sky islands of the Southwestern United States and Northern Mexico, suggesting that these communities and their ecotones may be both sensitive indicators of climate change and areas of concern with respect to climate change effects. We therefore developed a predictive model of current plant community distribution in a southern Arizona sky island ecosystem based on topographic and climatic data. This model was then applied under 36 different scenarios of temperature and precipitation change to project the potential reorganization of plant communities. Our goal in doing so was not so much to predict where communities will shift given a certain trajectory of climate change, which is complicated by a range of factors other than climate, but rather to identify areas that may be most sensitive to climate change.

Study Area

The study area was the ca. 27,000 ha East Unit of Saguaro National Park (SNP-E), located immediately east of Tucson, AZ (32°N, 111°W). The park contains most of the Rincon Mountains as well as lower lying desert basins to the south and west. Elevation ranges from 818-2,620 m asl, resulting in significant gradients in temperature and precipitation. Mean annual temperatures in the desert valleys are high ($\bar{x}_{\text{July}} = 30.3$ °C; $\bar{x}_{\text{January}} = 11.0$ °C) (Tucson, AZ, 1948-2003; http://www.wrcc.dri.edu/), and on average, temperature decreases 6.7 °C per 1,000 m of elevation gain. Mean annual precipitation in Tucson for the same period was 290 mm, with 51% occurring during the summer (July-September) monsoon season. Precipitation increases 24.5 cm per 1,000 m, with higher elevations receiving >750 cm yr^{-1}, some of it as snow.

Methods

Data Sets: Vegetation, Topography, Climate

Plant community types in the Rincon Mountains occur in climatically structured elevation zones and include: (1) Sonoran desert scrub, dominated by succulents and woody shrubs, (2) Sonoran grassland and savanna, dominated by herbaceous species with scattered woody individuals, (3) Madrean evergreen woodland and forest, dominated by oaks (*Quercus* spp.), alligator juniper (*Juniperus deppeana*), and pines (*Pinus* spp.), and (4) montane conifer forests, dominated by ponderosa pine (*Pinus ponderosa*), southwestern white pine (*Pinus flexilis*), and Douglas fir (*Pseudotsuga menziesii*) (Bowers and McLaughlin 1987). Two Landsat ETM+ satellite images (October 1999, June 2000; Path 36/Row 38) were used to classify land cover into five classes, including the four vegetation communities mentioned above plus rock outcrops (which are not included in this analysis). The overall classification accuracy was 85% with a Kappa

(κ) of 0.80 and accuracies for the vegetation types ranging from 75%-90%.

Six topographic variables were extracted from a USGS 7.5-minute digital elevation model (DEM) with 30 m resolution: elevation (m), slope (°), cosine-transformed aspect (cos (asp°) +1), profile curvature, planform curvature, and topographic position (1 = ridge to 5 = valley). Due to digital striping errors in the DEM that became apparent when calculating the secondary topographic variables, the topographic coverages and the land cover classification were aggregated to a 60 m resolution.

We also estimated climate variables for each 60 m pixel using a modified version of MT-CLIM, a mountain microclimate simulator designed to extrapolate routine National Weather Service data from a base station to adjacent mountainous terrain (Running et al. 1987). While the original MT-CLIM estimated climate for only a single location, it was modified to calculate conditions at multiple sites and thereby develop spatially explicit climate coverages (Cairns and Malanson 1997). The model produced estimates of ambient air temperature (mean daily high, mean daily low) and precipitation based on: (1) summarized daily high and low temperatures, precipitation, and dew point for a base station (Sabino Canyon: 805m asl), (2) the 30 m DEM (aggregated to 60 m resolution for consistency), and (3) regional climatic lapse rates. Lapse rates were calculated from daily temperature and precipitation values obtained from the National Climate Data Center for the years 1965-1980 for four weather stations in the Tucson area: Sabino Canyon, Oracle (1,375 m), Kitt Peak (2,070 m), and Palisades Range Station (2,425 m). As a rough assessment of the accuracy of the climate extrapolations, we compared, predicted, and observed mean monthly temperatures (1995 to 2000) for the Rincon Remote Automated Weather Station at Manning Camp (2,512 m), which was not used in developing the climate parameters. Predicted and observed temperatures were highly correlated ($r = 0.92$) but displayed seasonal variations in accuracy that were due to seasonality of the actual lapse rate.

Climate Scenarios

Projections from global climate models (GCMs) suggest that temperatures in the Southwest will increase 3-6 °C over the next 100 years with a doubling of carbon dioxide while annual precipitation may increase from 50-100% (Southwest Assessment Team 2000). However, confidence in projections of temperature is higher than that for precipitation because GCMs have difficulty capturing local scale meteorological processes that cause precipitation in the Southwest (e.g., convection for thunderstorms). Further, the Southwest Monsoon and El Niño-Southern Oscillation, key factors shaping precipitation amounts in the region, are not well represented in current GCMs, introducing more uncertainty into regional precipitation predictions. Given this uncertainty, we opted to produce 36 climate change scenarios and model vegetation community response for each. We used combinations of six temperature values (mean temperature from 1961-1990; mean temperature +1 °C, +2 °C, +3 °C, +4 °C, +5 °C) and six precipitation values (mean precipitation from 1961-1990; mean precipitation –10%, +10%, +25%, +50%, +100%). For temperature, we chose to use mean daily low temperature because: (1) it was most strongly related to vegetation patterns, and (2) most estimates of climate change suggest that the strongest temperature increase will be in overnight low temperatures.

Data Analysis

We created a predictive vegetation model (*sensu* Franklin 1995) to project potential vegetation patterns under the 36 climate scenarios by relating the current community types to matching coverages of the predictor variables using discriminant analysis. Discriminant analysis classifies cases (individual pixels) into distinct groups (vegetation classes) on the basis of a set of discriminant functions that represent combinations of predictor variables (Lachenbruch 1975). The first discriminant function maximizes between-class differences in the values of the predictor variables, and the second function is orthogonal to it and maximizes additional differences while controlling for the first factor. Analyses were performed using SPSS v. 11.5.

To build the predictive vegetation model, we extracted every fifth pixel (spatial interval = 300 m) in every fifth row from the full SNP-E raster dataset (*n = 2912 pixels*). This method decreased the amount of spatial dependence among the sample units (i.e., pixels) (*cf.* Brown 1994) and allowed us to develop an independent validation dataset for the resulting model. This second dataset (*n = 2882 pixels*), which was also manipulated to create the 36 climate change scenarios, was similarly sampled from the full SNP-E dataset at a sampling interval of five pixels but staggered from the first dataset by three pixels to the south and east. Since a regular sampling grid was used in both cases, the percentage of pixels falling into each class roughly approximated the extent of each community type within SNP-E.

Because of the high correlation between mean minimum temperature and precipitation, we used principal components analysis (PCA) to develop a single climate "variable" that incorporated both temperature and precipitation. This variable was then included, along with the five topographic variables (excluding elevation), in the discriminant analysis. The resulting predictive vegetation model was used to map the potential vegetation class for all of SNP-E under each of the climate change scenarios. We then determined the number of predicted pixels for each vegetation type and created a surface of sensitivity to potential climate change by summing the number of scenarios in which an individual pixel appeared as a different vegetation class than the current class.

Results

Discriminant Analysis

The first discriminant function (eigenvalue = 4.26) accounted for nearly 97% of the variance among community types and was almost entirely structured by the PCA-derived climate variable. The second (eigenvalue = 0.13) and third (eigenvalue = 0.01) functions were most strongly related to slope and aspect, respectively, but collectively accounted for only 3% of the variance. When the resulting model was used both to back-predict vegetation class for the pixels used in model development and to predict vegetation class for the validation dataset, 80% of the predicted pixel classes agreed with the land cover classification (desert scrub = 92.5%; desert grassland/savanna = 74%; Madrean evergreen woodland/forest = 81%; montane conifer = 76%). The primary effect of the predictive model was to smooth out fine-scale variation that was evident in the remote sensing-based classification of SNP-E plant communities (figure 1a versus 1b).

Projected Changes in Plant Community Distribution

Changes in the extent of community types were highly dependent on the magnitude of temperature and precipitation change (table 1). As would be expected, increasing temperatures (when holding precipitation constant) led to an upslope movement of vegetation communities, substantially increasing the area of desert scrub while reducing montane conifer forest (figure 1c). Increased precipitation led to a downslope shift of communities as the growth constraints imposed by arid conditions were lessened. Thus, even a 5 °C temperature rise when coupled with doubling of precipitation resulted in a 500% increase in montane conifer and a substantial reduction in desert scrub. Specific combinations of temperature and precipitation change created more or less extreme changes. A temperature increase of 3 °C accompanied by a 25% increase in precipitation, for instance, resulted in relatively little change in community area (table 1) or spatial pattern (figure 1d). This latter finding illustrates the complicated nature of sky island community responses to climate change; that is, temperature increases may not necessarily result in upslope migration of communities if precipitation also increases.

Desert savanna/grassland and Madrean evergreen woodland/forest experienced smaller % changes in area for most scenarios. This may be a function of both their location in the middle of the mountain (with area to migrate upslope in warmer scenarios and downslope in wetter scenarios) and their relatively large current area (i.e., more area must change to evoke a similar % change for the other types). Conversely, desert scrub and montane conifer forest changed by >50% in many scenarios, most likely because they: (1) are located at the base and top of the mountain, and (2) constitute only 23% and 7% of the pixels examined, respectively. Declines in the former class, however, are of less concern because the area surrounding the park is desert and because most of the scenarios resulting in large losses of desert are unlikely to occur. Declines in montane conifer forest, however, represent regional losses that will not be offset elsewhere.

By comparing each pixel's current vegetation class to that projected under each of the climate scenarios, we identified pixels that may be most sensitive to climate change (i.e., those that change class in a wide range of scenarios) (figure 1e). While areas near current ecotones were generally more sensitive than core areas (e.g., the lowest desert areas, core montane conifer areas in Mica Mountain), the entire Madrean evergreen zone, regardless of proximity to its upslope and downslope ecotones, was highly sensitive, likely because it serves as a transition zone between grassland/savanna at lower elevations and more continuous conifer forests at higher elevations. This approach to examining sensitivity to climate change effects, however, implicitly assumes that each climate change scenario is equally likely. The most likely scenarios, given current GCM projections, would involve increases of 3-5 °C temperature and 0-50% in precipitation. In these 12 scenarios: (1) desert scrub showed moderate (10-50%) to large (>50%) increases in area in 75% of the scenarios; (2) desert grassland/savanna showed moderate increases in nearly all scenarios with a 0-25% precipitation increase and small (<10%) to moderate losses with a 25-50% increase; (3) Madrean evergreen woodland/forest declined in all scenarios; and (4) montane conifer experienced large declines in cases with little to no change in precipitation but substantial gains in cases with a 50% increase.

Discussion

There are two basic categories of biogeographic models that are used to predict the response of vegetation patterns to climate change: dynamic (time-dependent) and static (time-independent) (Peng 2000). Most static models, such as the one used in this study, are empirical and employ response surfaces or "climate envelopes" to describe the relationship between topoclimatic variables and the distributions of species or community types. Projections from GCMs are then used to map future climate patterns, and biotic distributions are re-projected based on the current relationships (e.g., Brzeziecki et al. 1995; Shafer et al. 2001). These models, by their nature, do not address transient responses of individual systems and merely represent theoretical equilibrium locations for some future time period (Kirilenko and Solomon 1998).

Static, empirical models are generally crude and limited because they do not explicitly address the underlying mechanisms that structure vegetation response to climate change, although some have incorporated a more process-based approach (Neilson 1995; Haxeltine and Prentice 1996). Among other things, these models make an untenable assumption that species or community distributions are currently in equilibrium with the variables being used to predict them and that they could not, in the absence of other species or communities, occur in a broader range of conditions. In the case of species-level models, for example, the model typically utilizes the realized niche of the species and may miss dynamics that use of their fundamental niche would show (e.g., Malanson et al. 1992; Jackson and Overpeck 2000). Further, models that exclusively address community-level responses do not operate at the scale at which response to climate change is driven (i.e., individual trees and species).

A more robust treatment of vegetation change in the sky islands needs to incorporate both greater temporal complexity (e.g., time lagged or nonlinear responses) and a broader range of factors affecting vegetation response. Most notably, community patterns may originate not only from variations

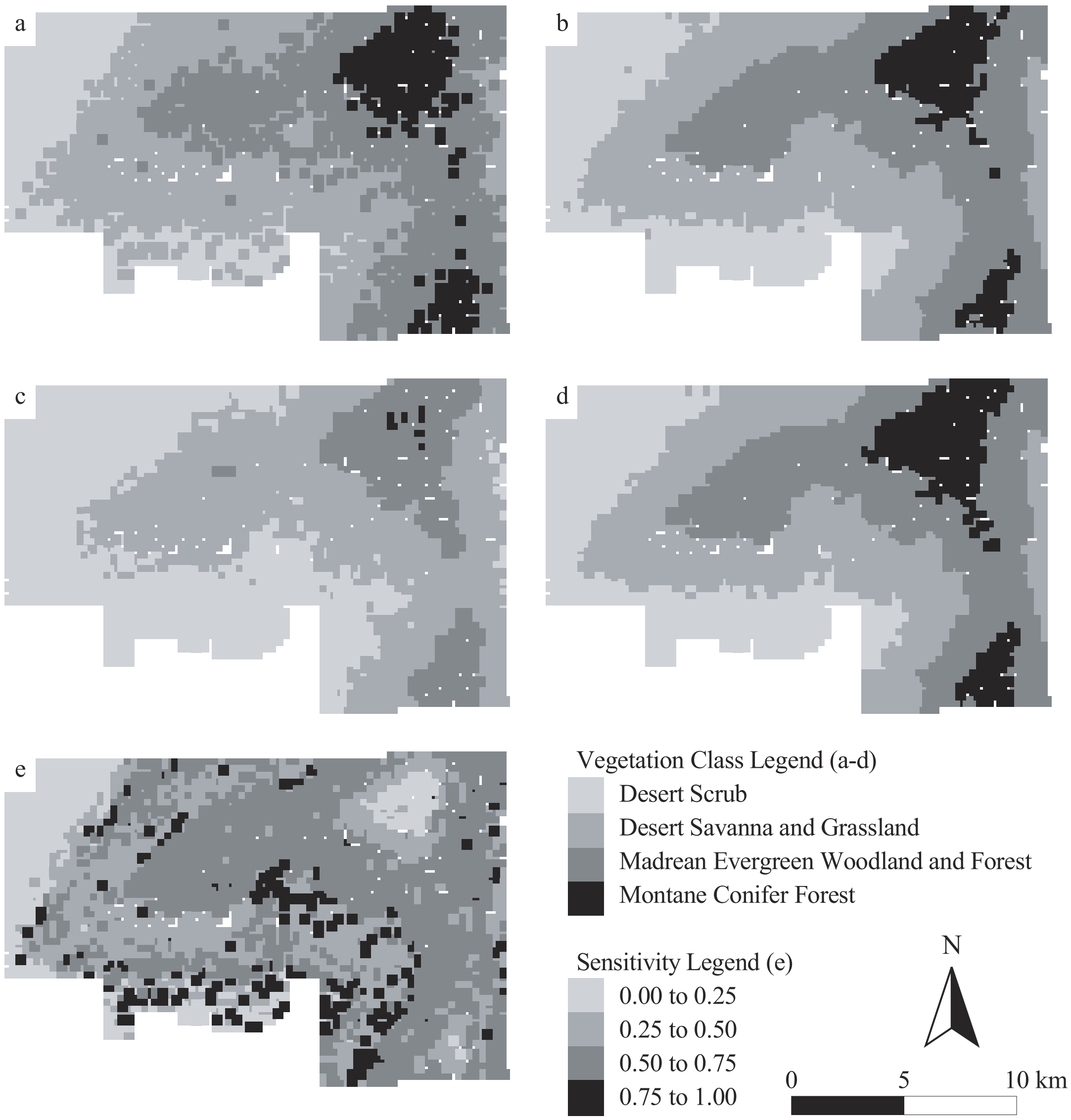

Figure 1—Current and modeled vegetation for Saguaro National Park East: (a) vegetation classification derived from Landsat ETM+ imagery; (b) modeled current vegetation; (c) projected potential vegetation with a 3 °C temperature rise and current precipitation; (d) projected potential vegetation with 3 °C rise and 25% increase in precipitation; (e) percentage of modeled climate change scenarios (n = 36 total) where vegetation in each pixel changed.

in average climate trends but also from: (1) limitations and feedbacks associated with species dispersal (e.g., Cole 1985), (2) resistance to invasion of the extant community and other interspecific interactions (e.g., Davis et al. 1998), (3) the importance of non-climatic controls on vegetation patterns (e.g., soil limitations; Kupfer and Cairns 1996), and (4) changes in the range of climate variability and the occurrence of extreme events such as prolonged droughts (e.g., Malanson 2001; Dullinger et al. 2004). Further, in the Southwest, changes in temperature and precipitation regimes will likely contribute to changes in the primary disturbance regimes, particularly fire and insect outbreaks. The ways in which altering disturbance regimes may further condition the response of sky island community pattern to climate change, especially given changes in community structure and function that have taken place with fire suppression and other human activities over the last century, is not well known.

It was in part these limitations that led us to focus not so much on the predicted output of any given climate change scenario but rather on changes in community extent along gradients of temperature and precipitation change as well as the spatial pattern of community sensitivity to a range of climate change scenarios. In this sense, the model projections become not so much predictions of vegetation change but rather neutral models of potential changes that should be examined using targeted, field-based inventory and monitoring of plant communities. This simple model also highlights the potentially complicated nature of vegetation responses and emphasizes the need for applications of more complex, dynamic biogeographic models.

Table 1—Predicted number of pixels of each vegetation class under various precipitation (columns) and temperature (rows) change scenarios. Values in parentheses represent % change with respect to current conditions (0% and +0 ºC). Bold values are changes in excess of 50% increase or decrease.

Desert scrub

	-10%	0%	10%	25%	50%	100%
+0 ºC	751 (+11%)	678 (+0%)	578 (-15%)	368 (-46%)	**135 (-80%)**	**0 (-100%)**
+1 ºC	875 (+29%)	764 (+13%)	684 (+1%)	547 (-19%)	**221 (-67%)**	**0 (-100%)**
+2 ºC	**1,070 (+58%)**	891 (+31%)	771 (+14%)	673 (-1%)	364 (-46%)	**0 (-100%)**
+3 ºC	**1,262 (+86%)**	**1,073 (+58%)**	906 (+34%)	745 (+10%)	537 (-21%)	**60 (-91%)**
+4 ºC	**1,454 (+114%)**	**1,254 (+85%)**	**1,077 (+59%)**	839 (+24%)	654 (-4%)	**148 (-78%)**
+5 ºC	**1,659 (+145%)**	**1,436 (+112%)**	**1,246 (+84%)**	1,000 (+47%)	727 (+7%)	**227 (-67%)**

Desert savanna and grassland

	-10%	0%	10%	25%	50%	100%
+0 ºC	1,232 (+19%)	1,037 (+0%)	905 (-13%)	844 (-19%)	747 (-28%)	**173 (-83%)**
+1 ºC	1,337 (+29%)	1,181 (+14%)	1,003 (-3%)	833 (-20%)	792 (-24%)	**364 (-65%)**
+2 ºC	1,324 (+28%)	1,278 (+23%)	1,140 (+10%)	876 (-16%)	771 (-26%)	592 (-43%)
+3 ºC	1,289 (+24%)	1,282 (+24%)	1,206 (+16%)	995 (-4%)	751 (-28%)	665 (-36%)
+4 ºC	1,222 (+18%)	1,249 (+20%)	1,227 (+18%)	1,108 (+7%)	779 (-25%)	690 (-33%)
+5 ºC	1,104 (+6%)	1,191 (+15%)	1,209 (+17%)	1,144 (+10%)	867 (-16%)	699 (-33%)

Madrean evergreen woodland and forest

	-10%	0%	10%	25%	50%	100%
+0 ºC	801 (-16%)	958 (+0%)	1,033 (+8%)	997 (+4%)	759 (-21%)	794 (-17%)
+1 ºC	617 (-36%)	805 (-16%)	941 (-2%)	995 (+4%)	821 (-14%)	697 (-27%)
+2 ºC	**473 (-51%)**	639 (-33%)	810 (-15%)	963 (+1%)	883 (-8%)	576 (-40%)
+3 ºC	**331 (-65%)**	495 (-48%)	672 (-30%)	881 (-8%)	898 (-6%)	579 (-40%)
+4 ºC	**206 (-78%)**	**372 (-61%)**	521 (-46%)	764 (-20%)	910 (-5%)	589 (-39%)
+5 ºC	**119 (-88%)**	**255 (-73%)**	**408 (-57%)**	628 (-34%)	878 (-8%)	629 (-34%)

Montane conifer forest

	-10%	0%	10%	25%	50%	100%
+0 ºC	**986 (-53%)**	209 (+0%)	**366 (+75%)**	**673 (+222%)**	**1,241 (+494%)**	**1,915 (+816%)**
+1 ºC	**53 (-75%)**	132 (-37%)	254 (+22%)	**507 (+143%)**	**1,048 (+401%)**	**1,821 (+771%)**
+2 ºC	**15 (-93%)**	**74 (-65%)**	161 (-23%)	**370 (+77%)**	**864 (+313%)**	**1,713 (+720%)**
+3 ºC	**0 (-100%)**	**32 (-85%)**	**98 (-53%)**	261 (+25%)	**696 (+233%)**	**1,578 (+655%)**
+4 ºC	**0 (-100%)**	**7 (-97%)**	**57 (-73%)**	171 (-18%)	**539 (+158%)**	**1,455 (+596%)**
+5 ºC	**0 (-100%)**	**0 (-100%)**	**19 (-91%)**	110 (-47%)	**410 (+96%)**	**1,327 (+535%)**

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Climate Mitigation Potential of the San Pedro River Riparian Zone

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***Abstract**—Carbon (C) and nitrogen (N) cycling within an open brush site, a sacaton (*Sporobolus wrightii*) grass and a mesquite (*Prosopis velutina*) grove, in the riparian zone was closely linked to the yearly litter N inputs. Yearly mesquite litter fall for 2 yr was remarkably similar and averaged 4.0 g N m^{-2} and 65 g C m^{-2} soil and resulted in higher soil C content compared to other riparian vegetation. The riparian soils held 7,000 metric tons more C than an adjacent nonriparian area suggesting the riparian zone processes result in a sink for atmospheric C. Water is essential for ecosystem function, and loss of water from the San Pedro River will severely impact the C sink in the riparian area.*

Introduction

Due to the semi-arid climate, few researchers have speculated on the role of the Madrean Archipelago for forcing or mitigating climate change. Since the mid-1800s, global average temperatures have increased by 0.6 °C, but during the 1990s, North American average temperatures were 0.9 °C warmer than during the centuries prior to Industrial Revolution, and comparison with ice cores, tree rings, and other proxy measures suggests that the warming of the 20th century is unprecedented (National Synthesis Report 2001). Predictions for the 21st century include further temperature increases for the continental United States of 3 to 5 °C, suggesting that current climate change parameters are inducing a positive feed-back mechanism on climate change. Thus it is vital to identify and research known zones of C sequestration as a means for limiting climate change.

Research into semi-arid terrestrial sinks for atmospheric C has been nonexistent due to the perceived notion that due to seasonal moisture deficits, semi-arid regions are not a source or sink for atmospheric C. Semi-arid lands are very sensitive to climate change because if regional temperatures increase or precipitation patterns change, then the rates of soil C mineralization from the existing soil organic C pools will increase, thus limiting the potential of semi-arid soils to sequester C as a mechanism for offsetting increasing levels of atmospheric CO_2.

Water is the most limiting resource to biological activity in semi-arid lands (Noy-Meir 1973). The increased demands for water due to the growing human presence in the San Pedro River valley has resulted in a need for understanding the water needs of both the growing human presence and the water needs of a healthy riparian zone. Here we report on the riparian C and N budget in the different vegetation communities that comprise the riparian area and also the surrounding nonriparian area.

Study Site

San Pedro Riparian National Conservation Area

The climate of the San Pedro valley is semi-arid with temperatures ranging from a mean maximum of 24.8 °C to a mean minimum temperature of 9.9 °C (30 year record in Tombstone) with a bimodal distribution of precipitation (total 343 mm) with 60% of the rainfall coming during the summer monsoon months of July–September. The study site is a mesquite grove located just south of Fairbank, Arizona, along the San Pedro River on river terraces that were historically composed of grazed grasses and forbs. The study site encompassed three vegetation types, the first dominated by velvet mesquite, a leguminous tree (mesquite site). Within the mesquite grove were open sites with only annual vegetation and sites with sacaton grass, each with significant impact from the mesquite canopies. The second site was dominated by sacaton, a perennial bunchgrass (sacaton site), and the third was populated by annual herbaceous dicots, including peppergrass (*Lepidium thurberi*), Fremont's goosefoot (*Chenopodium fremontii*), and toothleaf goldeneye (*Viguiera dentata*) (open site), both removed from mesquite impacts.

Soil Analyses

Triplicate soil and litter (O-horizon) samples were collected at 24 sites within the vegetation sites over a two year period. Each vegetation site was sampled at each of three collection times to establish a replication in time analysis. From each site, samples composed of the litter layer from 27.3 cm^2, the 0–5 cm depth, and the 5–10 cm depth from a 109.86 cm^3 volume were collected, with additional soil samples from the study sites taken by soil cores to a depth of 60 cm. The soils were stored at 4 °C until processing, weighed for bulk density determination, processed to remove rocks and passed through a 1 mm sieve for further analysis. Samples were analyzed for pH (2.5 g soil:10 mL 0.05 M CaCl) and C and N by dry combustion with isotope ($^{13}C/^{12}C$ ratio, $\delta^{13}C$; $^{15}N/^{14}N$ ratio, $\delta^{15}N$) analysis (Europa Hydra 20/20 mass spectrometer, Northwich UK). Carbohydrate content (Martens and Loeffelmann 2002) and amino acid content (Martens and Loeffelmann 2003) were extracted by separate acid digestion and determined by ion chromatograph coupled with pulsed amperometry detection.

Trace Gas Measurement

Nitrous oxide (N_2O) and methane (CH_4) fluxes were measured by the static chamber method (Hutchinson and Mosier 1981) using 22-cm diameter PVC chambers permanently installed at the soil surface. Lids were firmly affixed to the chamber surface and 10 ml sub-samples of the chamber atmosphere were removed through a sampling port every 15 min for 1 hour. Gas sub-samples were transported to the laboratory and analyzed within 24 hours using a Shimadzu GC14-A Gas Chromatograph (Shimadzu Corp., Columbia, MD), fitted with dual detectors (flame ionization and electron capture detection), and an 80/100 HayeSep-Q column (Supelco, Inc., Bellefonte, PA). Net gas fluxes were then calculated from exponential regression of the time series of gas concentrations within the chamber headspace (Koschorreck and Conrad 1993). Carbon dioxide (CO_2) fluxes were measured using the same static chamber with sealed lid as describe above. After 1 hour, the headspace air was pumped from the chamber into an infra-red gas analyzer (Qubit Systems, Inc., Kingston, Ontario, Canada). The CO_2 concentration in the chamber headspace was used to quantify net efflux from the soil surface.

Mesquite litter inputs were measured in the fall of 2001 through spring 2002 and again in the fall of 2002 through spring 2003. Litter traps (24.5 cm by 39 cm) were placed in triplicate under seven trees of various canopy diameters. The litter traps were emptied on a regular basis and the litter returned to the laboratory, dried, and weighed for total amount. Subsamples of litter fall (seven) were ground and analyzed for C and N content and isotope composition by the same method used for soils described above. In addition during 2002, sacaton bunches were harvested to determine the biomass produced within the mesquite grove and in isolated sacaton patches not influenced by litter fall and shading from the mesquite trees. The C and N content and isotopes of the different vegetation are reported in table 1.

Results and Discussion

The upper San Pedro River Basin in southeastern Arizona and northern Sonora, Mexico has a lengthy reach of perennial flow, which sustains relatively lush riparian vegetation (Grantham 1996), unlike many former semi-arid riparian areas that have been destroyed due to heavy use of ground water like the Santa Cruz River near Tucson. Vegetation along this stretch of the San Pedro River is mainly mesquite with areas of whitethorn acacia (*Acacia constricta*), sacaton, and open brushy areas outside of the mesquite growth. The vegetation sampled differed little in C content, although the isotopic composition ($\delta^{13}C$) directly reflected the differences noted between C_3 (mesquite and acacia) and C_4 (sacaton) plants (table 1). The plants also had distinctly different N contents due to N fixation by the mesquite and acacia trees and shrubs, but the $\delta^{15}N$ ratios were not different (table 1). The biochemistry of the shrubs versus the grasses was even more pronounced with the mesquite and acacia material lower in carbohydrates and higher in amino acid concentration compared to the sacaton grass. The sacaton grass bunches (n = 6) sampled under the mesquite growth that receives mesquite litter input was intermediate between the mesquite and the isolated sacaton grass (n = 6), suggesting that the mesquite N inputs were changing the biochemistry of the sacaton growing under the mesquite trees.

An extensive soil sampling under the different vegetation exhibited few differences between the C content of the litter layer (O-horizon) or the 0–5 and 5–10 cm depths in the mesquite community regardless of whether the samplings were in the open areas between the trees or directly under the trees (table 2). The isotopic composition of the organic C content within the mesquite community is a direct reflection of the mesquite C input even inside the sacaton grass growth ring. Only outside of the mesquite community in the sacaton and

Table 1—Properties of selected plant species (average ± standard deviation) present in the San Pedro Riparian Area (n = 3).[a]

Species	Organic Carbon	$\delta^{13}C$	Total Carbohydrates	Nitrogen	$\delta^{15}N$	Amino Acids
	-- g kg-1 --		----------- g kg-1 --------------			-- g kg-1 –
Acacia	531+14.1	-25.9	266+49.8	30.6+5.12	5.32	145+20.0
Mesquite	561+19.6	-27.1	246+30.9	35.9+3.33	3.38	187+6.10
Sacaton-Mesquite	492+9.17	-14.7	467+31.5	15.4+2.44	3.32	78.6+7.80
Sacaton	492±2.35	-13.5	528±28.2	13.0±1.37	2.16	66.9±5.20

[a] Sacaton-mesquite represents sacaton grass bunches growing within the mesquite groves, while the sacaton grass sampled was not impacted by mesquite litter fall.

Table 2—Properties of soils (averages ± standard deviation) developed under different vegetation in the San Pedro Riparian area (n = 4).[a]

Vegetation	pH	Organic Carbon	$\delta^{13}C$	Carbohydrates	Total Nitrogen	$\delta^{15}N$	Amino Acids
		-- g kg^{-1} --		----------- g kg^{-1}	--------------		-- g kg^{-1} –
Acacia							
O-Horizon	ND	169+29.7	-25.9	54.3±13.9	14.9±5.83	7.52	53.5±22.7
0–5 cm	5.59	43.7±27.0	-24.9	13.8±3.40	4.29±2.33	8.38	12.9±8.54
5–10 cm	6.38	19.8±4.57	-23.1	6.13±1.71	1.98±0.38	8.85	5.70±3.04
Mesquite							
O-Horizon	ND	172+60.5	-24.1	43.6±21.8	15.5±5.34	6.62	37.4±8.24
0–5 cm	6.38	48.7±14.2	-24.2	15.0±2.59	5.22±1.58	7.69	17.3±5.44
5–10 cm	6.99	21.9±12.0	-22.2	6.43±2.52	2.25±1.12	7.80	7.80±4.41
Mes–Open							
O-Horizon	ND	174+56.1	-25.8	46.4±6.59	16.2±4.96	6.96	53.9±14.6
0–5 cm	6.13	48.9±16.9	-23.8	20.2±13.7	5.40±1.87	8.06	23.6±12.6
5–10 cm	6.87	17.7±2.58	-21.7	5.00±1.69	1.89±0.19	8.37	6.21±0.89
Sac–Mes							
O-Horizon	ND	191+70.0	-23.3	52.9±21.7	18.4±9.36	6.60	54.0±19.3
0–5 cm	6.22	40.9±6.78	-22.2	21.4±13.1	4.23±0.68	8.41	15.8±3.79
5–10 cm	6.79	27.9±11.1	-21.1	10.5±6.33	2.81±1.11	7.98	11.3±4.64
Sacaton							
O-Horizon	ND	315+106	-13.4	22.2±3.22	13.9±0.43	4.31	26.2±1.86
0–5 cm	6.68	29.2±17.3	-16.3	12.0±2.33	2.85±1.53	7.92	12.8±1.54
5–10 cm	6.26	20.7±11.3	-15.8	5.92±1.32	1.98±0.95	7.83	7.99±0.89
Open							
O-Horizon	ND	94.4+8.3	-19.8	54.7±6.58	6.59±1.09	7.78	30.2±1.28
0–5 cm	7.14	13.8±6.61	-20.3	3.80±2.04	1.31±0.85	7.44	5.76±4.52
5–10 cm	7.20	10.2±3.29	-20.0	2.53±0.23	0.87±0.18	6.68	3.87±2.50

[a] Sacaton-mesquite represents sacaton grass bunches growing within the mesquite groves, while the sacaton grass sampled was not impacted by mesquite litter fall, and open area is outside of the riparian zone with annual grass and forb vegetation.

open areas did the soil C and N values not reflect the impact of the mesquite litter on the soil C and N content. The soil carbohydrate and amino acid concentrations also reflected the respective vegetation and the total C and N of the soil. The carbohydrates and amino acids are very important constituents of the soil organic matter as the fractions are generally very labile due to the ease of mineralization by soil microorganisms. The accumulation of large pools of C and N as carbohydrates and amino acids in these semi-arid soils is only possible due to the disconnect in time between production by the plants and mineralization by soil microorganisms. When litter is returned to the soil in the fall, cool soil temperatures limit decomposition that could occur with winter or early spring rains. The litter layer then is dry when the warm spring and summer temperatures occur. The brief summer monsoon period is very important for providing moisture while soil temperatures are warm enough for rapid microbial activity to mineralize the organic matter and return nutrients to the soil.

While the C and N content are indicators of amounts of C and N present in the different vegetation communities, determining the amount of C and N on a volume basis (m^2) provides a means for a more accurate comparison of total soil C and N. To determine the amount of soil C and N in a defined depth of soil, samples were taken to 60 cm, and by utilizing the bulk density of the depths (g cm^{-3}), the C and N content (mg C g^{-1} soil) of the soil depth sampled can be multiplied by the bulk density to obtain a total C and N content on the volume basis. Table 3 shows that although the C content of the sacaton O-horizon (table 2) had a higher C content [315 g (sacaton) versus 172 g (mesquite) kg^{-1} litter] when the amount (g) of litter on a m^2 basis was multiplied by the C content, the mesquite vegetation contained a much greater amount of C and N. The lack of O-horizon C in the open areas outside of the riparian mesquite community confirm the importance of the O-horizon C in the riparian zone as the O-horizon under the mesquite community accounts for 71% of the average profile C difference between the mesquite and open brush communities (table 3).

The San Pedro riparian zone covers approximately 22,660 ha in area and by assuming that mesquite impact 80% of the riparian zone as open areas within the mesquite, mesquite-sacaton and under mesquite trees, with an additional 10% impacted by acacia shrubs. By converting the g m^{-2} C values based on C and bulk density values taken from tables 2 and 3 to kg ha^{-1}, the riparian zone contains 21,660 metric tons of soil C compared to the 14,620 metric tons in a comparably sized area of shrub and brush that lie outside the riparian zone. The riparian zone is responsible for sequestration of an additional

Table 3—Minimum, maximum, and average total C and N contents for soils developed under different vegetation in the San Pedro Riparian area.[a]

Soil	Bulk Density	Organic Carbon Minimum	Organic Carbon Maximum	Organic Carbon Average	Total Nitrogen Minimum	Total Nitrogen Maximum	Total Nitrogen Average
		---------- $g\ m^{-2}$ ----------			---------- $g\ m^{-2}$ ----------		
Mesquite Vegetation							
O-horizon	ND	91.0	377	234	9.64	26.7	10.9
0–10	0.88	122	313	217	14.0	31.2	22.6
10-20	1.07	100	123	112	10.5	12.3	11.4
20-30	1.21	61.3	124	92.5	6.14	12.9	9.51
30-40	1.31	69.6	133	101	6.70	13.1	9.89
40-50	1.35	55.7	113	84.1	5.40	10.5	7.96
50-60	1.39	119	149	134	10.2	12.8	11.5
Total	ND	619	1330	974	62.5	119	83.7
Sacaton Vegetation							
O-horizon	ND	26.3	55.9	41.1	1.75	1.87	1.81
0–10	1.02	141	250	196	13.8	25.4	19.6
10-20	1.22	140	202	171	12.7	15.9	14.5
20-30	1.33	112	130	121	10.0	14.4	9.07
30-40	1.35	94.0	119	106	7.52	8.88	7.99
40-50	1.37	88.0	92.1	90.5	4.95	6.31	5.60
50-60	1.42	64.1	68.3	66.3	3.92	5.33	4.40
Total	ND	670	913	792	53.3	72.7	63.0
Outside Brush Vegetation							
O-horizon	ND	0.00	0.00	0.00	0.00	0.00	0.00
0–10	1.26	141	194	167	10.8	15.2	13.0
10-20	1.32	163	189	176	13.8	15.2	14.5
20-30	1.37	97.1	169	133	8.07	13.5	10.8
30-40	1.39	77.1	81.2	79.1	7.01	11.3	9.06
40-50	1.44	60.3	68.5	64.4	6.92	7.83	7.52
50-60	1.48	22.3	27.8	24.4	1.75	3.25	2.80
Total	ND	569	720	645	52.0	63.3	57.7

[a] Outside area is outside of the riparian zone with annual grass and forb vegetation.

7,040 metric tons of soil C, and the value does not include C stored in the woody plant tissue.

The litter accumulating in the soil O-horizon under the mesquite vegetation was measured during two seasons of litter collection to accumulate at the rate of between 170 g litter m^2 during 2002-2003 (249 mm monsoon moisture) and 127 g litter m^2 in 2001-2002 with 177 mm monsoon moisture (figure 1). The mesquite litter contained 469 $\pm$ 29.1 g C and 28.5 $\pm$ 2.7 g N kg^{-1} litter with a $\delta^{15}N$ of 4.25 and a $\delta^{13}C$ of -27.1. The results suggest that the moisture input during the monsoon season is very important for production of mesquite inputs to the riparian zone. The size of the mesquite tree was important for the amount of litter returning to the riparian community (r^2 = 0.91 and 0.92, respectively, for 2002 and 2003) for the seven trees monitored. The large amount of litter remaining under the mesquite trees (table 3) was greater than the amount of litter returning yearly to the understory by a factor of 1.5 (minimum O-horizon value) to 6.4, suggesting that less litter decomposes each year than is returned by leaf litter.

Cycling of C in ecosystems involves cycling of atmospheric C into plants and then through the soil environment via leaf litter and woody plant parts. Only part of the atmospheric C sequestered in plant growth is returned to the soil each year, and the plant material returned would be utilized by soil microorganisms for energy and growth. The C cycle also includes by-products of the microbial utilization of plant C as C is returned to the atmosphere as CO_2. Additional trace gases such as CH_4 and N_2O are also implicated in the C cycle and potential greenhouse warming. These trace gases were monitored in the San Pedro Riparian area during 2002 and 2003 to provide a yearly C budget for the system. Results showed little difference in CO_2 emissions from the open (208 g C m^{-2} yr^{-1}), sacaton (221 g C m^{-2} yr^{-1}), or mesquite (257 g C m^{-2} yr^{-1}) vegetation communities even though the soil C and N content were 2 to 3 times higher under mesquite than in the open areas (tables 2 and 3). The monitoring found higher levels of N_2O flux from under the mesquite (82 mg N_2O m^{-2} yr^{-1}) compared with the open area (35 mg N_2O m^{-2} yr^{-1}) and the sacaton vegetation (24 mg N_2O m^{-2} yr^{-1}). But the N_2O emissions are very small next to the C fluxes even if the greenhouse gas potential of N_2O (310 x CO_2) is applied. A surprising aspect of the study was the finding of a perennial sink in the riparian zone for CH_4. The CH_4 sink consumed 206 mg CH_4 m^{-2} yr^{-1} for the mesquite sites and 207 mg CH_4 m^{-2} yr^{-1} in the open and 149 mg CH_4 m^{-2} yr^{-1} in the sacaton grass site. By estimating the amount of mesquite litter fall (figure 1) and estimates of grass and shrub litter in the riparian zone, the amount of C accounted for, not including woody plant biomass is approximately 52% of the C equivalents exiting the riparian area as CO_2 and N_2O. By accounting for the C returned to the sacaton grass community,

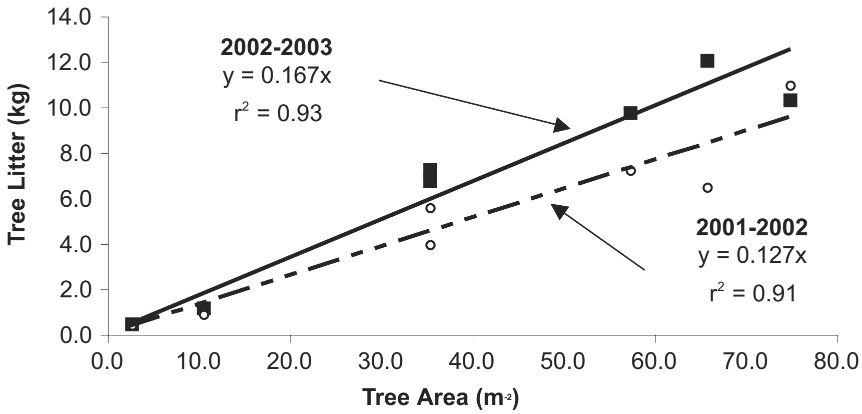

Figure 1—Mesquite litter collected during the fall of 2001 through spring 2002 and fall of 2002 through spring 2003 from seven mesquite trees of various sizes.

only 20% of the C emissions are recaptured by vegetation inputs to the system.

The San Pedro River supports a great array of animal and plant life and is a rare remaining example of a semi-arid riparian ecosystem. In addition to the great habitat, the riparian zone is also a major sink for atmospheric C. It is extremely difficult to place a value on a semi-arid ecosystem that is possibly a major player in the ecoregions ability to reduce the impact of increasing atmospheric C content.

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Studies of Methane Fluxes Reveal That Desert Soils Can Mitigate Global Climate Change

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Abstract—*Moisture limitations have led researchers to believe that semiarid soils are not significant consumers or producers of trace gases, and these regions are often overlooked in greenhouse gas inventories. We are studying environmental influences on soil fluxes of methane (CH_4) in southeastern Arizona. We found negligible CH_4 consumption in the very dry pre-monsoon period, but the first moisture pulses stimulated soil CH_4 flux. Thereafter, significant CH_4 consumption was found through the summer and winter months. The soil CH_4 consumption averaged 471 ± 278 µg CH_4 m^{-2} d^{-1} throughout the year, confirming the presence of a large, previously unreported CH_4 sink, and strongly suggesting that soils of semiarid ecosystems cannot be discounted in potential mitigation of climate change.*

Introduction

Atmospheric methane (CH_4) concentrations have risen from 0.7 to 1.8 ppm since the beginning of the Industrial Revolution. Methane is a greenhouse gas that has been implicated in global warming (Lelieveld et al. 1993; Rodhe 2001) and thus, its atmospheric concentration is a major focus of global change studies. Although researchers have estimated the contribution of world soils to the budgets of CH_4, flux data are extremely sparse for semiarid ecosystems. Moisture limitations in semiarid life zones have led to the belief that these soils are not significant consumers or producers of trace gases and as a result, semiarid soils are often largely overlooked in greenhouse gas inventories (Bowden 1986; Streigl et al. 1992).

Microbial production and consumption of CH_4 in soils are of crucial importance to the global CH_4 budget. Soil CH_4 production by methanogenic bacteria is a strictly anaerobic process, common in wetland soils with high carbon availability. Soil CH_4 consumption results from the activity of methanotrophic bacteria, organisms that thrive near the soil surface and intercept almost half of all CH_4 produced lower in the soil profile before it is released to the atmosphere. They also consume approximately 40-60 Tg per year of CH_4 directly from the atmosphere (Reeburgh et al. 1993; Watson et al. 1990). As a result, soils are the largest terrestrial CH_4 sink, in the absence of which atmospheric CH_4 concentrations would increase by at least 1.5 times the current rate (Duxbury 1994).

Only limited scientific information exists on soil CH_4 fluxes in semiarid ecosystems. A single study reported CH_4 consumption rates of 1.87 ± 1.45 mg CH_4 m^{-2} d^{-1} in Mojave Desert soils following rainfall (Striegl et al.1992). The authors suggested that high rates of CH_4 consumption in semiarid soils may be concentrated in brief periods following wetting events but decreases following soil drying because methanotrophic bacteria are not particularly xerotolerant (King 1997; West and Schmidt 1998).

Clearly, additional structured monitoring of CH_4 fluxes across different dryland vegetation zones is needed to improve our understanding of the role that semiarid soils play in the global CH_4 budget. Because semiarid soils constitute more than 25% of the terrestrial land mass worldwide (Bailey 1996; Potter et al. 1996), research examining the environmental controls of CH_4 production and consumption in these regions is of particular importance. Here we report the results of a monitoring study conducted in two ecosystems in southeastern Arizona. Over 18 months, we monitored gas fluxes and soil environmental variables to quantify CH_4 production and consumption as well as identify the factors controlling CH_4 fluxes in these soils.

Study Sites

San Pedro Riparian National Conservation Area

Our first study area is in the San Pedro Riparian National Conservation Area (SPRNCA) in southeastern Arizona. This Federally managed preserve is the subject of considerable scientific study, as it is a rare remnant of what was once an extensive network of similar riparian systems throughout the Southwest. Here, plants and animals thrive locally because of an availability of water and thus, the SPRNCA represents a unique system to quantify the effects of ecosystem desertification and vegetation change on trace gas fluxes.

Precipitation along the San Pedro averages ~350 mm per year, 60% of which falls in the monsoon season of July to September. We measured CH_4 fluxes in soils of three distinct vegetation types: (1) mesquite (*Prosopis* spp.), an N-fixing desert legume, (2) sacaton (*Sporobolus* spp.), a coarse perennial bunchgrass, and (3) a mixture of annual grasses and forbs.

Santa Rita Experimental Range

Our second area includes three vegetation zones in the Santa Rita Experimental Range (SRER), a Sonoran Desert grassland with a history of grazing dating back to the late 19th century. This area receives approximately 325 mm of rainfall per year, 60% of which falls in the summer monsoon season. Overgrazing and fire suppression have induced major vegetation changes in this area since the early 1900s. Currently, mesquite is the dominant overstory species on the majority of the rangeland where shrub-free grassland dominated 80 years ago. The non-native Lehman's lovegrass (*Eragostis lehmanniana*) is the dominant grass. We monitored CH_4 fluxes under a mesquite canopy, in a grass-dominated area, and an area over a mesquite stump that was killed by herbicides about 40 years ago.

Methods

Trace gas monitoring in the SPRNCA began in June 2002. Monitoring was done once or twice weekly during the summer monsoon period, and monthly or bi-monthly in the fall and winter. Trace gas monitoring in the SRER began in June 2003 and was done bi-weekly through the end of the monsoon period. Methane fluxes were measured by the static chamber technique using 22-cm diameter PVC chambers permanently installed at the soil surface. On sampling dates, lids were firmly affixed to the chamber surface and sub-samples of the chamber atmosphere were removed using gas tight syringes every 15 min for 1 h. Gas samples were analyzed in the laboratory using a Shimadzu GC14-A Gas Chromatograph fitted with a Flame Ionization Detector. Certified CH_4 standards (Praxair Inc., San Ramon, CA) were used for calibration. Net fluxes were calculated from the exponential regression of the time series of CH_4 concentrations (Koschorreck and Conrad 1993).

Environmental variables thought to impact CH_4 fluxes were measured using data logging stations installed at each of the monitoring sites in the SPRNCA and SRER. Every 5 minutes, these stations measured air and dew point temperatures at 60 cm above the soil surface, soil temperature at 15 and 30 cm depths, soil moisture at 5-10, 15, and 30 cm depths, and CO_2 concentrations at 15 cm above the soil surface.

Laboratory incubations to quantify methanotroph activity (CH_4 consumption) were performed once during the monitoring period using SPRNCA soils. Soils collected in 5 cm increments down to 50 cm were incubated under optimum conditions for CH_4 consumption (temperature of 20 °C; moisture of 80% of field capacity). Gas samples were collected from the incubation flasks every 24 h. Flasks were then flushed with ambient air and re-sealed. Methane consumption was calculated from the decrease in headspace CH_4 over the 24 h incubation period. Incubations were performed over a period of five days. In order to localize maximum CH_4 consumption *in situ*, and to quantify the effects of soil moisture on that activity, soil gas probes were installed in September 2003 at the Santa Rita sites. These probes allowed us to collect soil porespace gases at nine depths from 5 to 100 cm.

Results and Discussion

San Pedro Riparian National Conservation Area

SPRNCA surface soils were extremely dry in early July 2002, as the sites had received only 15 mm of precipitation in the previous 9 months. The first flux measurements on July 16, 2002, showed CH_4 consumption rates close to zero (figure 1). The arrival of monsoon precipitation on July 18 induced the development of a sizeable CH_4 sink, which continued through the winter and spring of 2003. Methane consumption averaged 25.7 ± 6.8, 32.6 ± 8.8, and 20.1 ± 6.8 μg CH_4 m^{-2} h^{-1} in the mesquite, open, and sacaton sites from July 2002 through April 2003 (figure 1), representing a net CH_4 sink similar in magnitude to that of temperate forest soils, reported to average 33.4 ± 28.3 μg CH_4 m^{-2} h^{-1}(Koschorreck and Conrad 1993). Lack of rain in May and June 2003 reduced the soil CH_4 sink strength by 25 to 55% in all three sites, but maximum CH_4 consumption rates were restored with the onset of monsoon rainfall in July 2003 and thereafter averaged 26.4 ± 6.8, 30.1 ± 10.8, and 7.5 ± 6.2 μg CH_4 m^{-2} h^{-1} in the mesquite, open, and sacaton sites through the end of the monsoon season in September 2003. This finding of sizeable CH_4 consumption nearly year-round was somewhat surprising, given that semi-arid soils had previously not been thought to contribute strongly to the terrestrial CH_4 sink.

Results of the laboratory incubations of SPRNCA soils collected in July 2002 showed that under optimum environmental conditions (moist soils, moderate temperatures), the largest CH_4 consumption rates occurred at a depth of 10-15 cm below the soil surface (figure 2), slightly deeper than that reported for temperate forest soils (Koschorreck and Conrad 1993). It should be noted, however, that the conditions imposed on these soils in the laboratory were rare *in situ*, as optimum moisture

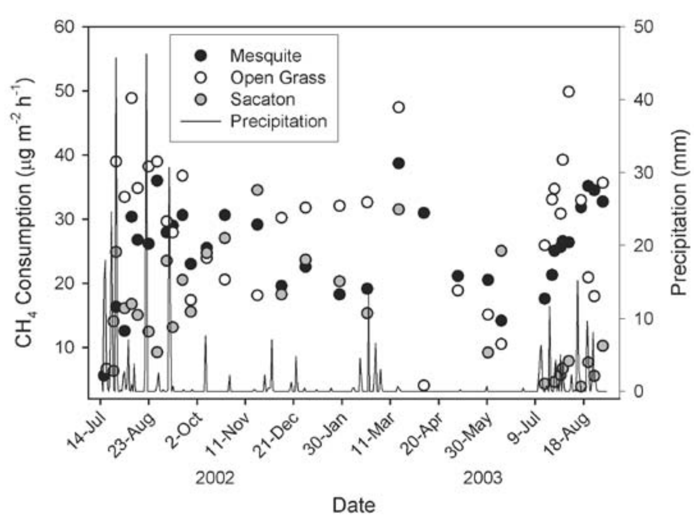

Figure 1—Soil methane consumption in three vegetation zones of the San Pedro Riparian Area from July 2002 through September 2003.

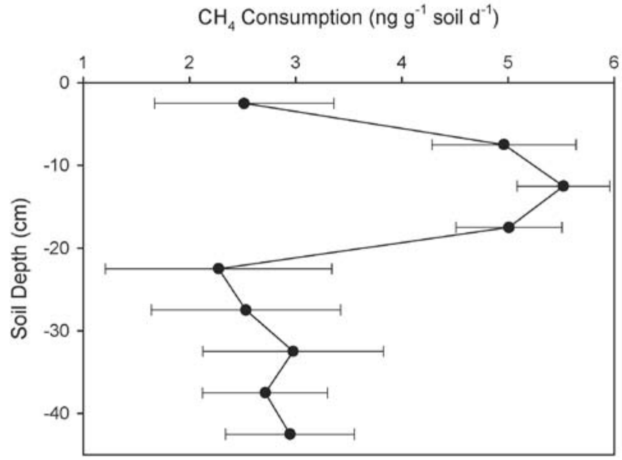

Figure 2—Methane oxidation in laboratory incubations of soils (0-50 cm depth) collected from the San Pedro Riparian Area.

levels (80% field capacity) were measured only three times during the summer of 2002 following rainfalls of 30 mm or greater, and were never measured during the summer of 2003.

Santa Rita Experimental Range

Monitoring of CH_4 flux in SRER soils began before monsoon rains in mid-June 2003. From that time until late fall, mesquite soils showed steady CH_4 consumption, averaging12.2 ± 7.5 µg CH_4 m^{-2} h^{-1} (figure 3), while monsoon CH_4 consumption averaged 8.8 ± 5.2 µg CH_4 m^{-2} h^{-1} in the grassland soil and 8.7 ± 3.6 µg CH_4 m^{-2} h^{-1} in the mesquite stump soil (figure 3).

A very surprising finding was that soils of the grassland and mesquite stump sites were net producers of CH_4 in the extremely dry pre-monsoon season, averaging CH_4 production of 10.3 ± 5.0 and 38.0 ± 18.0 µg CH_4 m^{-2} h^{-1}, respectively (figure 3). During this time, soil moisture potentials were below the permanent wilting point (-1500 kPa) to a depth of at least 30 cm. These conditions would preclude widespread formation of anoxic microsites necessary for soil methanogenic activity. We hypothesize that these differences may be attributable to termite activity in decaying roots. Poth et al. (1995) speculated that networks of underground termite nests could be sources of CH_4 in arid soils, and if so, this soil termite source could reduce the net soil sink for this ecosystem. Additional work is currently ongoing to explore the possibility that methanogenic bacteria are seasonally active in these semiarid soils.

Analyses of gases collected from soil probes confirmed that monsoon-moist soils represent a strong sink, reducing porespace CH_4 to < 0.2 ppm (figure 4). In agreement with our laboratory incubation data (figure 2), strong CH_4 consumption activity was found at 5-30 cm depth in soils when moisture was retained in the profile. As soils dried at the end of monsoon rains, CH_4 flux decreased in the surface soils while CH_4 consumption increased at 30+ cm depths in the soil profile. Eleven weeks after the monsoon rains ended, the Santa Rita Range experienced a 20 mm rainfall, and probe measurements taken following this moisture input showed that the belowground CH_4 profile had shifted once again as maximum CH_4 consumption moved upward in the soil in response to the moisture input (figure 4). This data confirms that depth zones of maximum CH_4 consumption change seasonally in semiarid soils and explains, in part, how methanotrophs remain active in semiarid soils during periods of extreme surface soil dryness. Research is ongoing to further elucidate seasonal variations in depth of maximum CH_4 consumption.

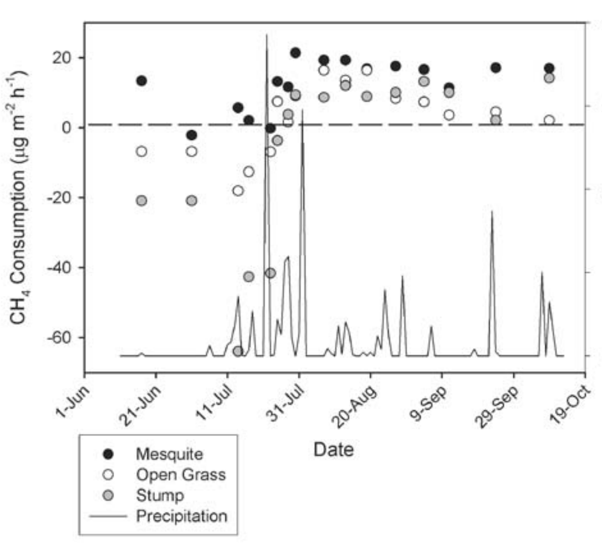

Figure 3—Soil methane flux in three vegetation zones of the Santa Rita Experimental Range from June through September 2003. Positive flux represents methane consumption, while negative flux represents methane production.

Environmental Controls on CH_4 Consumption in Semiarid Soils

Environmental data collected during the summer of 2003 from the SPRNCA weather stations were used to perform some

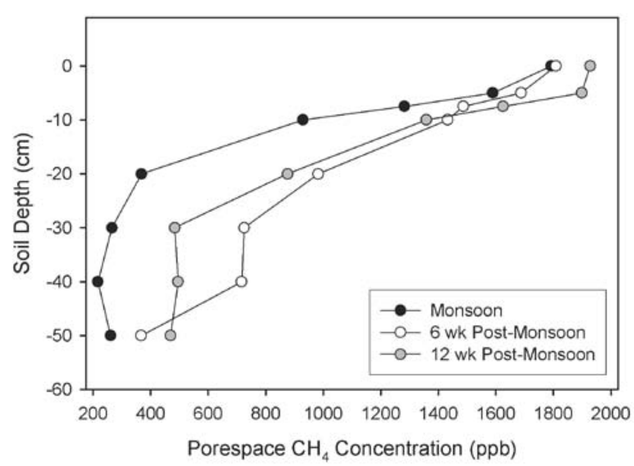

Figure 4—Porespace methane data from Santa Rita Experimental Range, showing alterations in methanotroph activity in response to soil moisture input.

Table 1—Estimated annual CH_4 consumption by San Pedro Riparian Area soils. Monsoon CH_4 consumption is estimated for monsoon period of July through September, non-monsoon consumption reflects fall, winter, and spring (~300 days).

Area	Model variables	Consumption		
		Monsoon CH_4 (mg m^{-2})	Non-monsoon (mg m^{-2})	Annual total (mg m^{-2})
Open	Soil moisture, dew point	56.6 ± 5.7	143.0 ± 14.4	199.6 ± 20.1
Mesquite	Moisture, dew point, air temperature	42.6 ± 3.5	120.8 ± 10.0	163.4 ± 13.5
Sacaton	Rainfall, dew point	12.7 ± 1.7	130.1 ± 17.6	142.8 ± 19.3
Average				168.6 ± 18.0

preliminary statistical calculations of the CH_4-consumption capacity of these soils. First, stepwise regression identified the environmental variables that best predicted CH_4 flux over all measurement dates during the summer monsoon period. The three vegetation areas differed slightly in variables predicting net CH_4 consumption (table 1), but in each case the driving environmental variables accounted for nearly 90% of the variability in CH_4 consumption. Using the stepwise regression models, we calculated daily CH_4 consumption for each vegetation zone for the summer of 2003. The monsoon CH_4 consumption data were then extrapolated to non-monsoon seasons using CH_4 flux data collected in 2002. For example, if CH_4 flux in the mesquite site was 20% lower than monsoon rates during December of 2002, then daily December CH_4 consumption for the mesquite was calculated by multiplying the monsoon rates by 0.8. These preliminary calculations indicate average annual CH_4 consumption rates of 168.6 ± 18.0 mg CH_4 m^{-2} in SPRNCA soils (table 1), a significantly larger sink than that estimated for temperate grassland (115.9 mg CH_4 m^{-2}), cool temperate forest (130.8 mg CH_4 m^{-2}), or warm temperate forest (128.4 mg CH_4 m^{-2}) soils throughout the world (Potter et al. 1996). If we assume that our three vegetation measurement areas are representative of the 22,660 ha of the SPRNCA, then the San Pedro soils consume more than 38,000 kg of CH_4 from the atmosphere annually.

Environmental data and CH_4 flux collection from the SRER is ongoing to allow future calculations of a similar nature of annual CH_4 consumption in those soils.

Conclusions

At the San Pedro and Santa Rita sites, we found net CH_4 consumption during periods when surface soils were extremely dry, even though CH_4 consumption has been shown to be intolerant of soil drying in numerous field and laboratory studies. This ongoing study demonstrates an ability of methanotrophic bacteria to adjust their activities upward and downward in soils in response to seasonal drying, allowing semiarid soils to act as a previously underestimated terrestrial sink for CH_4. Although the CH_4 sink strengths measured in the Santa Rita soils were smaller than that measured in temperate soils, the contribution of arid soils to the global CH_4 balance cannot be discounted because semiarid systems represent ~25% of the Earth's land mass. The importance of soil moisture in determining the magnitude and direction of CH_4 flux demonstrates the sensitivity of CH_4 consumption and production to future changes in climate.

The presence of CH_4-producing bacteria in desert soils has been previously confirmed using molecular techniques. Our work is the first, however, to suggest that methanogens in semiarid systems are active when surface soils are extremely dry. Our continued work will utilize isotope pool dilution to elucidate factors controlling the balance of methanotroph and methanogen activity in the SRER soils.

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Poster Papers

The Effects of Fire Events on Soil Geochemistry in Semi-Arid Grasslands

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Abstract—*Throughout the southwestern United States, vegetation in what historically was grassland has changed to a mixture of trees and shrubs; exotic grass species and undesirable shrubs have also invaded the grasslands at the expense of native grasses. The availability and amount of soil nutrients influence the relative success of plants, but few studies have examined fire effects on soil characteristics in a temporal, spatial, and species group-specific fashion. Our research investigates the effects of fire events on selected soil characteristics (pH, NO_3^-, PO_4^{-3}, TOC) on native grass-, exotic grass-, and mixed grass-dominated plots distributed on four different geological surfaces. Treated and control plots were sampled prior to burn treatment and at intervals after the burns. In addition to new geologic mapping of the study areas, post-burn results indicate geology is the most important variable for soil pH, NO_3^-, and PO_4^{-3}. Recovery to pre-burn levels varies with characteristic: there were no significant initial differences between vegetation types, but significant differences in NO_3^-, PO_4^{-3}, and TOC occur as a result of fire events, geological characteristics, and time. The research helps identify the soil response to fire and the recovery times of soil characteristics, further defines which fire frequency is optimal as a management strategy to maximize soil macronutrient contents, and illustrates the role geology plays in grassland ecosystems.*

Introduction

Information describing the physical framework in semiarid grasslands is critical for identifying solutions to land use and environmental issues. Desert grasslands are water limited but nutrient regulated: soil fertility is determined by the concentration of essential nutrients in soils, and nutrient availability to plants is determined by the ability of soil to supply those nutrients to plant roots. These nutrients include phosphorus in the bio-available form phosphate (PO_4^{-3}) and nitrogen in the nitrate form (NO_3^-). Phosphorus is critical to plant biomass production because it controls the accumulation and availability of nitrogen and carbon in ecosystems. Nitrogen can be fixed by plants from the atmosphere, but the amount of phosphorus is limited by the geologic substrate. Soil pH is an important factor in determining the solubilities of plant nutrients. Total organic carbon (TOC) is a measure of productivity in the grasslands. Management strategies may be thwarted by changes in the distribution and availability of soil nutrients, which are strongly affected by fire (Wright, 1980).

Because the ecological character of semiarid regions is determined by the dominant vegetation, change creates significant alterations in biotic and abiotic conditions (Schlesinger et al. 1990). One important change to the grasslands of Arizona and other parts of the Southwest has been the introduction and subsequent spread of South African Lehmann lovegrass (*Eragrostis lehmanniana* Nees), which has begun to dominate significant areas of the grasslands in large part due to disturbance events (Anable et al. 1992). The likely decrease in wildlife diversity in Lehmann-dominated areas, the less palatable character compared to native grasses, and the increase in fire frequencies (Anable et al. 1992) accompanying the increased dominance of non-native grass species are perceived to be detrimental to resource management goals such as maintenance of quality wildlife habitat and livestock grazing values.

Soil character may affect the levels and spatial distribution of nutrient concentrations which in turn may determine the competitiveness of native over non-native plants in semiarid grasslands. Improved understanding of the substrate could improve management techniques of the grasslands environment. The objectives of this project were to map the alluvial geology, determine the physical soil properties of the study sites, and examine the effects of a burn event on selected soil characteristics.

Study Sites and Methods

The study area is located on the Fort Huachuca Military Reservation along the eastern flank of the Huachuca Mountains in the upper San Pedro River Basin in southeast Arizona. The three types of grasslands—native grass-dominated, non-native lovegrass-dominated, and mixed native and non-native grasses—represent a continuum of invasion by non-native species. Paired 1-hectare treated and control plots were created on 18 sites distributed over the reservation, with nine of the sites burned in 2001 and nine in 2002. Within each plot, a 30-meter by 30-meter subplot was defined, and from each subplot 25-30 randomly distributed soil samples were taken from the treated and control sites. Sampling was repeated on the burned plots immediately after, 6 weeks after, 6 months after, and 1-year after the burn treatment. Control sites were sampled a second time one year after the burn. Analyses for key soil characteristics (pH, NO_3^-, PO_4^{-3}, and TOC) were done. The geology was determined through interpretation of aerial photographs and field work to produce geologic maps and descriptions of study site geomorphology.

Results

Geology of the sites

The study sites (figure 1) are underlain by alluvial fans composed of rock material transported from the adjacent Huachuca Mountains. Study sites were located on four different age surfaces. Relative topographic height, surface morphology,

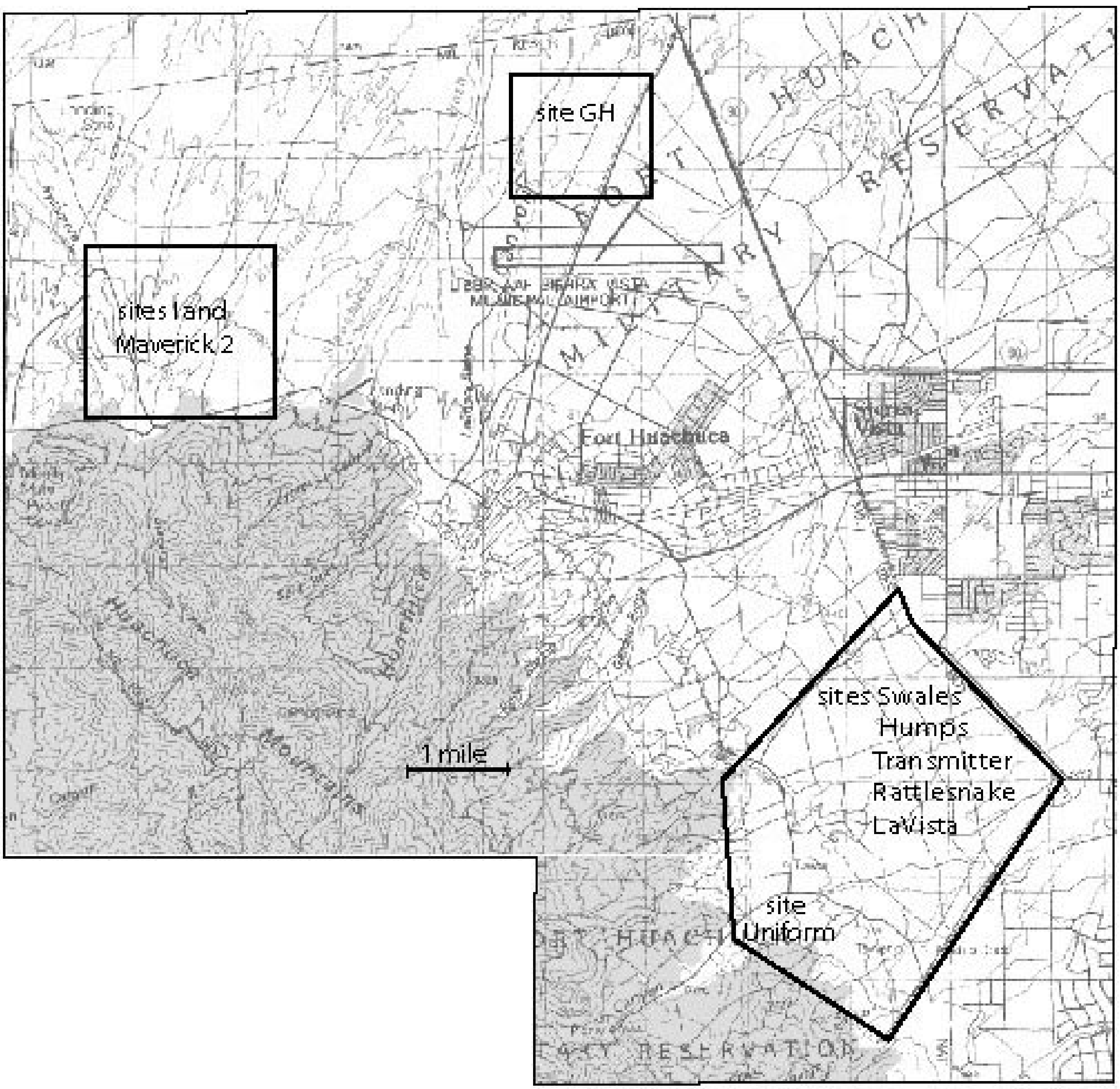

Figure 1—Locations of burned plots and proposed surficial geologic map areas. Proposed surficial geologic map areas are outlined by bold lines and incorporate all of the burned plots. The diamond-shaped map area in the southeastern part of Ft. Huachuca will be contiguous with existing surficial geologic mapping in Garden Canyon (Huckleberry 1996) and off of the base (Demsey and Pearthree 1994).

and soil development are key indicators of alluvial surface age. Older fan surfaces have more rounded, often dissected topography, and have strongly developed soils with thick clay and/or calcium carbonate-rich horizons. Younger fan surfaces often retain features of the original depositional topography and have weak soil development.

The age estimates of the alluvial units at Fort Huachuca are based on comparisons with similar depositional units described in earlier studies in the San Pedro Valley (Pearthree 2004; Demsey and Pearthree 1994; Huckleberry 1996). One plot (site Uniform) is on a Holocene (**H**) fan composed of brown (10YR colors) coarse micaceous loamy sand with only incipient soil development, and covered with lush native grasses. Four plots are located on early-middle Pleistocene (**emP**) fan surfaces (sites GH, I, Rattlesnake, and Transmitter). These surfaces have reddish orange (5 to 2.5YR colors) very bouldery clay-rich soils; vegetation on three of the sites is dominated by Lehmanns; site I has mixed grasses with abundant agave. Two sites (Humps and LaVista) are on early Pleistocene (**eP**) surfaces and both are dominated by native grasses. The surfaces are degraded with abundant boulders coated with carbonate (caliche); soils are brown (10YR colors) clay loams with abundant carbonate chips. Two sites (Maverick 2 and Swales) are on "veneered" late Pleistocene fan surfaces (**Vs**) characterized by bouldery orange (7.5YR) clay-rich soil with a thin, often patchy cover of brown sandy loam soil deposited by Holocene events and subsequently partially removed by sheet flow erosion.

Soil Geochemistry

The effects of vegetation types and geological substrates on the soil nutrient response to prescribed fire are discussed separately because only a limited set of vegetation types/geological substrates combinations are available in the field sites. However, by building separate statistical models incorporating either the vegetation or the geology factors, we could compare the model performance in explaining soil nutrient dynamics. Results indicate **Geology** is the most important variable for explaining soil pH, NO_3^-, and PO_4^{-3}, whereas **Vegetation** is most important in explaining TOC.

Effects of Dominant Plants

Sites were separated into the three dominant vegetation groups, and pre-burn values for each property were set to zero to provide a clearer picture of the data trends. Repeated ANOVA and pair comparison tests (at significance level α = 0.05) were done. The bottom-line results: dominant plants do not affect temporal response of soil geochemistry to burn events except for pH ($F^{pH}_{2,432}$ = 4.68, P = 0.001; $F^{nitrate}_{2,432}$ = 1.85, P = 0.16; $F^{TOC}_{2,432}$ = 2.23, P = 0.11; $F^{phosphate}_{2,432}$ = 2.46, P = 0.09). Burn plots with exotic plants became more acid one year after the burn comparing to control plots, but burn plots and control plots with native and mixed plants do not differ in pH trends after the burn (figure 2a). After one year pH was slightly lower on virtually all sites, even on sites with high pedogenic carbonate in the soils. Although there was some fluctuation of values during the year (probably an effect of monsoonal rains), levels of PO_4^{-3} on all burn plots, except for those with mixed plants, decreased only slightly or remained the same level one year after the burn, whereas control plots had decreased significantly over the same period (figure 2d). Nitrate behaved in a similar fashion, in that on all burn plots except those with mixed plants, NO_3^- increased one year after the burn comparing to control plots (figure 2b), indicating that volatilization was not a significant factor. The combination of nitrate and PO_4^{-3} behavior suggests ash was not removed from the study plots. Although not statistically significant, TOC seemed to be lower on burn plots compared to control plots with native and mixed plants, and higher on burn plots with exotic plants (figure 2c).

Effects of Geology

Because the original design of the controlled burns project was concerned with dominant vegetation, we did not have equal numbers of plots for each vegetation/substrate combination. However, with repeated ANOVA and pair comparison tests (at significance level α = 0.05) done based on four geological substrate types, we found that except for TOC, the temporal changes in soil geochemistry after the burn differed among the geological substrates ($F^{pH}_{3,430}$ = 5.27, P = 0.001; $F^{nitrate}_{3,430}$ = 6.38,

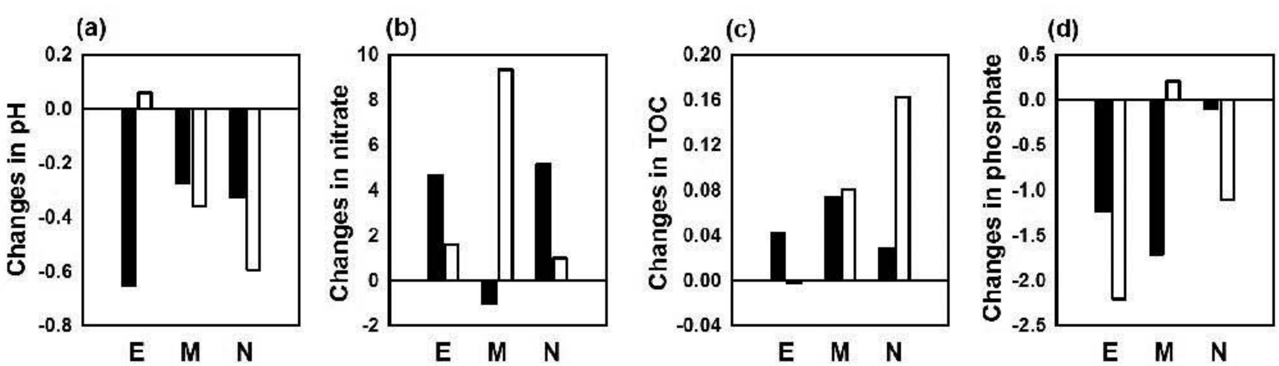

Figure 2—Soil geochemistry response to a burn event on sites with three different types of dominant plants. On each panel, black bars denote burn plots, while white bars denote control plots. Y-axis is the changes in pH (a) at the end of one-year period after the burn event from pre-burn values. Similarly, changes in nitrate are shown in (b), changes in TOC are shown in (c), and changes in phosphate are shown in (d). On X-axis, "E" is exotic plants, "M" is mixed plants, and "N" is native plants.

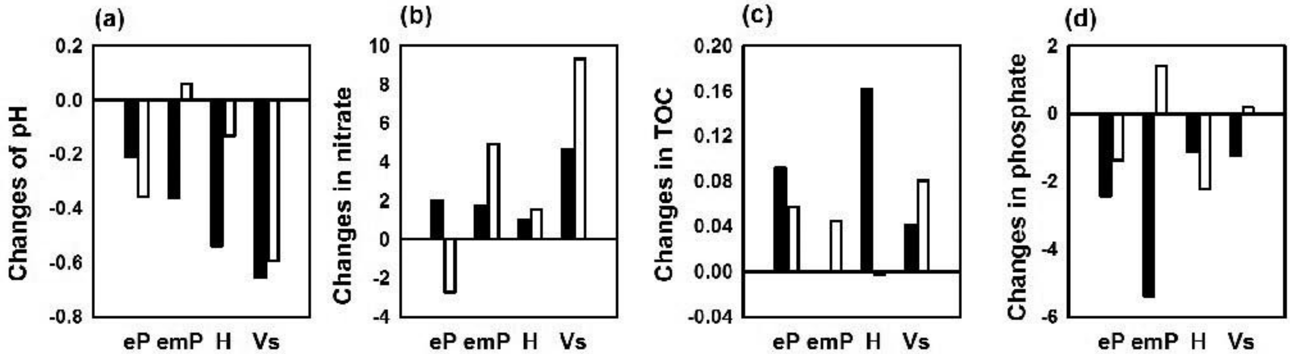

Figure 3—Soil geochemistry response to a burn event on sites with four different types of geological substrates. On each panel, black bars denote burn plots, while white bars denote control plots. Y-axis is the changes in pH (a) at the end of one-year period after the burn event from pre-burn values. Similarly, changes in nitrate are shown in (b), changes in TOC are shown in (c), and changes in phosphate are shown in (d). On X-axis, "eP" is early Pleistocene, "emP" is early-middle Pleistocene, "H" is Holocene, and "Vs" is late Pleistocene veneered surface.

$P < 0.001$; $F_{3,430}^{TOC} = 1.59$, $P = 0.19$; $F_{3,430}^{phosphate} = 6.47$, $P < 0.001$). Specifically, soil became more acid one year after the burn on early-middle Pleistocene and Holocene substrates, but not other substrates (figure 3a). Nitrates increased on burn plots comparing to control plots at early Pleistocene sites, but not at other sites (figure 3b). Phosphate decreased slightly or remained at the pre-burn concentration on burn plots comparing to control plots at all sites except for early-middle Pleistocene, which showed a significant decrease in PO_4^{-3} on burn plots (figure 3d).

All types of dominant plants/geological substrates combined, fire has an effect on pH, NO_3^-, and PO_4^{-3} but not on TOC during the one-year time period. In addition, dominant plants/geological substrates have an overall effect on all four characteristics studied, regardless of burn treatments and background temporal variations.

In order to trace detailed temporal response of soil geochemistry to the burn event at any given substrate and vegetation type combination, we compare data from the burn plots taken at five time intervals during the one-year period (figure 4), and we found:

1. Soil pH values dropped immediately after the burn, and remain more acid than pre-burn values at the end of the one-year period on all sites except early Pleistocene with native plant (eP + N) sites (figure 4a). At early Pleistocene with native plant (eP + N) sites, pH values were recovered more quickly than other sites, and soil did not appear to be more acid than pre-burn values at the end of the one-year period.
2. Soil NO_3^- levels decreased immediately after the burn, but recovered quickly and exceeded pre-burn values at the end of the one-year period for all sites. The trend of increasing NO_3^- levels stabilized by week 26 at early-middle Pleistocene with mixed plant (emP + M) sites and late Pleistocene veneered surfaces with mixed plant (Vs + M) sites, whereas on other sites NO_3^- levels remained increasing at the end (figure 4b).
3. Soil TOC levels dropped one week after the burn on early Pleistocene with native plant (eP + N) sites, early-middle Pleistocene with exotic plant (emP + E) sites, and late Pleistocene veneered surfaces with mixed plant (Vs + M) sites, recovered to pre-burn levels by week 6, and remained close to pre-burn levels at the end of the one-year period. Soil TOC levels increased by week 6 at early-middle Pleistocene with mixed plant (emP + M) sites, and remained slightly higher than pre-burn values at the end of the one-year period (figure 4c).
4. Soil PO_4^{-3} levels increased immediately after the burn, but gradually fell back to pre-burn values or lower on all sites. The pulse release of PO_4^{-3} after the burn is strongest at Holocene with native plant sites (figure 4d).

Discussion and Conclusions

Any long-term increase in the amount of nitrate or phosphate in treated plots is significant for management of the ecosystem. Eight of the nine treated plots showed increased nitrate concentrations over the control plots one-year after the burn. Seven of the nine treated plots showed a similar increase in phosphate at the one-year sampling.

The concentration of plant-available nitrate and phosphate did increase after the burn treatment due to ash deposition. Nitrate concentrations remained elevated above pre-burn levels one year after the burn. In addition, phosphate concentrations on treated plots were higher than phosphate concentrations on control plots one year after the burn. DeBano and Conrad (1978) found a significant loss of nitrogen in hot chaparral fires, whereas another study (Emmerich 1999) in grassland fires reported an absence of significant nutrient loss immediately after a burn event and concluded soil was the major control on nutrient loss. Results of this study suggest the intensity of the fires was not hot enough to volatilize these nutrients, and the nature of the soil does play a significant role in nutrient response. The surficial geology of the study sites was the main control on soil characteristics and response to burn events. Dominant grass vegetation—native, non-native, or mixed—had little effect on the response of soil geochemistry to fire events.

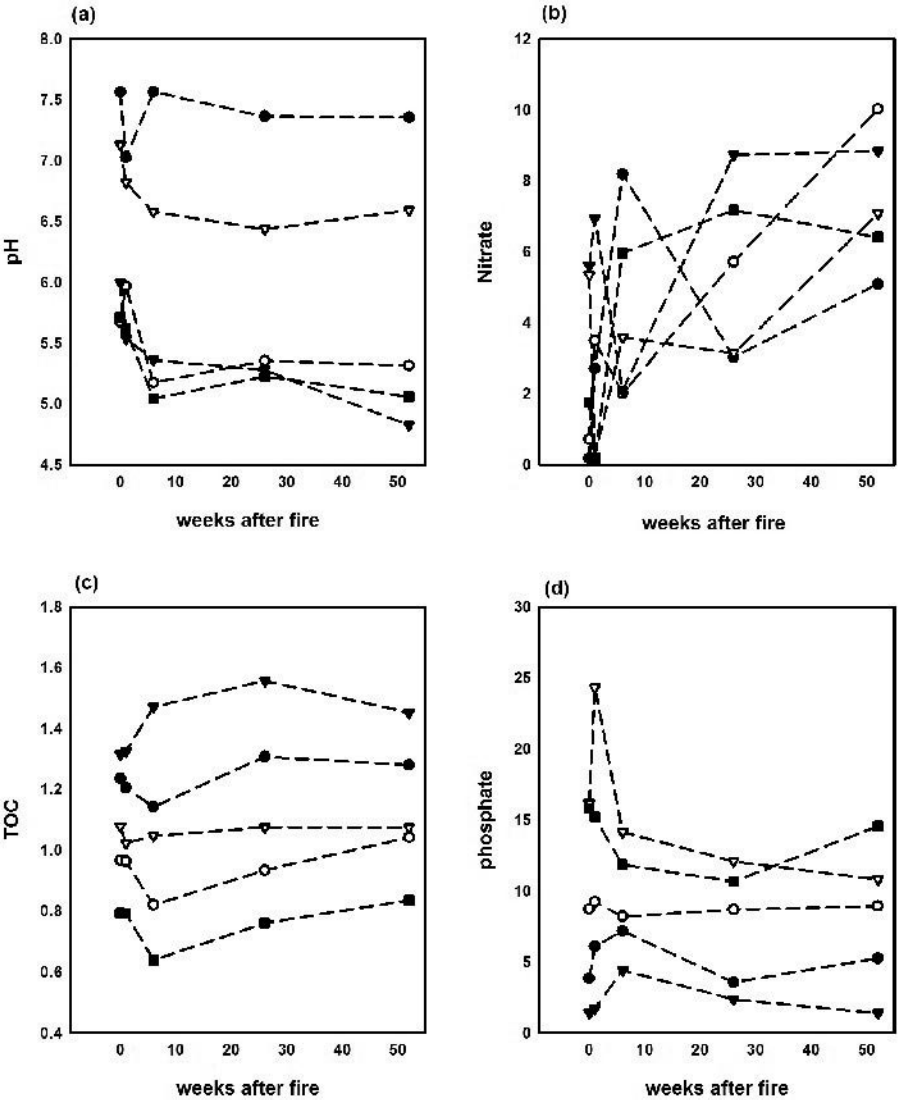

Figure 4—Temporal changes in soil pH (a), NO_3^-(b), TOC(c), and PO_4^{-3}(d) after prescribed fire. Week 0 is the pre-burn value, and week 1, week 6, week 26, and week 52 are values taken at each time period after the burn. Filled circles denote "early Pleistocene substrate with native plants"; open circles denote "early-middle Pleistocene substrate with exotic plants"; filled triangles denote "early-middle Pleistocene substrate with mixed plants"; open triangles denote "Holocene substrate with native plants"; filled squares denote "late Pleistocene veneered surface substrate with mixed plants." These are the five unique combinations of geological substrate + vegetation type at the study site.

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Assessing Indicators of Rangeland Health With Remote Sensing in Southeast Arizona

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Abstract—*The goal of this study was to scale up ground-based range assessments to ranch and landscape scales in southeast Arizona using remote sensing and minimum amount of field data collection. Remotely sensed metrics of canopy cover, biomass, and mesquite composition were used to assess soil and site stability and biotic integrity. Ground-based assessments were conducted on 11 field locations and used in conjunction with Natural Resources Conservation Service (NRCS) ecological site descriptions to develop evaluation criteria on two different ecological sites. The data were combined in a GIS and 1,386 km^2 of rangelands were assessed. A total of 13% of loamy upland range sites were categorized as "None to Slight Departure" from reference conditions for soil and site stability, and 63% were categorized as "Moderate to Extreme Departure" for biotic integrity. The model was sensitive to variation in climate and management. This method is currently being developed as a potential tool for land managers in Madrean Archipelago.*

Introduction

There are approximately 5.6 million acres of semi-desert grassland in USDA-NRCS major land resource area (MLRA) 41-3. Land management in this area relies on a diverse mix of State and Federal agencies as well as private land owners and non-governmental organizations. Rangeland management programs have traditionally relied on data acquired at plot and pasture scales; however, field data collection is time and labor intensive. Land managers are increasingly requiring less expensive and timelier information. The goal of this study was to devise and evaluate a cost effective method of scaling up range assessments from ground-based, pasture-scale assessments to ranch and landscape scales using remote sensing. The development of new remote sensing products under the RANGES program has enabled the measurement of relevant grassland metrics at larger spatial scales (Qi et al. 2002). These new remote sensing products, created specifically to aid rangeland managers, include canopy cover and standing biomass estimates that are sensitive to both green and senescent herbaceous vegetation. By combining these measurements with a limited amount of ground data collection a scaled-up method was developed for Arizona's semi-desert grasslands.

Procedure

The need for a unified method to assess rangelands has been widely discussed (National Research Council 1994, Society for Range Management 1995). The approach developed here closely parallels the established ground-based rangeland health assessment method (RLH) adopted by the NRCS and the Bureau of Land Management (BLM) and described by Pellant et al. (2000). This method identifies 17 indicators that are used to assess the ecological attributes of soil and site stability, hydrologic function, and biotic integrity. The result is not an overall determination of health, but a description of departure from ecological reference conditions ranging from "None to Slight Departure" to "Extreme Departure." Areas are thus evaluated by comparing the indicators to corresponding reference areas and ecological site descriptions. Ultimately, an ecological site-specific evaluation matrix is developed that defines a range of measured values for each indicator. The 17 indicators include bare soil, annual production, invasive species, and functional and structural plant groups. Similarly, this study performed assessments by using satellite derived measurements of herbaceous canopy cover, herbaceous biomass, and mesquite composition as indicators. Canopy cover and biomass (including both green and senescent vegetation) were derived from Landsat ETM+ imagery and empirical factors as described by Qi et al. 2002. Accuracy of these satellite data, as reported by Qi (2002), was determined to have no significant difference between satellite estimates and field observations at the 95% confidence interval. Mesquite canopy composition was derived with ETM+ data by exploiting the phenology of semiarid grasslands after a dry winter when the majority of photosynthetically active vegetation was mesquite (Marsett 2003).

Eleven study sites were established on two major ecological sites, loamy uplands and sandyloam uplands. These sites are dominated by warm season perennial grasses with an occasional over-story of mesquite and other shrubs. Average annual precipitation in this zone ranges from 12 to 16 inches (NRCS Land Resource Unit 41-3). Ground-based RLH assessments were performed on each site as described by Pellant et. al. (2000). An evaluation matrix was then developed for both ecological sites based on ground-based RLH assessments, ecological site descriptions, expert opinion, and reference area conditions. The evaluation matrix defined a range of indicator values for percent canopy cover, biomass in lbs/acre, and percent mesquite composition (see table 1). Herbaceous canopy cover was used as an indicator of soil and site stability, and herbaceous biomass and mesquite composition were used separately as indicators of biotic integrity.

Ecological site maps were derived at the landscape scale from soil surveys. A 10 m digital elevation model (DEM) was used to delineate relevant ecological sites from mapping units whenever possible. The remotely sensed measurements were then applied to the appropriate ecological sites on the landscape using values defined in the evaluation matrix to determine departure categories.

Results

The results were landscape scale assessments for indicators of soil and site stability and biotic integrity. The assessments covered 969 km^2 of loamy upland and 417 km^2 of sandyloam upland with a ground resolution of 30 x 30 m. Table 2 details the results of the assessments for each ecological site by departure category. The landscape scale ecological site map correctly identified all but one of 11 field sites. Results of the biotic integrity assessment based on mesquite composition demonstrated sensitivity to management. Figure 1 compares assessment results to a high resolution ortho-photo. In the photo large tracts of land treated by brush removal can be seen. In the assessment map, treated land was classified as "None to Slight" and untreated land was classified as "Moderate to Extreme" or "Extreme" departure from reference conditions.

Conclusions

Though the initial results are promising, additional studies are needed to quantitatively evaluate the models at landscape scales. Further research is also needed regarding the identification of key indicators, the effects of climate variability, and development of the evaluation matrices. The relationship between remotely sensed and ground-based indicators needs to be determined. This approach used canopy cover, biomass, and mesquite composition as proxy measures of the ground-based indicators of bare soil, annual production, and invasive species, respectively. In addition, because remote sensing may not feasibly measure all 17 ground-based indicators, key indicators will need to be identified for each ecological site.

This study also observed a high degree of variation in cover, biomass, and mesquite composition between sites at the upper and lower ends of the precipitation zone. This may require multiple evaluation matrices within a single precipitation zone. A comprehensive study is being developed for testing in the summer and fall of 2004. Results will be evaluated by range conservationists and land managers. In addition to landscape assessments, the models will be used in an attempt to map states and transitions within ecological sites. Ultimately, this study will identify and evaluate several issues related to scaled-up assessments of grasslands in the Madrean Archipelago.

Table 1—Evaluation matrix.

		Value	
Indicator	**Departure category**	**Loamy Upland**	**Sandyloam Upland**
Mesquite composition	None to Slight	0-2%	0-5%
	Slight to Moderate	2-10%	5-12%
	Moderate	10-15%	12-17%
	Moderate to Extreme	15-20%	17-25%
	Extreme	20-100%	25-100%
Biomass	None to Slight	>1,850 lbs/ac	>1,850 lbs/ac
	Slight to Moderate	1,100-1,850 lbs/ac	1,250-1,850 lbs/ac
	Moderate	600-1,100 lbs/ac	600-1,250 lbs/ac
	Moderate to Extreme	100-600 lbs/ac	100-600 lbs/ac
	Extreme	<100 lbs/ac	<100 lbs/ac
Canopy cover	None to Slight	42-79%	45-78%
	Slight to Moderate	32-42%	36-45%
	Moderate	24-32%	27-36%
	Moderate to Extreme	10-24%	10-27%
	Extreme	0-10%	0-10%

Table 2—Assessment results.

Indicator	Departure category	Loamy Upland		Sandyloam Upland	
		km²	Percent	km²	Percent
Mesquite composition Biotic integrity	None to Slight	633	65%	320	77
	Slight to Moderate	139	14%	36	9
	Moderate	49	5%	14	3
	Moderate to Extreme	34	3%	14	3
	Extreme	115	12%	33	8
Biomass Biotic integrity	None to Slight	3	0.33%	2	0.40
	Slight to Moderate	33	3%	13	3
	Moderate	86	9%	48	12
	Moderate to Extreme	608	63%	223	53
	Extreme	239	25%	131	31
Canopy cover Soil and site stability	None to Slight	129	13%	62	15
	Slight to Moderate	365	38%	185	44
	Moderate	215	22%	84	20
	Moderate to Extreme	184	19%	57	14
	Extreme	75	8%	29	7

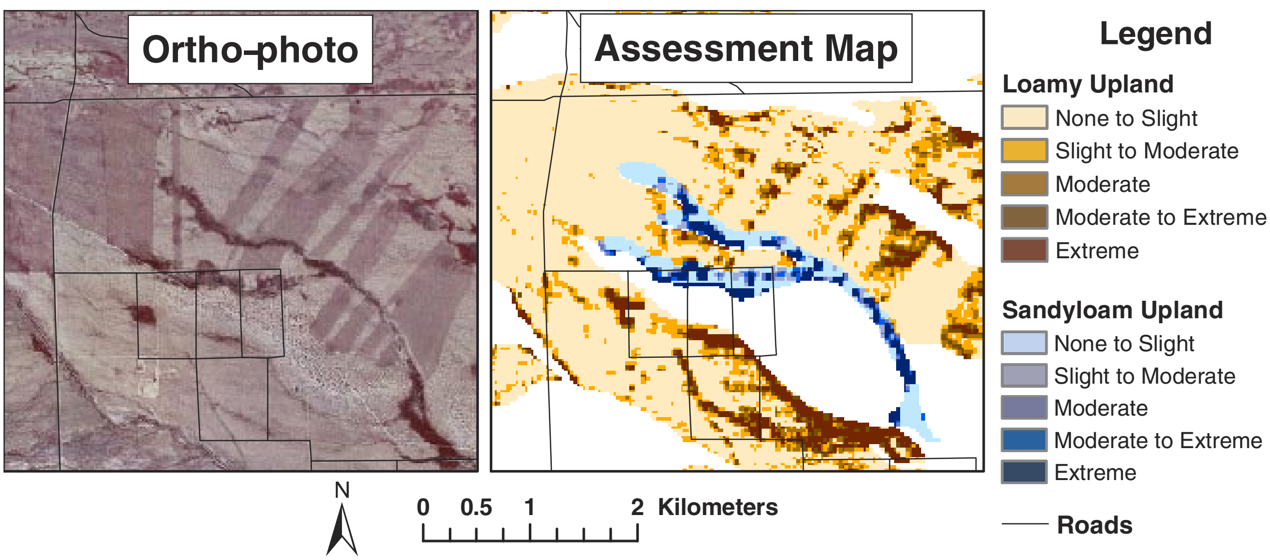

Figure 1—Assessment map, biotic integrity based on mesquite composition.

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Status of Black-Tailed Prairie Dog (*Cynomys ludovicianus*) in Sonora, Mexico

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Abstract—*Prairie dog is a keystone species throughout the habitat where it occurs, but its populations have declined about 98% in the last century. This species has been considered of international importance for the United States of America, Canada, and Mexico.*

Only two populations are recorded for Mexico, and the westernmost (isolated by Sierra Madre Occidental from the other) remains basically unknown, in the Upper San Pedro River Watershed in Mexico. This species has been eradicated from Arizona. The closest population is hundreds of kilometers away, in New Mexico.

Since July 2003, we have been working collecting basic information that is needed for this species conservation: actual distribution, population parameters, habitat, and threats. Methodology being used is standardized to those underway in other places. Geographic Information Systems and Remote Sensing are being used as tools in range, habitat, and threats analysis. This project is in progress and final results are expected to be ready by November 2004.

Introduction

Prairie dog is a keystone species throughout the habitat where it occurs, but its populations have declined about 98% in the last century.

Historically its distribution was from Canada to Northwest Mexico (figure 1). Today, its distribution represents less than 3% of its former number.

This species has been eradicated from Arizona, for local ranchers thought them to be competing with cattle for grass. In other words, they were treated as pests. The closest population is hundreds of kilometers away, in New Mexico.

Only two populations are recorded for Mexico, and the westernmost (isolated by Sierra Madre Occidental from the other) remains basically unknown, in the Upper San Pedro River Watershed in Mexico. The one in Chihuahua is close to the Mexican town of Janos, while the one in Sonora is located north of Cananea. For a long time it was believed that this species had been extirpated from the last State, but it was re-discovered in the early 1990s.

Black-tailed prairie dogs are diurnal, burrowing rodents. Being colonialist is perhaps the most striking feature of

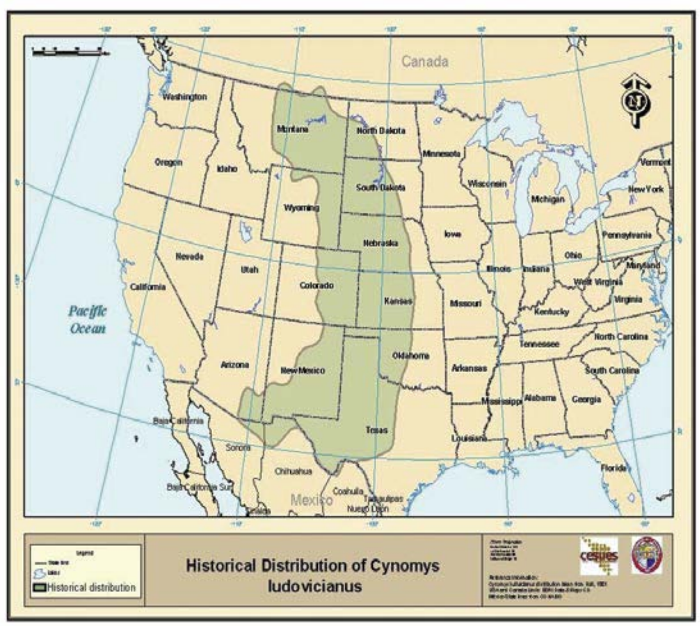

Figure 1—Historical disctibution of *Cynomys ludovicianus*.

these herbivorous squirrels that forage from dawn until dusk (Hoogland 1995). During extremely cold weather, however, black-tailed prairie dogs sometimes remain underground for several consecutive days (Hoogland 1995).

The daily activities change the physical characteristics of the community, which leads to increased plant and animal diversity. Prairie dogs are a source of food for several predators, and their burrows provide homes for a variety of species, including the endangered black-footed ferret.

Prairie dogs also change their surrounding environment. For example, they alter vegetation processes by maintaining vegetation at an early growth stage, decreasing vegetative height, increasing bare ground, and increasing the percentage of forbs cover. This provides a diversity of habitat on the plains essential to wildlife species that depend upon these conditions. Prairie dogs also alter long-term soil building processes through bioturbation, or mixing of soil horizons. This in turn leads to new soil types (Koford 1958).

This project development will provide basic information to know the present status of *C. ludovicianus* colonies in Sonora, their population density, habitat situation, and present threats. This information is key in long-term conservation of the species, as well as of great help in reintroduction plans for Arizona, which have been in the mind of several researchers and agencies.

Study Area

It is located very close to the United States-México border, in the Upper San Pedro River watershed part of the Colorado River Watershed. It is located within the Mexican municipality of Cananea, from 30° 37’ 12’’ to 31° 19’ 48’’ North latitude and from 109° 48’ 36’’ to 110° 37’ 12’’ West longitude (figure 2).

The upper portion of the San Pedro River watershed is a transition between the Chihuahuan and the Sonoran Desert, with great variations in topography, climate, and vegetation.

Elevation ranges from 900 to 2,900 meters, and mean annual rainfall goes from 300 to 750 mm. Communities present in the watershed are desert scrub, grasslands, oak forest, pine forest, mesquite woodland, and riparian vegetation. Total estimated area of the upper watershed is 7,600 km^2 (5,800 km^2 in Arizona and 1,800 km^2 in Sonora)

It presents Regosol eutrico soil type (FAO-Unesco classification system). This type of soil is subject to erosion going from moderate to high. It comes from non-consolidated materials.

The general region shows perturbations due to heavy cattle grazing, especially in the American portion of the watershed, which has led to mesquite intrusion into former grasslands.

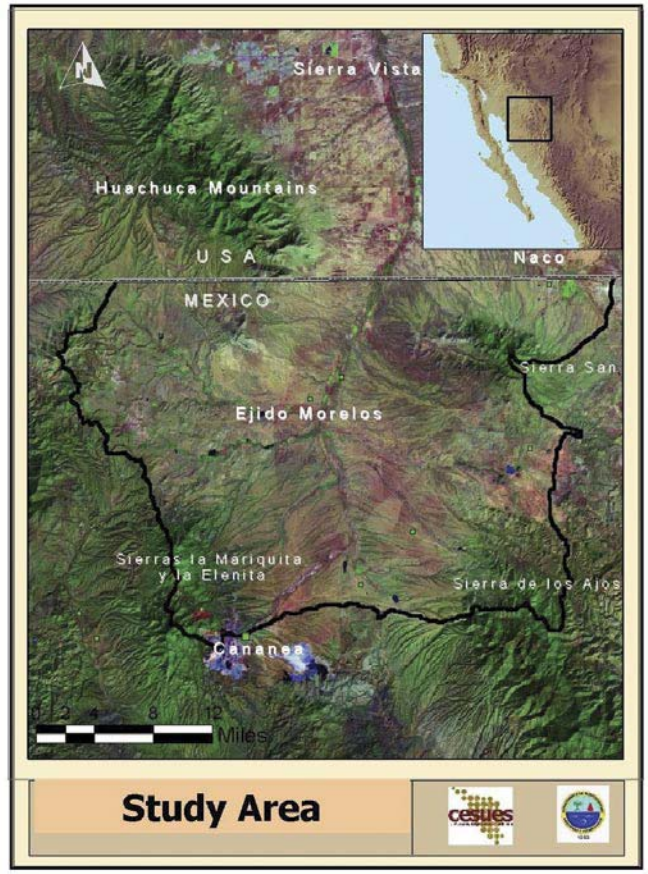

Figure 2—Study area.

Methods

Burrow Density

It is being estimated using “wandering quarter method” (Catana 1963). Total and active prairie dog burrow densities are determined by running 10-m-wide parallel transects systematically through prairie dog colonies. A person walks in a pre-determined direction and counts active and total numbers of prairie dog burrows that are within the transect. When a partly completed transect approaches the edge of a dog town, the transect turns 90 degrees toward the unsampled section of the town. After 10 m, transects again turns 90 degrees, creating a transect parallel to the previous one, but in the opposite direction. Active burrows are being defined as those containing fresh prairie dog feces observable within or around the opening.

Population Density

All individuals within the dogtowns are counted in 15-minute periods, one per hour during daytime (visual counting method: Fagerstone and Biggins 1986; Menkens et al. 1990; Menkens and Anderson 1993; Powell et al. 1994). There are six visits planned, each one of them of two days. Already two of them have been made to this date, one in November 2003 and the other April 2004. Density is being considered and maximal values are recorded.

Range

Actual range determination will first be developed using potential distribution maps through GIS modeling (multicriteria evaluation using weighted linear combination in IDRISI32 platform, according to Jack 1999) and surveying those areas trying to locate new colonies. Potential maps will include the next variables: soils (type, depth, and texture), land cover, slope, and exposure, following Clippinger (1989) and Proctor et al. (1998).

GPS (Garmin eTrex and eTrex Vista) were used to establish the known colonies' perimeter. ArcView 3.2 and ArcMap 8.2 were used to calculate perimeter and area.

Grassland Conservation Status and Tendencies

Land cover series were obtained from IMADES-EPA projects (Kepner et al. 2000a,b) derived from Landsat MSS (1974, 1983, 1992) and Landsat (1997) in GIS format (Erdas GIS), as well as National Forest Inventory from SEMARNAP (derived from Landsat 2000 images). Time series analysis will be performed in Idrisi32 platform, and causal analysis will be discussed with local communities and peer researchers. Those results will be correlated with socioeconomic information to establish tendencies. Socioeconomic data was obtained from Morales et al. (1994) and Arias et al. (1998).

Threats analyses will be developed after Haro-Martinez et al. (2000).

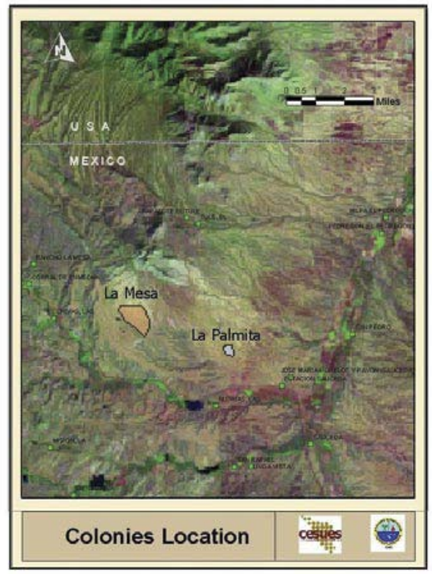

Figure 3—Colonies location.

Results and Discussion

Population Density

Two censuses have been conducted at "La Palmita": during November 2003 and in April 2004. Prairie dog density was 1.9 individuals per ha in November and 3.5/ha in April. At the Janos region in Chihuahua, much higher ranges were determined at 20.9 to 30.7 individuals per ha.

Due to its recent discovery, no records have been undertaken for the town at "La Mesa" but the first observations carried out point towards an even lower density here.

Present in both sites were females with swollen mammae indicating feeding. Reports of juveniles are expected for the next month.

Burrow Density

At "La Palmita," 61% of the burrows were active resulting in a density of 7.8/ha of active burrows, and a total of 14.4 total burrows per ha. At "La Mesa" 42% of the burrows were inhabited adding to a density of 4.5 active burrows, and a total of 10.7 total burrows per ha.

The results shown above are in sharp contrast to the ones cited for the Janos region (Ceballos et al. 1999). The prairie dog complex there has a density per ha of 42.3 to 86.5 total burrows, and 26.9/ha to 55.6/ha of active ones.

The parameters found in the San Pedro area are well below the burrow averages in the United States where density has been established between 49 to 287 per ha (Cully 1989).

Actual Distribution

To date, two active dogtowns have been found as well as an abandoned one (figure 3). While the first one situated at "La Palmita" ranch covers 28 ha, the second one at "La Mesa" ranges at 183 ha. The extent of the populations recorded points toward a much smaller area than the one previously calculated by Ceballos et al. (1993), which suggested total range of 700 ha in the San Pedro River area.

The third town is situated at the site known as "La Traila" where according to local reports, no prairie dogs have been seen for over two years. The conditions of the few burrows found here verify this perception.

The two active colonies are 4.1 km apart, while the third, non-active one is respectively at 1.5 and 2.9 km from the other two. According to Biggins et al. (1993) no town in a prairie dog complex is more than 7.0 km away from the closest one, by which we could determine that the two active communities constitute a prairie dog complex in the region.

Potential range maps are being constructed at the present time and will be evaluated during the next surveys.

Grassland Conservation Status and Tendencies

Results showing tendencies for these variables are being compiled and conclusions are expected soon.

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Cultural Resource Management and the Necessity of Cultural and Natural Resource Collaboration

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Abstract—*Cultural Resource Specialists function as interpreters of past and present human behavior through the analysis of cultural/natural resources vital to human ecological sustainability. When developing short and long-term preservation strategies for cultural resources, it is more current and innovative for Cultural Resource Specialists to think of past human populations as occupiers of broad ranges of landscapes and not limit our interpretive spheres of preservation and conservation to site-specific locales only. Cutting edge Cultural Resource Specialists are expanding their knowledge through integrated research, public interaction, and state-of-the-art preservation techniques. The current paper and presentation are a contribution to this expansion.*

Justification for Taking Steps to Develop a Conceptual Models of Collaborative Efforts Between Cultural and Natural Resource Specialists

The primary purpose of this paper is to present some preliminary ideas and propose to make a scientific argument for the development of steps toward a *methodology* for the necessity of collaborative efforts between Cultural and Natural Resource Specialists as participants in large-scale preservation and conservation strategies. Preliminary ideas for the creation of this argument were presented at the Madrean Archipelago Conference in Tucson, Arizona, in May of 2004. At the conference, two areas related to collaboration and interdisciplinary study were highlighted as integral subjects that must be discussed in the context of establishing a methodological case for the necessity of collaborative efforts: 1. Natural Resource Regulations and the Cultural Resource Specialist and 2. The Collaboration and Application of Natural and Cultural Resource Data-The Creation of a Professional Role.

Natural Resource Regulations and the Cultural Resource Specialist, Part I

Throughout the history of monitoring culturally sensitive areas, the Cultural Resource Specialist's work has been influenced by an array of natural resource regulations such as: the Endangered Species Act, 1973, amended 1982; the Fish and Wildlife Coordination Acts, 1958 and 1980; the Migratory Bird Treaty Act, 1974; the Clean Water Act; Executive Order 11900 (Protection of Wetlands); the Clean Air Act as well as the National Environmental Policy Act of 1969 ([1]). The National Environmental Policy Act (NEPA) of 1969 created a specific context in which anthopological social knowledge was to be applied by agencies in determining whether to prepare an Environmental Impact Statement (EIS) ([2]). The EIS document consists of specific natural and cultural studies that are used collectively as collaborative and interdisciplinary studies of conditions within the *affected area*. The EIS must also assess impacts and consider policy alternatives. The EIS document is created to inform agency decision makers and the public of the intended *action* and its *effects* within the project *area*. Principally speaking, the EIS document's purpose is to provide better scientific information to agency decision-makers, which will lead to more environmentally and socially conscious decisions. However, in the application of better scientific information the relationship between scientific knowledge and its application is much more complex.

NEPA makes necessary certain knowledge of resource conditions to direct and evaluate the effectiveness of cultural and natural resource conservation programs. This formal evaluation is regulated by the Section 106 Compliance process. This approach has placed Cultural Resource Specialists in an advantageous position to assist in the development of Integrated Resource Management Plans (IRMP) and *large-scale* conservation programs. The people who were living here first used large landscapes (i.e., watersheds) in establishing themselves as residents. Current cultural resource strategies of preservation are site-specific, with little regard for the preservation of adjacent large-scale geographical areas. Some Cultural Resource Specialists might understand the contradiction of archaeological site-specific preservation and large-scale residential land use as a reflection of explaining more accurately a "social reality" of how people truly lived.

NEPA provides a distinctive opportunity (as well as a legal mandate) for considering the uses of cultural and natural knowledge in the policy process and the decision-making process of public agencies.

The Development of a Professional Role—Philosophical Issues and the Basis of Collaboration and Application of Natural and Cultural Resource Data Part II

The second part/answer to this question is even more complex and a portion of the complexity under scrutiny here lay someplace within an individual scientist who is critically reflective of his/her own philosophical and socio-political positions, their internal and psychological *bias*, if you will (and the assertion of that *bias*), with respect to varying degrees of preservation/development application practices. If a Natural or Cultural Resource Specialist has a primary philosophy of conservation and preservation one would expect to see a reflection of this philosophy in their actions. For example, one would expect to see less emphasis on development projects and more emphasis on preservation projects ([3]).

The problem however, could be that presently little is being done by either Cultural or Natural Resource Specialists in the way of developing field and analytical methods to address the *interdisciplinary nature* of cultural and natural scientific research data. Murray (1983) argues that policy makers perhaps don't always use social knowledge as well as they might or make better use of available knowledge, and Weaver (1985) argues that Resource Specialists (and particularly cultural resource specialists) "have not presented their findings in a manner …usable by other disciplines and by policy makers" (Weaver 1985:102). This is most likely due to the nature and development of methods of inquiry regarding cultural and natural resources. Expansion and improved knowledge can lead to conceptual convergences, whereas in the social sciences it tends to rather result "in a richer, more diverse picture of things" (Cohen and Weiss 1977:68).

Natural Resource Specialists tend to be more "thing-directed." Their methods revolve around the manipulation of these "things" (scientific units), which are assumed to persist through time. If these scientific units do change, they change into other things and can be studied as an evolutionary scientific unit. Cultural Resource Specialists are also "thing-directed." However, Cultural Resource Specialists are hampered by a shortcoming of the scientific method. "Things" in the context of cultural resource management have human behavior attached to them. Acting simultaneously as natural and social scientists, as Cultural Resource Specialists, we are unable to adequately apply the scientific method to human behavior and to transpose the human behavior associated with artifacts, features and sites into *purely* scientific units. This has been a curse and a blessing for cultural resource management and archaeology as a whole. The curse is that the discipline has suffered because it can not be viewed as a "pure" scientific discipline. The blessing is that human behavior can teach us about what others in the past have done and what we might do in the present and the future to sustain ecosystems in perpetuity ([4]).

Crafting a *professional role* to accompany the *technical role* for the application of this type of knowledge is critical in establishing a more holistic approach and application to resource management strategies geared towards *serious* consideration of *large scale* ecological preservation of landscapes. An effective methodological approach must have at its base the collaborative nature of natural and cultural resources to address the *contradiction of archaeological site-specific preservation and large-scale residential land use*. To my knowledge, Cultural Resource Specialists have yet to produce any specific methodology for Cultural and Natural Resource Specialists to collaborate and to concentrate on this contradiction. Collaboration is already taking place in the context of cultural resource management philosophy ([5]). The problem has been based, not so much on the lack of recognition of *collaborative landscape elements* by Cultural Resource Specialists, but the lack of recognizing the *meaning and application* of *collaborative landscape elements* of natural and cultural resource data. What evidently follows is a lack of understanding about the method-data relationship between cultural and natural resource specialists and the application of *collaborative landscape elements*. ([6]).

Cultural Resource Management Methodology and the Existing Presence of Collaborative Ideology

Many indigenous plant species have been identified as cultural resources through indigenous use (Bronitsky and Merrit 1986; Ciolek-Torrello 1995; Cordell 1997; Gumerman 1979; Mabry 1998; Huckell 1997). Within the Madrean Archipelago and the Tucson Basin some "phases" in the archaeological data suggest the *gathering* of specific medicinal plants. These harvesting practices are similar to horticulture but plants were allowed to remain in their natural habitat, which fostered their own growth. The subsistence pattern of gathering implies movement, constant movement away from overused gathering areas and the possibility of a strategy of rotation of gathering areas of specific medicinal and subsistence plants so as to allow them to regenerate and, subsequently, the gathering area could be used again for food production at a later time. In this context, not only should CRM Specialists consider the specific location of plants and archaeological sites, but they should also consider areas *in between* the archaeological sites and gathering areas. The significance and use of these "in between areas" are referred to here as "*archaeological landscapes*" and should be defined as a *collaborative element* and become a part of the preservation and conservation strategies (i.e., Collaborative Resources Inventories or CRIs) of natural and cultural resource specialists. The CRI could be included in existing Cultural Resource Inventories. A further step might be to create a Collaborative Resource Inventory (CRI) as part of the existing Cultural Resource Inventory (CRI).

Although current archaeological preservation strategies are site-specific, we know that people gathered water resources and plant resources from their adjacent and surrounding areas. What we haven't done is establish this known behavior as a criterion for analyzing archaeological data. It is no mistake that early settlements in portions of the Madrean Archipelago, like the Tucson Basin, were near water sources like river confluences. We can also see clusters of archaeological sites within certain areas that maintain perennial water sources. Yet, what are we stuck on here: site specific preservation strategies? It is a known scientific fact that indigenous people were never completely isolated to the remnants of the visible sites we uncover and interpret. Site-specific preservation does not adequately mirror what we know about indigenous "social reality." An important question to ask here is *why are CRM strategies of preservation and conservation limited to site-specific management and not moving towards large-scale preservation of landscapes when there is scientific archaeological evidence that people were not always strictly confined to a specific site; physically or cognitively* (Stoffle 2001)?

One aspect of overcoming this oversight might be found in collaborative efforts with Natural Resource Specialists, who are concerning themselves with large-scale preservation of landscapes, via watersheds. Another aspect of overcoming this oversight is the reconsideration of *oral/ethnographic data* as a viable and reliable scientific data set that can be used for recognizing and establishing the validity of sacred sites and gathering areas (and the in between areas), for example, that are important to instituting *collaborative elements* and expanding the concept of landscapes beyond a mere naturalist or culturalist perspective (Stoffle 2001).

Conclusion

A Conceptual Model as a Basis for Collaborative Resources Inventories

The development of a conceptual model for cultural and natural resource collaboration has roots in the author's creative approach to the contradiction listed above as well as some fundamental roots in the National Parks Service's (NPS) "Crossing Boundaries in Park Management: Proceeding of the 11th Conference on Research and Resource Management in Parks and on Public Lands in 2001. One of the primary purposes of the conference was to promote multidisciplinary problem solving.

> "Contemporary experience with managing parks and outdoor recreation suggests that more integrated and synthetic approaches are needed, and that this will involve crossing multiple physical and perceptual boundaries. [There is a need to address] 1. the crossing of disciplinary boundaries-natural and social sciences must be more closely integrated…." (National Park Service).

Another prime directive of the conference was to promote their relatively new methodological approach called Cultural Landscapes Inventories (CLI's). CLI's are comprehensive inventories of all historically significant landscapes within the National Park System. CLI's are an evaluative inventory that can provide comprehensive documentation for cultural landscapes: including physical development, historical significance, and existing and historical characteristics. Some of these characteristics include *natural systems*, spatial organization, land use, vegetation, circulation, structures and views. CLI's can also assess the integrity and conditions of the *landscape*. According to the National Park Service (NPS), cultural landscapes are composed of four types: historic design, vernacular, historic sites, and ethnographic. CLI's are composed of a process of four levels (see figure 1).

Each level builds on the previous level to give an overall inventory of the specific research area and to provide a more comprehensive and collaborative approach to better stewardship of park resources via multidisciplinary problem solving.

The cultural model (and subsequent methods to include Collaborative Resource Inventories) which is partially derived from the CLI's in this study is composed of information related to four stages (see figure 2).

This cultural model (which promotes the use of Collaborative Resource Inventories) represents a uniform set of scientific assumptions regarding the importance of large-scale preservation strategies and multi-disciplinary problem solving. This cultural model is also supported by three salient and collaborative themes identified from the contents of the methodological information provided in the legal overview above. Each of these themes can be highlighted in the form of questions (see figure 3).

Much like the Cultural Landscape Inventories, the Collaborative Resource Inventory (CRI) is an initial methodological step in the direction of establishing an inventory methodology between Natural and Cultural Resource Specialists. This methodology is rooted in the legal history of conservation and preservation strategies presently employed on the Federal level and currently manifesting itself as part of the National Park Service's Cultural Landscape Inventories.

Cultural resource specialists function as interpreters of past and present human behavior through the analysis of cultural/natural resources vital to human ecological sustainability. When developing short and long-term preservation strategies for cultural resources, it is more current and innovative for cultural resource specialists to think of past human populations as occupiers of broad ranges of landscapes and not limit our interpretive spheres of preservation and conservation to site-specific locales only. Cutting edge Cultural Resource Specialists are expanding their knowledge through integrated research, public interaction and state-of-the-art preservation techniques. The current paper and presentation are a contribution to this expansion. Cultural Resource Specialists must begin to articulate the similarities (and differences) of Cultural and Natural Resource Specialists and to use their collaborative context to contribute, scientifically, to *landscape* preservation strategies. We must begin to combine our scientific efforts in an endeavor to confront, collaboratively, the future of the overall innovative and emergent management strategies required to meet ever-increasing demands and impacts on the physical and social environment by humans and non-humans on significant landscapes so that future generations may benefit from these landscapes in perpetuity.

Cultural Landscape Inventory Methodology: A Four Level Process

Level 0: The Park reconnaissance survey-identifies the scope of landscapes and component landscapes in a particular park, existing and needed information about the resources, and immediate threats to the resources, and establishes priorities for Level I inventory.

Level 1: The Landscape reconnaissance survey-identifies existing and needed information for a specific landscape or component landscape in a park and establishes priorities for Level II inventory. A site visit is conducted and an initial evaluation is done of the significance and character of the landscape or component landscape.

Level II: The Landscape analysis and evaluation-defines and landscape characteristics and their associated features of a specific landscape or component landscape. Both existing and historic conditions are analyzed to determine contributing character-defining features. National Register eligibility is evaluated and integrity and condition assessed. Landscapes at this level are on, or eligible for, the National Register, or are otherwise treated as cultural resources.

Level III: The Feature Inventory and assessment-provides an inventory and evaluation of a physical feature identified in Level II as contributing to the significance of a landscape or component landscape.

Source: NPS-Crossing Boundaries Among Disciplines to Share Information-Proceeding of the 11th Conference on Research and Resource Management

Figure 1—NPS cultural landscape inventory methods.

Stage 1—The understanding of the method-data relationship and the experience of the CRM specialists that leads to cultural resource management decisions of conservation and preservation recommendations.

Stage 2—Conservation and preservation experience which would allow CRM specialists to come to terms with the problems that may have led to their recommendations, choices that may have led to their conditions of the decision-making environment and the *modes of adaptation* to their conditional environment of decision-making.

Stage 3—Achieving a successful trajectory to re-establish and re-define conservation and preservation management strategies as comprehensive, long-term, and large-scale with respect to overall cultural and natural *landscape* use.

Stage 4—Achieving an integration of scientific knowledge gained from their collaborative experiences as adjunct to maintaining conservation and preservation autonomy and control over conservation and preservation decisions that directly or indirectly conflict with "common-sense" decisions (ie. Moving native peoples off their traditional lands to establish a NPS area commemorating traditional native peoples and their traditional heritage) or large-scale "development" projects.

Figure 2—Interpretive and applicable developmental stages as steps to the establishment of Collaborative Landscape Inventories (CLI's).

Theme 1—Research Methodology and Design

Collaborative Resource Inventories:

Question: What archaeological sites are associated with major migratory paths, areas with endangered flora/fauna, or known plants used by indigenous peoples either for subsistence or medicinal purposes, or both?

Theme 2—Research Findings

Collaborative Resource Inventories:

Question: What is the "significance" and "determination" of the project area as a valuable ecological resource requiring long-term and large-scale landscape preservation strategies?

Theme 3—Data Representation and Results

Collaborative Resource Inventories:

Question: What is the "significance" and "determination" of the relationship between natural and cultural resources within the project area?

Figure 3—Some suggestions of CLI's (Collaborative Landscape Inventories) concerning methodology, research, and results.

Notes

[1] The holistic perspective means that no single aspect of a community can be understood unless its relations to other aspects of the community's total way of life are explored. The comparative perspective takes into account the enormous diversity in space and time of human cultures. This diversity means that any general theories might have about human cultures must be tested against other cross-cultural data and must take into account information from a wide range of societies. The perspective of cultural relativity suggests that no culture is inherently superior or inferior to any other.

[2] Please see Volume 40, Chapter V, Article 1500.8 of The Code of Federal Regulations ([40 C.F.R. 1500.8] [1988]).

[3] The Archaeology Conservancy functions much the same way as The Nature Conservancy. They seek to prioritize potentially endangered sites with the intent of purchasing the sites, leaving them *in situ* for future students of archaeology to study in their natural form rather than studying the artifacts left over after data recovery. Local conservation organization like the Sonoran Institute and the Rincon Institute will play important roles in the future of large-scale preservation. It is important to note that the Archaeology Conservancy mostly deals more with issues related to private landowners.

[4] There is a belief among some Cultural Resource Specialists that there can be a balance between "pure" preservation and "restrictive" development, usually encompassed in the rhetoric of "management strategies." However, it is *development* that fuels many local, regional, and national archaeological projects. So, even if a cultural resource specialists believes in preservation on a large scale, there is usually little in the way of legal apparati at her/his exposure to exercise this belief.

[5] Please see the National Park Service's Cultural Landscapes Inventory Database, which includes park reconnaissance surveys, landscape reconnaissance surveys, landscape analysis and evaluations, and feature inventory and assessment data. This is one of the closest models of data collaboration that encompasses strategies that are argued for in this paper. When dealing with gathering information on the level of entire ecosystems, I'm not sure that biological/natural resource specialists have an easier time.

[6] For example, an organization like Desert Southwest Cooperative Ecosystems Studies Unit (founded in 2002) is one of the leading national groups whose awareness of the importance of collaborative studies is reflected in their "focus on multidisciplinary problem-solving." Collaborative landscape elements are explained in more detail below. An elaboration on this idea can be found in Stoffle et.al (2001) and the Bureau of Applied Research in Anthropology (BARA) at the University of Arizona.

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International Arid Lands Consortium's Contributions to Madrean Archipelago Stewardship

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Abstract—*The International Arid Lands Consortium (IALC) was established in 1990 to promote research, education, and training activities related to the development, management, and reclamation of arid and semiarid lands worldwide. Building on a decade of experience, the IALC continues to increase the knowledge base for managers by funding research, development, and demonstration projects and special initiatives. Results from these scientific and technical efforts enhance management of arid and semiarid ecosystems for sustainable use within the framework of maintaining the integrity of the ecological processes. Contributions of the IALC to stewardship of the natural resources in the Madrean Archipelago are presented in this paper.*

Introduction

The IALC promotes research, education, and training activities related to the development, management, and reclamation of arid and semiarid lands worldwide. Member institutions are indicated by affiliations of the authors of this paper. The IALC supports ecological sustainability and environmentally sound use of these lands by funding research, development, and demonstration projects. Results from these scientific and technical efforts enhance management of arid and semiarid ecosystems for sustainable use within the framework of maintaining the integrity of the ecological processes (Ffolliott and others 2001). This paper presents a synopsis of the contributions of the IALC's programs to stewardship of natural resources in the Madrean Archipelago region.

Soil and Water Resources Development and Conservation

Carbon pools in dryland environments are comparatively large, but fluxes of carbon to and from the atmosphere have been poorly understood. Therefore, the extent that these environments sequester CO_2 from the atmosphere into the calcium-carbonate system and the magnitude of its formation was estimated in an IALC study. With this information, soils can be managed to sequester CO_2 and mitigate impacts of the greenhouse effect, leading to the possibility of "carbon credits" for these ecosystem managers.

Soil-organic matter plays a key role in stabilizing sandy soils in arid and semiarid environments. Studies in other ecosystems have shown that the contribution of soil-organic matter to soil structure depends largely on its composition and distribution. The results of an IALC study helped to identify the biotic and physical resources to manage when promoting soil aggregation, optimizing soil stability and productivity, and reducing land degradation from excessive soil losses through the actions of water and wind.

Increased awareness about wastewater disposal by using environmentally sound and economically beneficial methods evolved from this demonstration project. Specialists in water and soil management, small-business development, and community planning from the Southwestern United States and Northwestern Mexico collaborated in applying treated wastewater to landscapes not suited for agriculture to grow short rotation pulpwood trees for profit. This low-cost approach safely recycled sludge and wastewater from small communities along the border, while protecting the environment and providing enhanced economic development opportunities.

Land Use and Reclamation

Coppice (sprouts) evolving from the rootstocks of harvested Emory oak trees use disproportionately high amounts of water (up to 80 percent of the annual precipitation) in transpiration in comparison to mature trees (about 45 percent of the annual precipitation). Less water is then available to recharge groundwater aquifers, produce streamflow, and help other plants grow. This research provides a basis for prescribing the management of post-harvest oak stands to optimize fuelwood production, achieve water conservation, and, through the results of companion studies, benefit other resource benefits in these woodlands.

Status and management opportunities for sensitive bird species have been evaluated as a contribution to the Southwestern Borderlands Ecosystem Management Research Project, headed by the USDA Forest Service (Gottfried and others 1999) to provide a basis for better ecosystem management. Greater seasonal shifts in species richness occurred on sites supporting the greatest woody cover, while total bird numbers varied little between seasons except on sites with little woody cover. Prescribed burning treatments and lower livestock grazing intensities are likely to create a mosaic of diverse woody plant communities that would support the greatest bird-species diversity.

Historical and current information on public grazing lands has been assembled to develop electronic formats that facilitate the planning process used by Federal agencies in preparing livestock-allotment plans. The database template provides a model to maximize benefits of past financial inputs, offer new planning opportunities, and operate in compliance with Federal laws and regulations pertaining to public grazing lands. A variety of delivery mechanisms are available to ensure that the broadest constituency possible is served.

Processes Enhancing the Management of Ecological Systems

Human disturbances often lead to habitat fragmentation, which influences the sustainability of wildlife populations and other natural resources on the affected sites. Understanding how habitat fragmentation impacts ecosystem processes at species, community, and population levels was determined in this investigation. Availability of this information (in turn) facilitates proper management of wildlife resources when fragile ecosystems are impacted by livestock grazing, urbanization, and interventions to restore degraded landscapes.

The IALC supported preparation of a video called *Survivors in the Sand* that increased the awareness and interest in natural resources and their management issues. Conservation, sustainable use, and management of arid and semiarid lands were documented in the 1-hour video through on-site interviews and film archives from the Madrean Archipelago and other dryland regions. Topics presented included the conservation of water resources, land reclamation treatments, and sustaining endangered and threatened species. There has been widespread airing of the video by public and private television.

Inventorying and Measurement Techniques and Monitoring

Landscape-scale management often requires information that is not easily obtained from sample plots or extrapolations from time-dependent data sets. Long-term photographic databases of broom snakeweed (*Gutierrezia sarothrae*) have been incorporated into information visualization system to overcome this problem for this noxious plant species. The ability to couple historical information with the results of small-scale experiments conducted at specific points in time represents a powerful tool to help people to better understand the landscape changes that result from alternative management activities and land-use practices.

Sampling of large rainfall and runoff events, flooding, and other outlier events is difficult in the Madrean Archipelago because of the extreme variability of the occurrence of these events. Research on the Walnut Gulch Experimental Watershed showed that peak stormflows can be estimated from knowledge of surface water profiles indicated by high water marks and post-flow stream channel geometries. The uncertainty associated with these indirect peak streamflow-discharge estimates was also estimated. These methodologies can be expanded to improve estimates of hydrologic processes on lands with little ground-based monitoring.

Summary

Efforts of the IALC to learn more about the ecological sustainability and development of arid and semiarid landscapes such as those represented by the Madrean Archipelago region continue. Results from these scientific and technical efforts enhance management of arid and semiarid ecosystems for sustainable use of the inhabiting resources within the framework of maintaining the integrity of the ecological processes.

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Abundance of Birds in the Oak Savannas of the Southwestern United States

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Abstract—*Oak ecosystems of the Southwestern United States are important habitats for a variety of wildlife species. Information is available on the abundance and habitat preferences of some species inhabiting the more densely structured oak woodlands, but little information is available on these topics for the comparatively open oak savannas. Studies are underway to alleviate this situation by determining the abundance of wildlife species commonly found in the oak savannas, identifying the habitat preferences of these species, and assessing the impacts of prescribed burning on the wildlife species. Initial estimates of the abundance of birds in oak savannas obtained in the first year of a comprehensive investigation on the abundance and habitat preferences of a more complete representation of avifauna, mammals, and herpetofauna inhabiting oak savannas are presented in this paper.*

Introduction

Abundance and habitat preferences of birds and some of the other wildlife found in the densely structured oak woodlands of the Southwestern United States are known for some of the representative species, but little information on these topics is available for the more open oak savannas of the region. In terms of avifauna, habitat needs of the diverse bird species permanently or temporarily inhabiting the oak woodlands and associated vegetation include food, protective cover, and nest, roost, and perch sites (Block and others 1992; Schemnitz and Zeedyk 1992; Schemnitz and Zornes 1995). However, the species of oak, proportion of the tree foraged upon, and accompanying herbaceous plants foraged upon are species-specific (Marshall 1957; Balda 1969; Hutto 1985; Block and others 1992; Morrison 1999). Comparable information is needed for oak savannas to enhance the knowledge base for the assemblage of wildlife species in the composite of oak ecosystems in the region. A study of abundance and species diversity of birds in oak savannas is part of a comprehensive investigation of the abundance of a representation of avifauna, mammals, and herpetofauna inhabiting the oak savannas, their habitat preferences, and the impacts of prescribing burning on these species. This paper presented the first-year results of this study. This effort is coordinated with other investigations of the ecological and hydrologic characteristics of oak savannas and their response to land management practices such as prescribed burning treatments.

Study Protocol

Twelve small watersheds located on the eastern side of the Peloncillo Mountains in southwestern New Mexico to evaluate the impacts of prescribed burning on ecological and hydrologic characteristics of these watersheds (Gottfried and others 2000) are (collectively) the study area. The areal aggregation of these watersheds, called the Cascabel watersheds, is about 450 acres. Baseline geological and physiological characteristics of the Cascabel watersheds have been described by Gottfried and others (2000) and, therefore, will not be presented. Vegetation has been described by Ffolliott and Gottfried (this proceedings).

On each of the watersheds, between 35 and 45 sample points have been permanently established along transects perpendicular to the main stream system and situated from ridge to ridge to provide a sampling basis for this and the companion studies. Intervals between sample plots varied among the watersheds depending on the size and configuration of the watershed sampled. The total of 421 sample points on the 12 watersheds served as the sites to tally birds in the spring and fall of the initial year (2003) of this study. Bird sightings in a 5-minute observation period were tallied by species in the spring and in the autumn at the sample points.

Results and Discussion

A larger number of birds and a greater diversity of species were observed on the Cascabel watersheds in the spring than in the fall. While some species (bushtit, Mexican jay, juniper titmice, mourning dove, and scaled quail) were tallied in both observation periods, other species (dusky-capped flycatcher, northern mockingbird, and turkey vulture) were observed in spring but not fall. Montezuma quail were observed only in the fall. Listings of the birds tallied on the Cascabel watersheds in the spring and autumn of 2003 follow.

Whether this pattern of abundance and species diversity continues to persist on the watersheds remains to be seen. It should be noted that 2003 was the sixth year of a prolonged drought period in the region, and, it is assumed that the listings of birds presented reflect these conditions. No meaningful relationships between bird sightings and the habitat conditions (vegetation, physiography, etc.) represented by the sample points were observed in this initial year of study.

Species **Spring birds**	**Number of** **birds seen**
Bushtit (*Psaltriparus minimus*)	71
Cardinal (*Cardinalis cardinalis*)	2
Common nighthawk (*Chordeiles minor*)	7
Common raven (*Corvus corax*)	2
Dusky-capped flycatcher (*Myiarchus tuberculifer*)	11
Gambel's quail (*Callipepla gambelii*)	9
Gila woodpecker (*Melanerpes uropygialis*)	3
Gould's turkey (*Meleagris gallopavo* var *mexicana*)	10
Hummingbirds (species unknown)	4
Juniper titmice (*Baeolophus ridgwayi*)	31
Lark sparrow (*Chondestes grammacus*)	2
Mexican jay (*Aphelocoma ultramarina*)	44
Mexican spotted owl (*Strix occidentalis*)	1
Mourning dove (*Zenaida macroura*)	28
Northern mockingbird (*Mimus polyglottos*)	15
Phainopepla (*Phainopepla nitens*)	4
Red-tailed hawk (*Buteo jamaicensis*)	9
Say's phoebe (*Sayornis saya*)	1
Scaled quail (*Callipepla squamata*)	24
Turkey vulture (*Cathartes aura*)	13
Unknown	30
Total	321
Fall birds	
Bushtit (*Psaltriparus minimus*)	77
Common nighthawk (*Chordeiles minor*)	5
Common raven (*Corvus corax*)	7
Gila woodpecker (*Melanerpes uropygialis*)	1
Juniper titmice (*Baeolophus ridgwayi*)	16
Mexican jay (*Aphelocoma ultramarina*)	24
Montezuma quail (*Cyrtonyx montezumae*)	6
Mourning dove (*Zenaida macroura*)	2
Phainopepla (*Phainopepla nitens*)	4
Scaled quail (*Callipepla squamata*)	10
Unknown	13
Total	165

Conclusion

The listings of birds observed on the Cascabel watersheds represent only one year of observations and, therefore, must be considered preliminary. Continuing observations will be necessary to determine how representative of the oak savannas these listings might be. Avifauna habitat associations, or lack thereof, will also be evaluated with future measurements and monitoring.

Acknowledgment

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Defining Boundaries Across Borders: A Case Study Extending a Major Land Resource Area Into Mexico

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Abstract—*Geographic information science (GIS) and field work were applied to extend Major Land Resource Area (MLRA) 41, Southeastern Arizona Basin and Range, from Arizona and New Mexico into Sonora and Chihuahua, Mexico. The result of this analysis is a tentative boundary line that delineates MLRA 41 for both the United States and Mexico based on elevation, soils, temperature, precipitation, and vegetation. This delineation will allow for a more effective linkage of research and increased availability of information across the international border.*

Introduction

The United States and Mexico not only share a border, but also many natural, economic, and cultural resources. The Chihuahuan and Sonoran Deserts occupy significant areas on both sides of the border and demonstrate similar climate, geology, soil and water resources, and vegetation. Comprised of arid and semi-arid regions, the area includes California, Arizona, New Mexico, and Texas and is divided by botanists into three deserts (EPA 2002) and by the USDA Natural Resources Conservation Service (NRCS 1978) into three corresponding Major Land Resources Areas (MLRAs) for land management purposes (figure 1).

The NRCS defines MLRA 40, Central Arizona Basin and Range, as primarily Sonoran Desert, with no perennial water and vegetation dominated by desert shrub and cacti, especially the Giant Saguaro cactus. Winters are warm, and precipitation and elevation are relatively low, with a few mountain peaks reaching 1,400 meters.

MLRA 42, Southern Desertic Basins, Plains, and Mountains, dominates southern New Mexico and part of western Texas. A large portion of this area is the Chihuahuan Desert, and thus is home to only a few perennial watercourses, the Rio Grande, Conchos, and Pecos Rivers. Winters are cold, with elevation ranges from 800-1,500m, and precipitation falls primarily in the summer. This area is also dominated by desert shrub and grass, but has several species of deciduous and coniferous trees at higher elevations.

The focus of this study, MLRA 41, Southeastern Basin and Range, encompasses southeastern Arizona and a small portion of southwestern New Mexico. MLRA 41 is a very diverse ecological area in the transition zone between the Sonoran and Chihuahuan Deserts, with a relatively homogeneous pattern of topography, soil, climate, water resources, and land use, consisting of a series of isolated mountain chains and arid river basins. There are three Land Resource Units (LRUs) defined by the NRCS (1978) within MLRA 41. LRU 41-1: Mexican oak-pine woodland and oak savannah is found in the higher range of elevations, above 1,300m, the precipitation ranges from 400-800 mm, and the vegetation is dominated by oak savannahs and perennial grasses, with conifer woodlands in the higher elevations, above 1,700m where there is greater than 500 mm of precipitation. The relatively small area of land, consisting primarily of river valleys, with elevation ranging from 880-1,440 m and annual precipitation ranging from 200-300 mm is classified as 41-2: Chihuahua-Sonora Desert shrub mix due to its sparse cover of perennial grasses and shrubs and only a few trees. The third LRU, 41-3: Arizona semi-desert grassland, is by far the largest, and covers the mid-range of elevation from 975-1,500 m, and of precipitation from 300-400 mm. The vegetation here is characteristically warm season perennial grasses, shrubs, and cacti, with a few summer annuals.

The need for a common land classification scheme between the United States and Mexico is discussed in Heilman et al. (2000), which proposes a method to link NRCS ecological sites with the Comisión Técnico Consultiva de Coeficientes

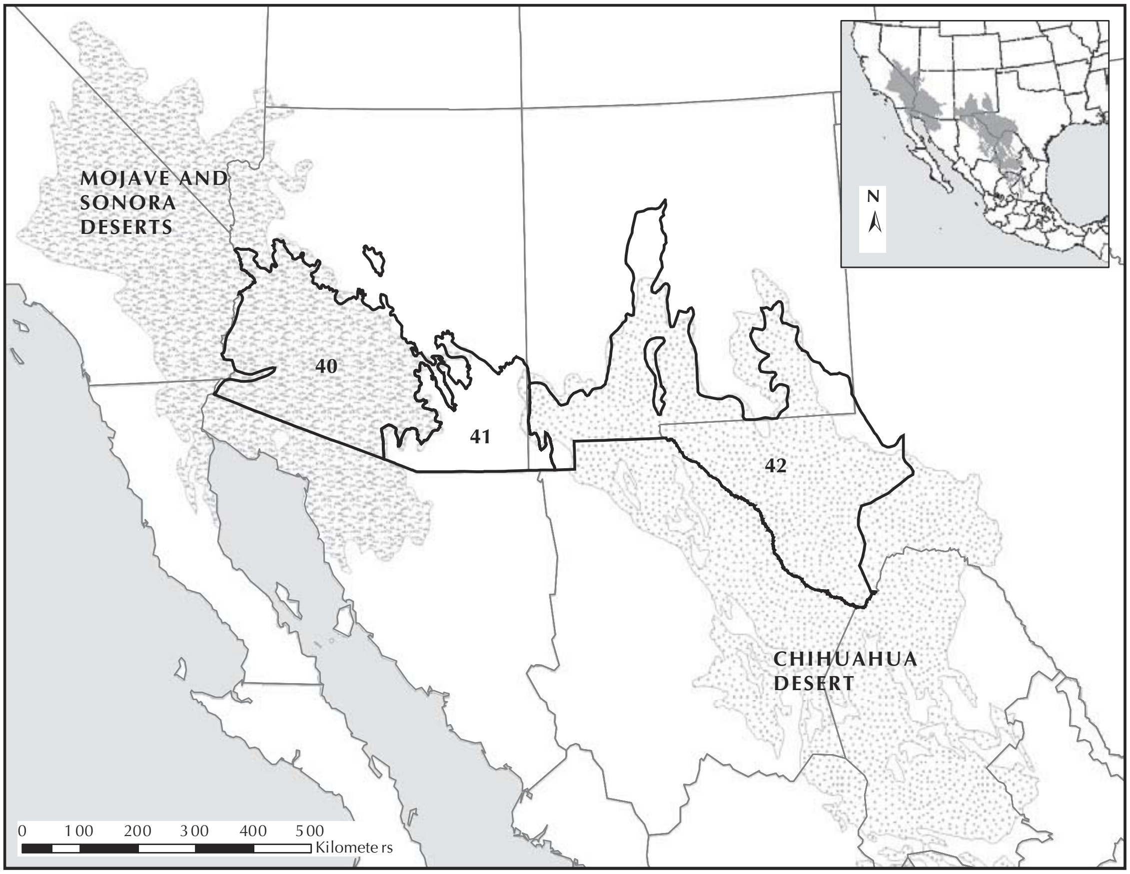

Figure 1—Major Land Resource Areas and deserts in the Southwest.

de Agostadero (1978) (COTECOCA-Technical Commission for Stocking Rates) Sitios de Productividad Forrajera (Forage Production Sites). COTECOCA was chosen because of its correspondence with ecological sites, and more detailed level of classification. This linkage will allow land managers and investigators in Mexico to take advantage of the existing data for MLRA 41, and thus future resource data could be more easily shared across the border, reducing time and cost to both sides.

Data

Arizona and New Mexico

Precipitation and temperature

The precipitation and temperature data used for the United States were obtained from the Oregon Climate Service's Spatial Climate Analysis Service, which applies **PRISM** (**P**arameter-elevation **R**egressions on **I**ndependent **S**lopes **M**odel) to adapt orographic effects into the interpolation of temperature and precipitation (Daly 1996).

Vegetation and soils

The National Gap Analysis Program (2003), a geographic planning tool that identifies gaps between land areas that are managed by conservation and those naturally bio-diversely rich, was completed for the State of Arizona, but not New Mexico; therefore, vegetation and land use data at a scale of 1:100,000 were only available for Arizona. Soil data was obtained from the USDA-NRCS (1994) State Soil Geographic (STATSGO) Database, which has a scale of 1:250,000 for the conterminous United States.

Sonora and Chihuahua

Precipitation and temperature

Precipitation data were obtained from Comisión Nacional para el Conocimiento y uso de la Bioversidad (CONABIO) and Instituto Mexicano de Tecnología del Agua (IMTA). Data from these sites that were available included both monthly and annual minimums, maximums, and averages in predefined ranges.

Vegetation and soils

The initial vegetation information was created by digitizing a Brown and Lowe (1994) vegetation map of both Sonora and Chihuahua. Site maps developed by COTECOCA (1978) were then used to compare vegetation found through field observations with the digitized Brown and Lowe information for verification and adjustment of vegetation communities. Numerous sites were sampled comparing soil descriptions in

Arizona with soils in Chihuahua and Sonora. Vegetation and soils maps from INEGI (2004) were also used to reference the field observations and other sources. Their more general classifications are consistent with those of the specific COTECOCA in that MLRA 41 includes pastizal (grassland) and bosques de encino (oak forests), and has a southern boundary north of the selva caducifolia (thorn forest) and bosques de coniferas (conifer forests).

Elevation

The Digital Elevation Model (DEM) was retrieved from the National Elevation Dataset center, and then converted from decimal degrees to meters, having a resolution of approximately 900 m. The DEM covers the western coast of the United States, and extends down into Mexico to include the States of Sonora and Chihuahua.

Field Data

Field data were collected on several occasions. This included collecting GPS points that indicated changes in vegetation or landform, vegetation field notes, and soil/site correlation data. Pictures were also taken to document differences or similarities in vegetation and landform within MLRA 41 in the United States (figure 2).

Methods

Zonal statistics in ArcMap were applied using the elevation data to calculate the range for all three LRUs. These ranges were used to determine areas in Northern Mexico that were within the elevation and precipitation limits of MLRA 41. This large area was further divided by use of the field notes that stated an area was possibly characteristic, or not indicative of, any of the three LRUs of MLRA 41and then compared to the vegetation data for Mexico. Vegetation was one of the biggest factors in determining the extent of MLRA 41. Elevation and, to a degree, precipitation were then used to separate the area into the three LRUs based on the NRCS defined and statistically determined ranges.

Results

The elevation range was found to be 716 to 3,261m. The published elevation range is 800-1,800 m in the mountains, with the highest peaks around 3,300 m. This indicates the ranges determined from the statistics are within the parameters set by the NRCS, and could be applied to the Mexico side. We were also able to determine that MLRA 41 had annual precipitation ranging from 229-1,143mm, minimum temperatures ranging from 1.47-12.91 °C, and maximum temperatures ranging from 15.93-28.86 °C. These values being similar to the USDA-NRCS published data, which includes having an average annual precipitation range of 275-375mm, but as much as 900 mm in higher elevations, an average annual temperature of 13-17 °C with lows below freezing and highs above the 37.8 °C, allowed us to apply similar techniques to the Mexico data sets.

Through field observation it was discovered that the western part of Sonora, like that of the Arizona/California border, is more typical of the Sonoran Desert, like that of MLRA 40, and is accordingly the western limit. The vegetation of the Chihuahuan Desert becomes more evident toward Texas, as

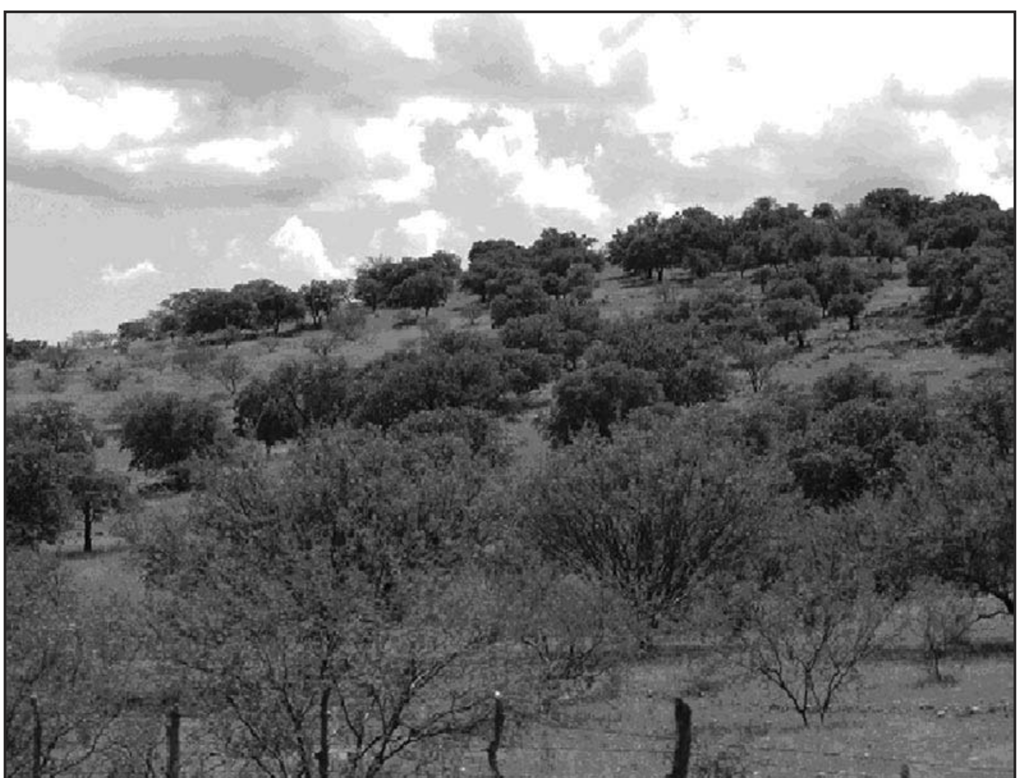

Figure 2—Example of vegetation indicative of MLRA 41-1 in Sonora, Mexico.

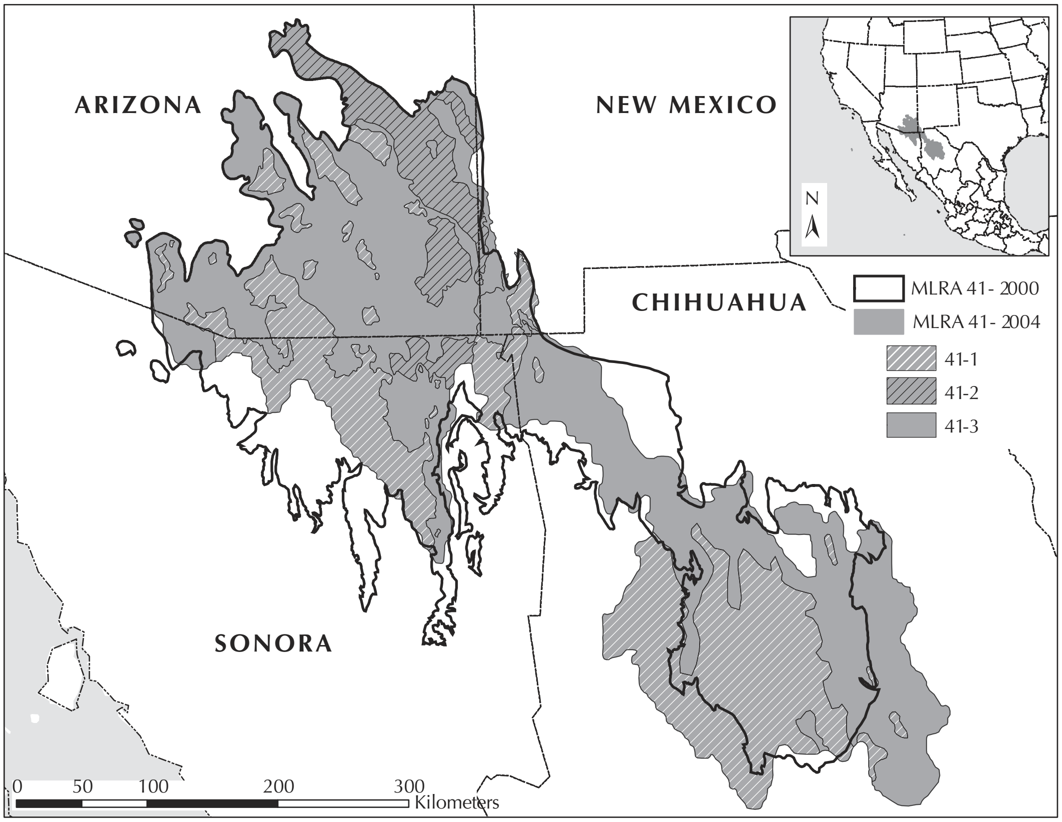

Figure 3—New MLRA 41 area and previous boundary.

in the vegetative composition of MLRA 42; and thus becomes the eastern boundary of MLRA 41. The southern boundary was drawn where the thorn forests begin.

The result of this analysis is an updated boundary, slightly different than the boundary proposed in Heilman et al. (2000) that was based solely on the Brown and Lowe vegetation map and COTECOCA forage sites. This new boundary of MLRA 41 does not extend as far west or south as the previous boundary, as the ecological and forage sites may have eluded (figure 3). This boundary should still be considered tentative until confirmed by vegetation experts in Sonora and Chihuahua.

Conclusions

Discontinuities between the LRU boundaries across the border were seen, especially within LRU 41-1. The areas with discontinuities need to be field checked for vegetation and elevation change on both the United States and Mexico sides of the border. The boundary could then be adjusted accordingly. The southeastern boundary of MLRA 41 in Chihuahua also needs to be examined further for changes in vegetation to better define the LRU boundaries.

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Pollination of Pima Pineapple Cactus (*Coryphantha scheeri* var. *robustispina*): Does Pollen Flow Limit Abundance of This Endangered Species?

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Abstract—*Pima pineapple cactus (PPC) (*Coryphantha scheeri *var.* robustispina*), a federally listed endangered species, occurs throughout southeastern Arizona and has relatively low population densities. To determine whether pollination limits reproduction of PPC we used florescent dye to quantify pollen flow between individuals in a PPC population. Preliminary results suggest* Diadasia *bees are capable of transferring pollen analogs nearly 1 km, but most transfers occur over a few hundred meters. PPC may not be pollen limited, at least when few competing cactus species are in bloom. Ongoing work will delineate the competition for pollinators between PPC and other cacti.*

Introduction

Rare plants respond differently to a variety of ecological phenomena compared to their abundant counterparts. Rarity can be defined across gradients of geographic range, habitat specificity, and population size (Rabinowitz 1981). Rare plants can experience reproductive constraints through Allee effects, difficulties in the reproduction of organisms with small population sizes. These effects are caused by a variety of genetic, ecological, or demographic mechanisms associated with small population sizes and/or increased isolation, each of which can act alone or in combination (Forsyth 2003).

Pima pineapple cactus (PPC) (*Coryphantha scheeri* var. *robustispina*: Cactaceae) is a low-growing hemispherical succulent restricted to a relatively small range in the Altar and Santa Cruz Valleys in southeastern Arizona and Sonora, Mexico. It occurs on gently sloping bajadas and alluvial soils in the ecotone between Sonoran desert grassland and Sonoran desert scrub. PPC is federally endangered due to habitat loss, illegal collecting, habitat degradation and habitat alteration by non-native species, and range management practices (USDI 1993). The total number of PPC plants has yet to be determined, but approximately 3,000 have been located. The densities of populations vary between 1 plant per hectare to less than 1 plant per 10 hectares, and PPC occurs in a cactus community dominated by the genera *Opuntia*, and *Ferocactus*. PPC is primarily pollinated by the cactus specialist bee, *Diadasia rinconis*, and is also an obligate outcrosser (Roller 1996). Obligate outcrossers that require animal vectors for pollination are more likely to be affected by Allee effects (Huenneke 1991). Because PPC occurs at such low densities, lives in an ecotone, is pollinated by a specialist, and occurs in a community where PPC competitors for pollinators are greatly more abundant, we believe that reproductive success potentially limits PPC abundance.

PPC aborts 18-59% of its flowers, but reasons for floral abortion are unknown (Roller 1996; Schmalzel 2000). There are two main explanations for floral abortion, proximate (ecological) and ultimate (evolutionary) mechanisms (Queller 1985). Of the proximate mechanisms, pollination failure, predation, and resource limitation are generally tested (Ackerman and Montalvo 1990; Parra-Tabla and Bullock 1998). An indirect pollen-flow experiment (i.e., delineation of the dispersal of pollen and pollen analogs) allows assessment of pollen limitation because individual pollen grains are counted rather than identifying seed paternity. An indirect pollen-flow experiment, coupled with selected crosses, would efficiently identify if pollination failure results in floral abortion. A pollen flow experiment would also illustrate how many individuals interact with each other in populations of rare organisms. These two benefits, identifying potential causes of floral abortion and estimating population interactions, are of prime importance in the reproductive ecology of PPC.

Reproduction is one of many areas of PPC ecology that has received little scientific attention. PPC flower buds begin to form in May and flowers bloom from June through August, although individual flowers bloom for only one day (Roller 1996). PPC flowers exhibit several synchronous flowering events a year and participation varies from only a few to nearly all individuals on a site (Roller 1996). Each flowering event occurs 5-7 days after a substantial (approximately 0.5 cm) "monsoon" rain. Female *Diadasia rinconis* are thought to be the primary pollinator of PPC; however, other bee species visit during flowering (Schmalzel 2000).

Determining the amount and distance of pollen flow in the population will indicate how many individuals are interacting with each other in a specific area, thus enabling identification of neighborhoods of PPC plants (*sensu* Wright 1943). Our objective is to quantify the relationship between distance and pollen flow in a PPC population.

Methods

Methods for pollen flow experiments are adapted from Waser and Price (1982), Thompson et al. (1986), and Waser (1988). All known PPC plants in an approximately 40-ha area were surveyed and mapped with a global positioning system before they bloomed in the summer of 2003.

During the summer of 2003, flowering events took place on June 5, July 17, July 29, and August 20. The August event was later than indicated by previous research (Roller 1996). Using a toothpick, we placed small amounts of fluorescent powder, a mimic for pollen, on the anthers of PPC flowers. These flowers are the source flowers. The dye powder is transported on the body of the pollinator and is deposited on flowers subsequently visited by the pollinator. Four plants were chosen at random, and each plant received one color of dye for a total of four different colored source plants every flowering event. During the third flowering event (July29) we dyed two plants with two colors, due to a small sample size (n = 8 plants). All source plants were separated by at least 50 m to minimize spatial autocorrelation.

The day after flowering the stigmas were removed from all PPC plants in the study area and individually placed in small glassine envelopes. The stigmas were then taken back to the laboratory where the number of dye grains was counted under a UV light through a 50x-dissecting microscope. Pollen grains were not counted because the proportion of self pollination associated with each stigma is unknown.

Future experiments will calibrate the relationship between pollen deposition and dye deposition (Waser 1988). Until this relationship is known we assume that the flow of dye grains is equivalent to pollen flow in the population. Previous studies report a 9% error rate when making this assumption (Waser 1988).

Data were log-transformed to fit simple linear regressions between the number of dye grains transported and the distance between source and recipient plants. We also analyzed mean transport distance. All analyses excluded source flowers as a recipient of dye because of the difficulty associated with detection of dye grains on these flowers.

Many flowers had few to none of the potential dye colors present. Reasons for the lack of deposition are unknown, so we defined the neighborhood size two different ways: considering only the flowers that transported dye or all potential recipient flowers in the population. In other words, each flower had the potential to receive four distinct colors, but many flowers did not receive all four colors, so we either considered the entire set with the missing colors (all potential crosses and colors) or we excluded the absence of dye and analyzed the data based only on the presence of the dye.

Results

The proportion of flowers that aborted increased over time (figure 1). However, the abortion rate data from the third flowering period was discarded due to small sample size (n = 8 plants) and asynchronous flowering. When analyzing all potential recipient flowers in the four flowering periods there was a significant decrease in the mean number of dye grains deposited through the summer (figure 2). When analyzing the flowers that received dye the mean number of dye grains transferred did not significantly differ between flowering events (ANOVA; mean = 1.50, F = 1.15, df = 3, 696, p = 0.327).

Flowering events 1, 2, and 4 had negative regression coefficients between the log-number of dye grains deposited and the log-distance dye grains traveled for all potential flower crosses and for flowers with dye present (all $p < 0.001$). Flowering event 3 did not have a significantly negative slope for flowers with dye present and for all potential flowers and thus was excluded from further regression analysis. The three remaining flowering events (1, 2, and 4) showed a consistent trend of decreased dye grain deposition with increased distance between the source and recipient flower.

The estimate of the x-intercept for the above regressions highlights the distance where the average dye deposition equals zero. When analyzing the x-intercept of only flowers with dye present no significant evidence of a relationship through time emerges (figure 3, dark bars). When expanding this x-intercept analysis to all potential recipients in the population, the x-intercept decreased throughout the season (figure 3, light bars). There is also evidence that the proportion of flowers that did not receive dye (i.e., “missed” crosses) increased as the season passed (regression coefficient = 5.492×10^{-3}, t = 3.71, p = 0.066).

Discussion

In one model of a perfectly pollinated system each flower would receive pollen from each source plant at a quantity inversely proportional to the distance from the source plant. This model population exists when three assumptions are met: (1) there are no barriers to pollen dispersal (i.e., no isolation), (2) each flower has an equal chance of being pollinated, through space and time, and (3) pollinators are present and their activity is constant. If these assumptions were met every stigma we observed should have received all four dye colors. Most stigmas did not have this expected pattern, especially after the first flowering event. Thus, we would like to determine which assumptions were violated and led to the resulting lack of deposition in the three flowering events.

Three non-mutually exclusive hypotheses may explain why the reproduction of PPC was relatively low. The lack of reproductive success may have resulted from a paucity of pollinators available to deposit sufficient quantities of pollen either through (1) the pollinator being absent or (2) through PPC competitors securing the pollinator’s attention. Or, (3) there could have been a lack of plant-available resources, which would constrain PPC fruit development regardless of the success of pollination. This latter hypothesis is supported

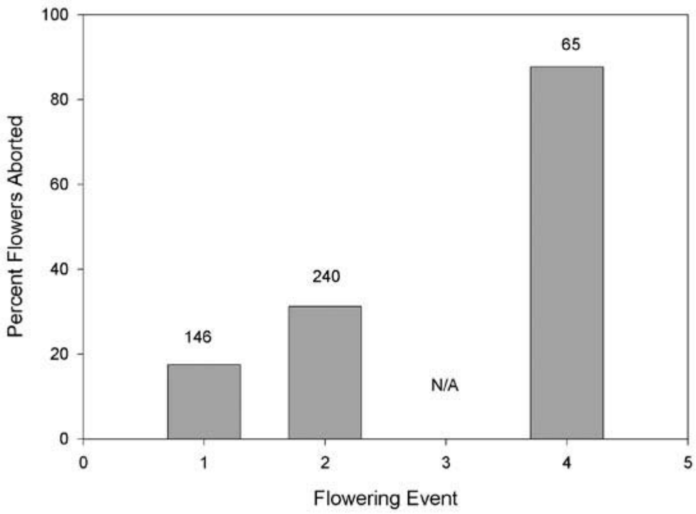

Figure 1—Percent of flowers aborting during each flowering event; numbers indicate sample size.

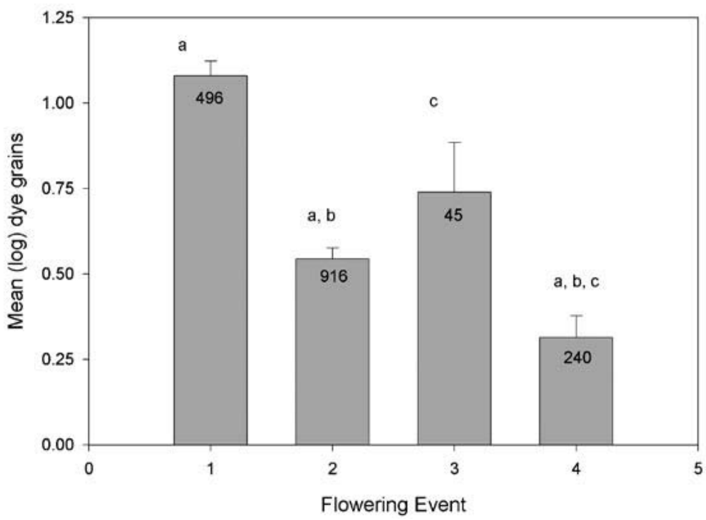

Figure 2—Mean number of dye grains deposited for all potential crosses; a, b, c denotes a significant difference ($p < 0.01$) between means. Numbers indicate sample size.

by the increase in proportion of flowers aborted throughout the season and cannot be excluded at this time. Nevertheless this mechanism does not account for the observed differences in dye dispersal, which suggests that pollinator presence and/or abundance explains the decrease in pollination success.

Of our initial three assumptions, (1) no isolation, (2) all flowers have an equal chance of pollination, and (3) pollinators are present and their activity is constant, we believe that a lack of pollinator activity provides the best explanation for our results. *Diadasia* bees are capable of moving pollen analogs nearly 1 km, and we suspect they have the capacity to move dye farther. This suggests that all plants on our site had the potential to receive dye from all of the four source plants, thereby eliminating assumption number 1. The observed lack of transferred dye may indicate an Allee effect in which PPC is constrained in reproduction by its small population size. However, we were unable to determine if our second assumption, that flowers have unequal pollination success, was violated and could have confounded our results.

The pollination success of PPC in our study site decreased during the summer. Previous studies did not look at pollination success for this length of time (Thompson et al. 1986; Waser 1988). The decrease in pollination success could be explained equally well by decreases in pollinator abundance and activity. However, female *Diadasia* bees decline only slightly between June and July, whereas we found that abortion rates nearly doubled during the same period (Ordway 1987). Evidence of partial bivoltinism occurring in *Diadasia rinconis* suggests that the second generation of bees would emerge to pollinate *Ferocactus wislizenii* (Neff and Simpson 1992). It is unknown whether these lines of evidence support the prediction that there were enough *Diadasia* present to successfully pollinate PPC.

PPC generally produces flowers between the flowering period of its main competitors *Opuntia*, and *Ferocactus*. In southern Arizona *Opuntia* cacti typically bloom coincident with the spring rains, and *Ferocactus* plants begin to bloom a few weeks after the beginning of the "monsoons" which typically start in July (Turner et al. 1995). Future experiments will determine if plant-available resources are limiting PPC reproduction during the flowering season, but we believe that the decline in reproductive success can be attributed to a lack of pollinator resources.

PPC occurs in relatively low densities, is pollinated by a cactus specialist bee, and probably cannot out compete its competitors for this resource. PPC produces flowers temporarily between its major competitors, likely because this period is a stable point in time during which PPC can maximize its chance of successful pollination. Our data reveal that the proportion of flowers missed by pollinators increased when PPC was blooming at the same time as its competitors. This could account for the decrease in pollination success through the summer. When *Ferocactus* begins to bloom the potential exists that *Diadasia* preferentially pollinate *Ferocactus*, which is a more stable resource compared to the sporadic resources PPC provides. However since a nucleus of dye transfer exists during all flowering periods a significant number of bees may have discovered this sporadic reward during the later part of the summer.

An estimate of neighborhood size can be developed from the greatest distance at which the average plant receives pollen. This point is modeled by the x-intercept in figure 3. In a highly fragmented population with widely spaced individuals the x-intercept represents the maximum distance PPC plants could be separated and still receive significant pollen. In our un-fragmented study population this x-intercept determines the number of potential sources of pollen a PPC plant could receive. Future research will determine the distance correlated with the x-intercept. This distance would be critical for reserve design in areas of fragmented PPC habitat.

Acknowledgments

We would like to thank the Bureau of Reclamation and the Fish and Wildlife Service for providing the opportunity

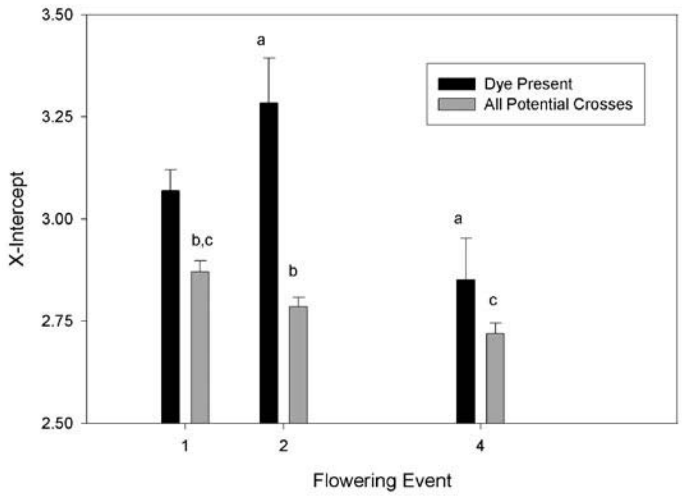

Figure 3—X-Intercepts of the regression of log dye grains deposited versus log distance for flowers with dye present and for all potential crosses; a, b, c indicates significant difference ($p < 0.05$) between pairs.

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Monitoring Post-Fire Vegetation Regeneration in a Madrean Ecosystem

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Abstract—*Fire suppression over the past century has contributed to the conversion of grasslands to shrublands in Sky Island communities. Two prescribed fires were ignited in the Peloncillo Mountains: Baker Canyon in 1995 and Maverick Spring in 1997. Remote sensing data were used to examine prescribed fire effectiveness in reducing shrub cover and to monitor post-fire regeneration. Landcover maps identified an initial decrease in shrubcover due to foliage loss and top-killing, with shrubcover increasing in following years where low burn severity did not kill shrubs completely. Results indicate the need for a regular schedule of prescribed fire to achieve permanent shrubcover reduction.*

Introduction

Sonoran and Chihuahuan Desert ecosystems have been identified as major biodiversity "hot spots" because they contain an abundance of unique flora and fauna concentrated within a relatively small geographic area (Mittermeier et al. 2003). In particular, the Madrean Archipelago is the only sky island complex extending from subtropical to temperate latitudes and contains an exceptionally diverse pattern of flora and fauna. The conservation status of this area has been declared "vulnerable," with recent research indicating deterioration due to climate change, wildfire, grazing, suburbanization, and invasive species. Monitoring land cover modifications is crucial to understanding the role and effects of disturbances, and quantitative research is needed to understand what changes are occurring, the rate of occurrence, and how to minimize impacts of change through land management methods.

Fire suppression over the past century has caused significant change in Madrean ecosystems. The semi-arid grasslands located throughout the Madrean complex require frequent, low intensity fires to keep shrub encroachment in check. Local ranchers decided, with the help of the Forest Service, to reintroduce fire in these deteriorating grasslands. Two prescribed fires were ignited in the Peloncillo Mountains: Baker Canyon in 1995 and Maverick Spring in 1997. The purpose of this research was to examine the effectiveness of prescribed fire in reducing shrub cover and to monitor post-fire regeneration patterns using remote sensing.

Study Area

The Peloncillo Mountains extend north and south along the Arizona-New Mexico border near the United States-Mexico border. Baker Canyon and Maverick Spring are located in the southwestern portion of the Peloncillo Mountains with elevations ranging from 900 to 2,000 meters. Vegetation communities found in both areas include semi-arid grasslands, shrublands, and some Madrean woodlands. Baker Canyon covers an area of 41 sq km and Maverick Spring covers an area of 76 sq km. While a substantial percentage of the Baker Canyon site burned in 1995, only a small percentage of the Maverick Spring site burned in 1997.

Data

This study used eighteen Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper-plus (ETM+) images, broken into two seasonal sets of annual images from 1994 to 2002, with anniversary dates in February and August of each year. Station-collected precipitation data from the National Climatic Data Center (NCDC) were used in conjunction with Landsat TM and ETM+ data to provide evidence of vegetation phenological state. Ancillary data included 1 m spatial resolution color infrared digital orthophoto quarter quadrangles (DOQQ) from 1997 and 1998, field plot measurements of percent bare, grass, and shrub cover in each study area acquired in June and July 2003, and digital photographs of plot sites and other parts of the study areas acquired in June, July, and August 2003. Other ancillary data incorporated in this research were vegetation maps generated during prior research in this area (Muldavin et al. 1998).

Methods

Field Observations

Post-fire field observations in Baker Canyon revealed large expanses of grassland in areas that were once occupied by shrubs such as tarbush, acacia, and mortonia. This confirms the assertions made by Rogan and Yool (2001) because the most severe damage caused by the prescribed burn occurred in shrub-dominated areas. Some regeneration was seen in areas dominated by *Juniperus monosperma* and *Prosopis glandulosa*; however, many shrubs were killed completely with only snags remaining. Observations in Maverick Spring revealed only a few patchy areas of shrub mortality and resulting new grassland where high burn severity was experienced. Most of the area experienced low burn severity, and *Juniperus monosperma* and *Prosopis glandulosa* regenerated robustly. The magnitude of change in Maverick Spring was nearly negligible in terms of the spatial resolution used in this research.

Image Processing

Landsat TM and ETM+ data were projected to UTM WGS 84, and images were coregistered to each other to within less than 0.5 pixels (15 meters). Atmospheric correction was performed using a dark object subtraction technique to remove atmospheric path radiance. Standard orthorectification was omitted from this research intentionally in order to take full advantage of the built in topographic shade reduction technique in the unmixing algorithm.

The entire Landsat TM and ETM+ dataset was transformed using spectral mixture analysis (SMA), a linear unmixing algorithm that calculates a least-squares best fit for each pixel along a mixing line extending between the endmembers for each image band. Fraction images of each endmember were produced, each representing the per-pixel fractional amount of the given endmember. Prior to performing SMA on the two datasets, the image spectra were evaluated to derive candidate pure image endmembers for green vegetation (GV), non-photosynthetic vegetation (NPV), soil and photometric shade. Four image endmembers were chosen to represent the fractional land cover for the study area. In this case, GV was green grass, NPV was a mix of non-photosynthetic grasses, Soil was bright-bare soil, and shade was deep water.

Accuracy Assessment

Validation was performed using the root-mean square error (RMSE) image to calculate the fit of the model to the given endmembers and measure the spectral residual not explained by the model. In addition, DOQQs and field-collected data were used to quantify the accuracy of the fraction images. Boundaries of the test sites (chosen via stratified random sampling) were selected and identified on the DOQQs, and areas of the polygons were calculated to represent the reference data. For each polygon, the percentage of corresponding endmember fractions in the pixels was summed to indicate the area of the polygon estimated by SMA. This amount was compared to automated canopy cover measurements calculated on the DOQQs. Endmember fraction accuracy was identified as the mean of the percentage absolute difference between actual (DOQQ and field data) and modeled (TM/ETM+ fraction images) cover estimates.

Results

Spectral Mixture Analysis

An average percentage was computed for each endmember in each area for February and August to track change over time. In the February imagery, the endmember fractions did not exhibit much variability. Low precipitation amounts and resulting lack of vigor are responsible for diminished signal. In the August imagery, GV and NPV were influenced strongly by precipitation variability and associated vegetation phenological state. Soil and Shade remained relatively constant, indicating both were well modeled. Results of the comparison between August and February image sets indicated August is the best time period for this work, since the regeneration signal is peaked during the monsoonal greenup. The shade fraction was influenced significantly by topographic effects from mountainous terrain, indicating it worked well in removing topographic shade from the image. This demonstrates the suitability of the shade fraction as a substitute for standard topographic normalization procedures (O'Neal 2004). Average RMSE values fell below 0.025 ρ, with the exception of areas with dark, rhyolitic soils.

The endmember fraction trends from August in Baker Canyon exhibited a strong regeneration signal. The pattern produced by the signal displayed a divergence between post-fire GV and NPV and indicated an inverse relationship between these endmembers. The signal was lost in 1999 when an above average amount of precipitation fell in the study area, which caused a sudden, dramatic increase in the GV fraction and in turn reduced the amount of NPV.

The endmember fraction trends from August in Maverick Spring did not appear to contain a clear regeneration signal. There was a decrease in GV and an increase in NPV; however, the trends did not appear to be correlated completely since the decrease in GV was gradual and the increase in NPV was sudden; this signal was also lost in 1999. The control area endmember fraction trends in August looked very similar to those from Maverick Spring and supported observations from fieldwork in Maverick Spring of a small area experiencing significant burn. Results indicated better spatial and/or spectral resolution is needed to examine lower intensity fires with less visible damage.

Accuracy Assessment

Endmember validation was performed on the August 1997 and the February 1998 SMA fraction images, since they were closest in date to the DOQQs acquired in late 1997 and early 1998. Accuracy rates were extremely high for NPV in both dates, and within an acceptable range for GV and Soil, indicating fractional estimates for these endmembers were generally accurate. Lower accuracy for GV was attributed to different vegetation phenological states between reference data and imagery. Accuracy rates for Soil were expected to be low, due to the extreme spectral differences between the dark and bright soils. Fraction validation was not performed on the

Shade endmember due to illumination differences between reference data and imagery.

Conclusions

From an operational standpoint, this work combines a reasonable dataset and method for evaluating the effectiveness of prescribed burns and assessing regeneration pace and magnitude over time. Landsat TM and ETM+ data provide a cost effective view of the area and SMA offers a method for viewing biophysical differences due to fire. This research presents an excellent foundation for future post-fire regeneration monitoring and offers encouraging contributions to Madrean ecosystems research.

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Evaluation of Post-Wildfire Runoff and Erosion on Semiarid Ecological Sites

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Abstract—*Field studies are being conducted to quantify runoff and erosion rates following wildfires in semiarid rangelands. Rainfall simulator experiments were conducted on two grassland sites and one oak woodland site in Southern Arizona immediately following wildfires in 2002 and 2003. The experiments applied a range of rainfall intensities between 50 and 180 mm/h. Infiltration, runoff, and erosion rates were measured for each application rate. The post wildfire runoff and erosion responses are much higher on the oak woodland site and show much more variability than the responses from the two grassland sites. The results from this and other field studies will be used to determine model input parameters for a post-wildfire erosion risk tool.*

Introduction

Land managers and Burned Area Emergency Rehabilitation (BAER) teams need to be able to quickly assess the effects of wildfires on runoff and erosion processes on semiarid rangelands to determine the potential on and offsite risks. However, post wildfire runoff and erosion rates on semiarid rangeland ecological sites are not well known. Currently in southeastern Arizona, peak runoff and erosion rates following a rangeland fire are typically estimated by the USFS using TR55 (USDA-NRCS 1986) and Universal Soil Loss Equation (ULSE) (Wischmeier 1959). Although these methods are robust, they may not be applicable in the Southwest where high intensity thunderstorm rainfall dominates the runoff and erosion processes. Both these methods have uncertainties in parameter estimation and questions regarding their applicability to semiarid rangelands.

Field experiments using a variable intensity rainfall simulator are being conducted immediately following wildfires to quantify post-wildfire runoff and erosion rates over a two year period to monitor the recovery. This paper presents post-wildfire results from three Natural Resource Conservation Service (NRCS) Ecological Sites. In April 2002, the Ryan Fire burned two grassland sites, a Loamy Upland Ecological Site (Post Canyon) and a Limey Slopes Ecological Site (East Mesa) on the Audubon Research Ranch near Elgin, Arizona. An oak woodland site (A-Bar), dominated by manzanita, burned in May 2003 as a result of the A-Bar fire near the San Rafael Valley. This site is also mapped as a Loamy Upland Ecological Site.

Methods

The rainfall simulator experiments were conducted immediately following the fires and before the onset of the summer monsoons. The Walnut Gulch Rainfall Simulator, an oscillating boom, variable intensity rainfall simulator (Paige et al. 2003a) was used to apply a range of rainfall intensities (50 to 180 mm/h) on 2 m by 6 m plots installed at the three sites. Two plots were installed at the grassland sites on "uniform" hillslopes. Four plots were installed at the A-Bar site—two on shrub interspace areas and two on interspace (no shrub mounds) areas. All plots had a dry run, 60 mm/h for 45 minutes, at initial soil moisture conditions followed by a wet run one hour after the cessation of runoff from the dry run. For the wet run, a sequence of application rates from 25 to 177 mm/hr in increasing increments was used. The application rates were changed after runoff had reached steady state for at least five minutes. Runoff was measured at the down slope outlet of the plot using a pressure depth gage attached to a pre-calibrated flume. Sediment samples were taken during the runs using grab samples, dried, and weighed to compute sediment concentrations. Plot cover characteristics, canopy and ground, were measured at 400 points per plot using the point intercept method.

Results and Discussion

Results from the rainfall simulator experiments were analyzed using data collected from the wet runs. Ratios were used to account for the different amounts of water applied on the plots. The runoff ratio, the total runoff (Q) divided by the total amount of water applied (I), was used to quantify the differences in runoff. The sediment yield ratio was computed as the total sediment yield (SY) divided by the total runoff (Q) amount times the plot slope (So) to account for the range of slopes (8-15%) at the sites. The total amount of applied rainfall and the runoff and erosion measurements from the wet runs are presented in table 1 along with the runoff and sediment yield ratios. A comparison between runoff and sediment yield

Table 1—Total rainfall (I), runoff (Q), and sediment (SY) amounts and runoff (Q/I) and sediment yield (SY/Q S_0) ratios for the wet runs.

Site	Plot	I mm	Q mm	SY T/ha	Q/I	SY/QSo T/ha/mm
East Mesa	EM2	85	58	6.50	0.69	0.74
	EM3	106	52	5.58	0.50	0.89
Average:					0.59	0.81
Post Canyon	PC1	94	48	2.53	0.50	0.66
	PC2	94	58	3.21	0.62	0.61
Average:					0.56	0.64
A-Bar	AB1	64	40	16.43	0.63	3.98
	AB2	84	62	16.11	0.74	2.84
	AB3	90	65	2.11	0.72	0.40
	AB4	84	68	4.42	0.81	0.66
Average:					0.72	1.97

ratios from the burned grassland ecological sites with similar unburned ecological sites showed increases in runoff from 5 to 74% and significant increases in erosion (399 to 2,200%) on the burned sites (Paige et al. 2003b). The results from the oak woodland site are much greater than those from the burned grassland sites, especially for the sediment yield (table 1). The runoff ratio from the A-Bar site is 18 to 22% greater than the two grassland sites, and the sediment yield is 58 to 68% higher. There is more variability in the runoff results from East Mesa and Post Canyon (22 and 15%) than for the A-Bar site (10%). However, there is much greater variability in the erosion (88%) from the A-Bar site than the East Mesa and Post Canyons Sites (13 and 5%).

Comparing the results from the A-Bar site, the sediment discharge rate as a function of runoff rate is much higher on plots 1 and 2 (figure 1). Concentrated flow was observed on plots 1 and 2, the shrub interspace plots, at the higher intensities. Multiple flow paths developed on plot 1, while plot 2 developed a single flow path down the center of the plot. Plots 3 and 4 displayed uniform sheet flow similar to the flow observed on the burned grassland sites.

Differences in the runoff and erosion responses for the full range of rainfall intensities from the three burned sites are illustrated in figure 2. The responses for the East Mesa and Post Canyon grassland sites show strong relationships between measured runoff and sediment discharge rates with R^2 values of 0.99 and 0.95, respectively. The runoff and erosion responses from the A-Bar oak woodland site show much more variability and a much greater range in sediment discharge rates for similar runoff rates. However, the response from plots 3 and 4 from the A-Bar site, which did not have shrub mounds, is very similar to Post Canyon grassland sites. Both sites are mapped as a Loamy Upland Ecological Site. This preliminary evaluation of the data from three wildfire burn sites indicates (1) that there is a range of runoff and erosion responses that can occur due to variable intensity rainfall and (2) that there appear to be significant differences between oak woodland and grassland responses immediately following wildfires.

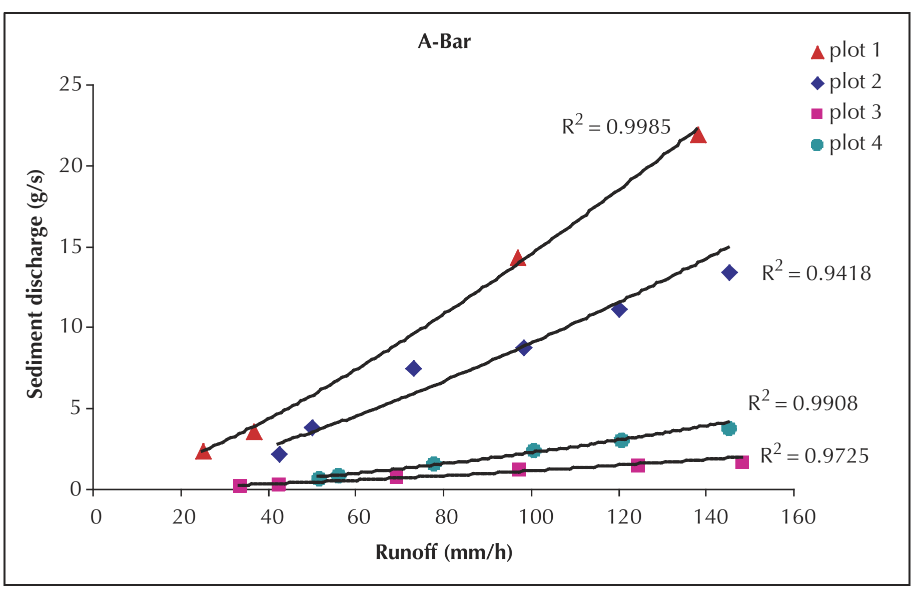

Figure 1—Comparison of sediment discharge rate as a function of runoff rate from the four plots at the A-Bar site.

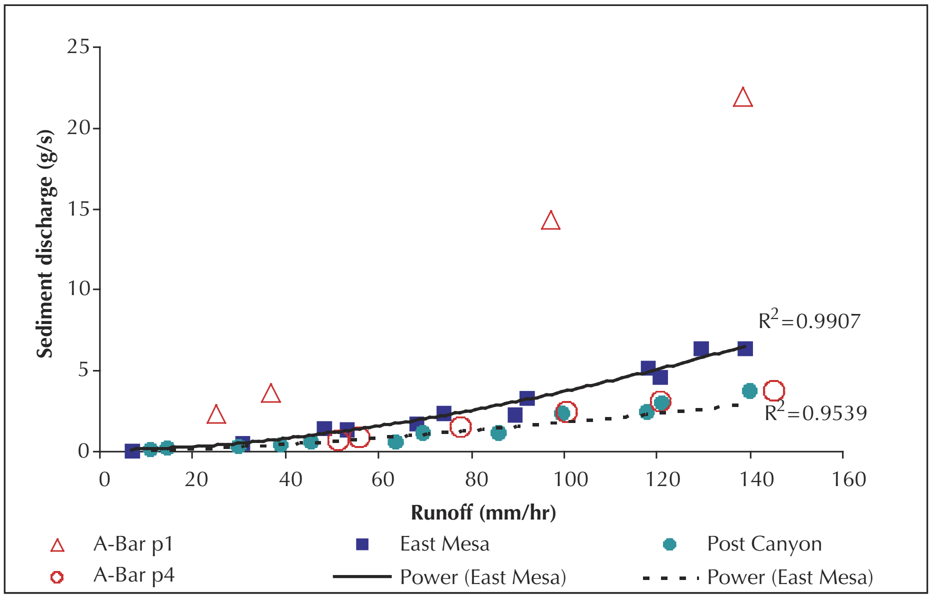

Figure 2—Sediment discharge rate as a function of runoff rate from the East Mesa and Post Canyon grassland sites and plots 1 and 4 from the A-Bar site. The erosion response from plot 4 (A-Bar) is very similar to the response from the Post Canyon Site.

Next Step

The post-wildfire runoff and erosion measurements from this and future field studies will be used to develop parameters for semiarid rangelands that can be used in Disturbed WEPP (Elliot et al. 2000) to evaluate runoff and erosion risks following wildfires. The model is being implemented within an erosion risk management tool (ERMiT http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl) in the Great Basin region (Elliot et al. 2001). The model is easy to use and parameterize and has an extensive database for the soil-vegetation complexes considered in the Great Basin. WEPP has the potential to be more applicable than TR55 and USLE to conditions in the Southwest because the hydrology and erosion components account for rainfall intensity and spatial characteristics of overland flow.

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Vegetation-Environment Relations of the Chisos Mountains, Big Bend National Park, Texas

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Abstract—*The Sky Island Archipelagos of the Sierra Madre Oriental and Occidental contain a unique array of endemic flora and fauna. Plant species composition in these elevationally restricted forests is thought to vary in relation to environmental gradients. This study quantifies plant population abundance and spatial distribution patterns in pine-oak woodlands of Big Bend National Park using cluster analysis and non-metric multidimensional scaling. Results from this study indicate that vegetation abundance and spatial distribution patterns are correlated with environmental gradients of potential soil moisture and elevation. Xerophytic tree species dominate lower elevations, while mesophytic trees are found on wetter, high elevation sites.*

Introduction

Species-environment relationships are important determinants of the abundance and spatial distribution of vegetation. Environmental variables including soil moisture, topographic position, slope, elevation, and aspect are important controls on plant population structure at both local and landscape-scales (Whittaker 1956; Christensen and Peet 1984; Allen et al. 1991; Camp et al. 1997). Forest stand density, basal area, and species composition vary according to these environmental gradients (Taylor and Skinner 1998; Taylor and Solem 2001). Northern exposures are often more mesic than southern expositions, resulting in potentially divergent species composition. Likewise, high elevation sites have more moderate site conditions than low elevation sites due to adiabatic cooling, which may result in differences between high and low elevation species composition.

Different species may be adapted to specific site conditions or elevations, and can hold a site by out competing other, less adapted species (Oliver and Larsen 1996; Ashton et al. 1995; Gunatilleke et al. 1998; Singhakumara 2000). Plants that dominate lower elevations in the Southwest are generally more drought tolerant than higher elevation species (Padien and Lajtha 1992; Linton et al. 1998). Differences in the physiological tolerance of plants species drought strongly influence plant distribution patterns across landscapes of the Southwestern United States.

This study investigates relationships between vegetation abundance and distribution patterns, elevation, and topography in the Madrean pine-oak woodlands in the Chisos Mountains of Big Bend National Park, Texas. We use a macroecological approach (sensu Brown 1995) to identify the key factors regulating forest ecosystem structure and function at the plot and landscape scales.

Study Site Description

The Chisos Mountains of Big Bend National Park (BBNP) are located in the Trans-Pecos region of western Texas (figure 1). Forests in BBNP are dominated by pinyon-juniper-oak and mixed conifer woodland. Dominant species include *Pinus cembroides*, *Juniperus deppeana*, *Juniperus flaccida*, *Juniperus pinchotii*, *Quercus grisea*, *Quercus gravesii*, and *Quercus emoryi*. Chihuahuan Desert grasslands bound the site at lower elevations, while relict montane conifer forests form the upper elevational boundary (VanDevender and Spaulding 1979).

The climate is arid, characterized by cool winters and warm summers. Annual precipitation ranges from <200 to >480 mm and is distributed bi-modally (Adams and Comrie 1997). Climate influences fire seasonality in the Southwest and Northern Mexico, with most fires occurring just prior to summer monsoons (Swetnam and Betancourt 1992, 1998). This fore-summer period is usually very dry, with low humidity and high temperatures that reduce live and dead fuel moisture levels. Fires also occur during mid-summer monsoons, as a result of lightning ignitions during rainstorms.

Methods

One hundred sixty one plots in BBNP were stratified by forest cover type, slope aspect, and elevation based on topographic maps, aerial photographs, and field reconnaissance (figure 2). A 250-meter grid was placed over the Chisos Mountains, and plots were systematically located at the junctions of grid points. The location of each plot was recorded with a GPS, and a series of nested plots were used to sample vegetation. Overstory vegetation was sampled in circular 10 m radius plots. Percent cover of shrubs, grass, and bare soil was recorded in six classes (<1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-100%), and dominant shrub and grass species were recorded. Species, condition (live or standing dead), canopy class (suppressed, intermediate, co-dominant or dominant), height, and diameter at breast height (dbh) were recorded for all trees >5 cm dbh. Seedlings and sprouts were tallied in 5 m radius plots, and seedling heights were measured. Environmental variables including elevation, aspect, slope (in degrees), slope configuration (concave or convex), and topographic position were also measured

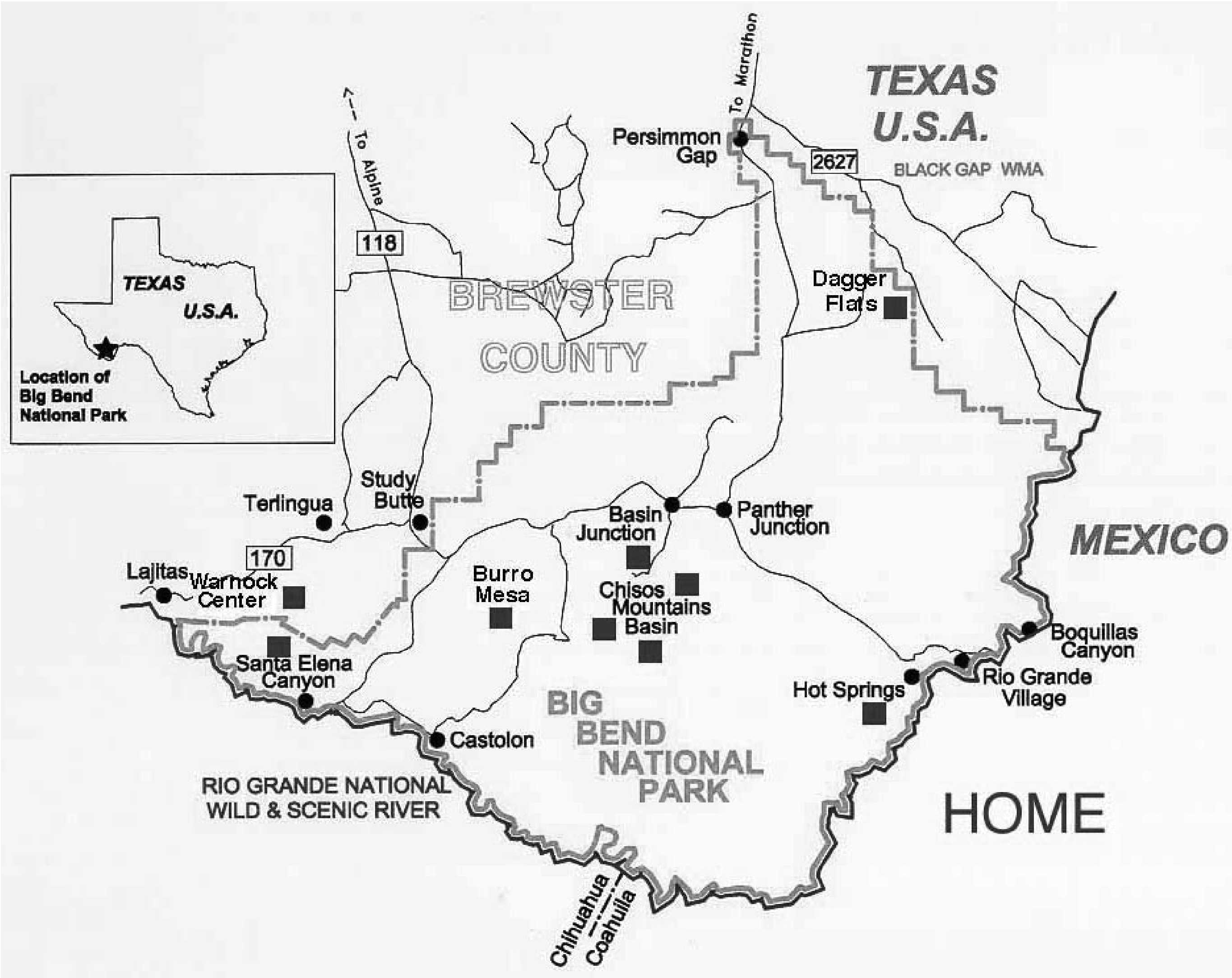

Figure 1—Map of Big Bend National Park, Brewster County, Texas.

at each plot. Slope contour, aspect, topographic position, and slope were used to generate a topographic relative moisture index (TRMI) that estimated potential soil moisture (Parker 1982). Aspect was used to calculate a heat load index using the formula $(1-\cos(\theta - 45))/2$ where θ = aspect in degrees east of true north (McCune and Grace 2002).

Species Importance Values (IV) were calculated as the sum of relative basal area and relative density for each plot. We used Cluster Analysis to identify forest compositional groups. Clustering was performed using relative Euclidean distances and Ward's method. We used Species Indicator Analysis to determine the number of clusters to retain. Differences between species composition groups were determined using Multi-Response Permutation Procedures (MRPP). Separation between cluster groups was assessed, and environmental gradient length was determined using Non-Metric Multidimensional Scaling (NMS). Pearson's correlation coefficients were calculated between species axis scores and environmental variables to determine the relationship between species axis scores and the environmental variables.

Results

Six species composition groups were determined from Cluster Analysis and Indicator Species Analysis (figure 3; table 1). Species composition groups were significantly different ($p < 0.001$) from each other according to Multiple Response Permutation Tests. *Juniperus deppeana-Pinus cembroides-Quercus grisea* stands are dominated by alligator juniper (*J. deppeana*), and contained pinyon pine (*Pinus cembroides*), gray oak (*Q. grisea*) associates. These stands dominate middle to high elevation sites of intermediate soil moisture. *Quercus grisea-Pinus cembroides-Juniperus deppeana* stands overlap in their distribution with *Juniperus deppeana-Pinus cembroides-Quercus grisea*, but are dominated by gray oak, and have pinyon pine and alligator juniper associates. Mesic woodland stands exist at higher elevations on moist sites, and are dominated by *Quercus gravesii* and *Cupressus arizonica.* They contain *Arubutus xalapensis* and *Acer grandidentatum* as understory associates. Other mesic species including *Pinus ponderosa*, *Pseudotsuga menzesii*, and *Quercus muhlenbergii*

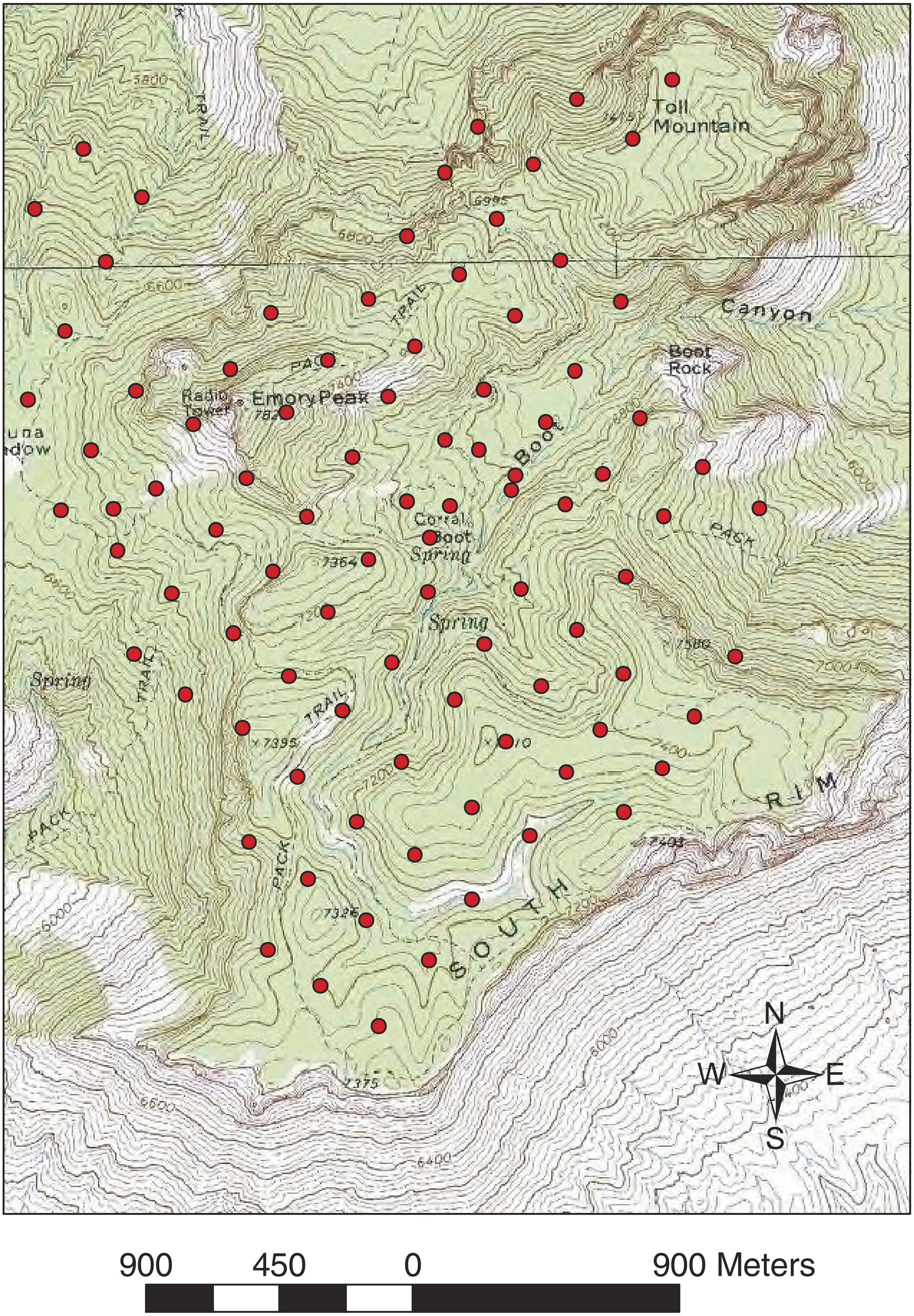

Figure 2—Sample plot locations in Big Bend National Park.

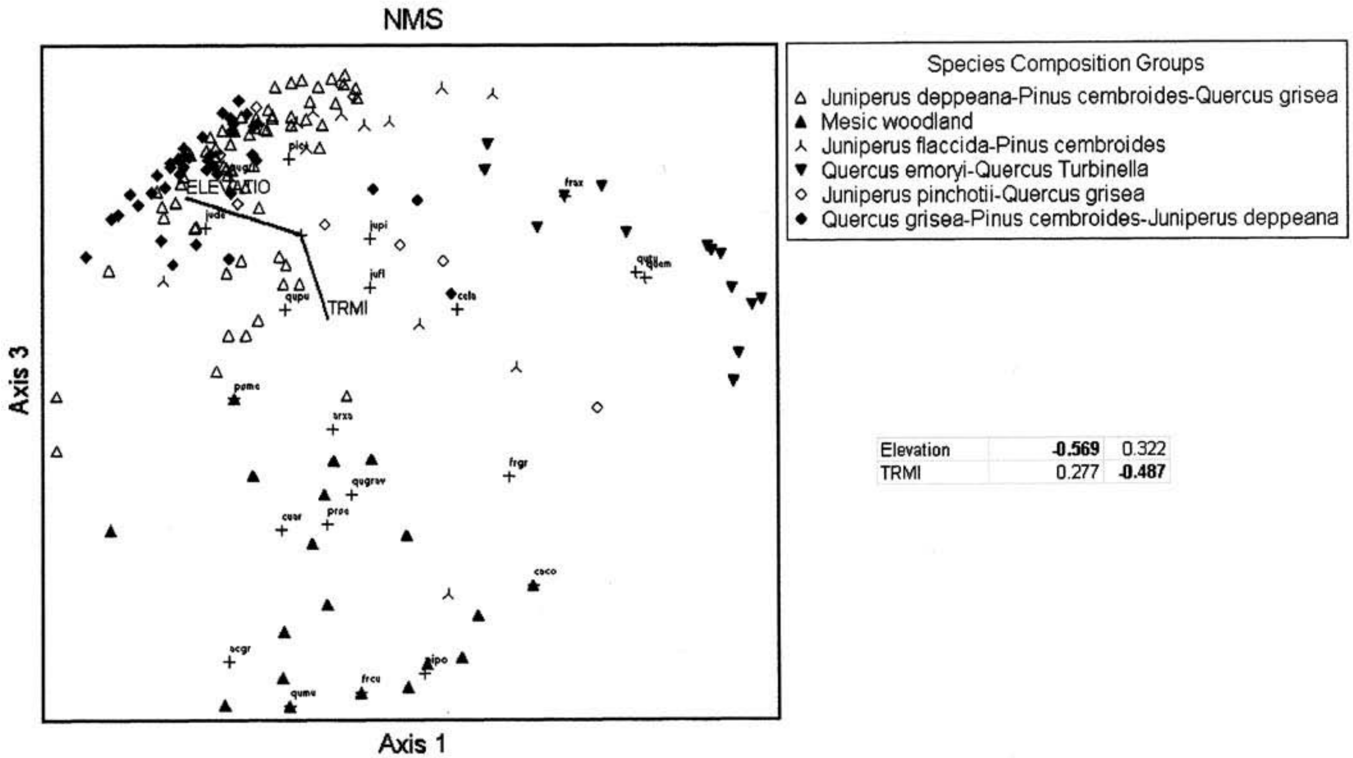

Figure 3—Nonmetric Muldimensional Scaling of Species importance values (n = 161) from Big Bend National Park. Species composition groups are derived from Cluster Analysis. The Nonmetric Multidimensional Scaling solution was achieved using a Detrended Correspondence Analysis starting configuration, relative Euclidean Distances, and a three-axis solution.

are also found on restricted sites within this group. *Juniperus flaccida-Pinus cembroides* stands exist across a range of elevations and potential soil moistures. Weeping juniper (*J. flaccida*) is the dominant tree in this group, though pinyon pine is also a significant indicator species in this stand type. *Juniperus pinchotii-Quercus grisea* stands occupy middle elevation sites of low potential soil moisture. These stands exist at low elevations, and also within the higher elevation Blue Creek burn area where a high severity fire burned in 1988. Within the burn, there are large amounts of dead and downed pinyon pine that died in the Blue Creek Fire (personal observation). *Quercus emoryi-Quercus turbinella* stands are found on low elevation, dry sites with pinyon pine as a minor associate.

The Non-metric Multidimensional Scaling of species importance values separated plots according to species composition, elevation, and potential soil moisture (figure 3; table 2). Axis 1 separated alligator juniper and gray oak from weeping juniper and Emory oak (*Q. emoryi*). Alligator juniper and gray oak are found on more mesic, high elevation sites, while the other two species exist at lower elevations on drier sites. Axis 2 separated alligator juniper and pinyon pine from red berry juniper (*J. pinchotii*) and gray oak. Gray oak and red berry juniper are found on drier sites than alligator juniper and gray oak. Axis 3 separated pinyon pine and gray oak from mesic tree species with high amounts of coarse woody debris. Pinyon pine and gray oak grow on more extreme sites than the species that are negatively correlated with this axis. Species negatively correlated with axis 3 exist in closed canopy forests that have greater amounts of overall biomass and downed coarse woody debris.

Conclusions

Tree species abundance and distribution patterns in the Chisos Mountains of Big Bend National Park are correlated with elevation and potential soil moisture gradients. Aspect and heat load did not significantly predict species abundance or composition. These patterns correspond to the ecophysiological tolerance of tree species to drought (Padien and Lajtha 1992; Linton et al. 1998). Species tolerant of drought dominate lower elevations, while more mesophytic species dominate moist, high elevation sites. Studies on tree species water relations in BBNP could provide a mechanistic explanation for the observed abundance and distribution patterns of vegetation in BBNP.

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Table 1—Results from Indicator Species analysis. * indicates significance of Monte Carlo permutation tests (* = $p < 0.01$, ** = $p < 0.001$). Significant indicator species were used to name species composition groups from Cluster Analysis.

	Cluster Group					
Species	**1**	**2**	**3**	**4**	**5**	**6**
*Acer grandidentata***	0	**32**	0	0	0	0
*Arbutus xalapensis***	1	**33**	0	0	0	0
*Cupressus arizonica**	0	**25**	0	0	0	0
Fraxinus pensylvanica	0	0	0	7	0	0
Fraxinus greggi	0	6	0	2	0	0
*Juniperus deppeana***	**44**	1	2	1	0	**16**
*Juniperus flaccida***	1	7	**64**	3	0	6
*Juniperus pinchotii***	0	0	0	0	**94**	0
*Pinus cembroides***	**34**	2	**20**	10	4	**15**
*Pinus ponderosa**	0	**16**	0	0	0	0
Prunus serotina	0	9	0	0	0	0
Pseudotsuga menzesii	0	5	0	0	0	0
*Quercus emoryi***	0	1	0	**87**	0	0
*Quercus gravesii***	1	**75**	2	2	0	1
*Quercus grisea***	**11**	2	9	0	**24**	**39**
Quercus muhlenbergii	0	5	0	0	0	0
Quercus pungens	0	2	4	0	0	0
*Quercus turbinella***	0	1	0	**93**	0	1

Table 2—Pearson product moment correlation (n = 161) of species importance values, TRMI and elevation for axes 1, 2, and 3 of NMS for Big Bend National Park.

Species	**Axis 1**	**Axis 2**	**Axis 3**
Acer grandidentata	-0.078	0.035	**-0.428**
Arbutus xalapensis	0.059	-0.102	**-0.353**
Cupressus arizonica	-0.026	-0.227	**-0.364**
Juniperus deppeana	**-0.493**	**0.446**	0.031
Juniperus flaccida	0.245	0.125	-0.177
Juniperus pinchotii	0.129	**-0.418**	-0.007
Pinus cembroides	-0.112	0.614	**0.677**
Pinus ponderosa	0.109	-0.026	**-0.364**
Prunus serotina	0.024	-0.042	-0.254
Pseudotsuga menzeisii	-0.037	-0.093	-0.083
Quercus emoryi	**0.771**	-0.029	-0.089
Quercus gravesii	0.161	-0.065	**-0.784**
Quercus grisea	**-0.552**	**-0.641**	**0.393**
Quercus muhlenbergii	-0.007	-0.011	-0.239
Quercus pungens	-0.015	-0.203	-0.066
Quercus turbinella	**0.782**	-0.014	-0.081
Elevation	**-0.569**	0.224	0.322
TRMI	0.277	-0.265	**-0.487**

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Management of Thinned Emory Oak Coppice for Multiple Resource Benefits

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Abstract—*Managers are increasingly moving toward an ecosystem-based, multiple-use approach in managing Emory oak woodlands in the Southwestern United States. Often of particular interest is managing the coppice that evolves from earlier fuelwood harvesting activities. Emory oak (*Quercus emoryi*) is a prolific sprouting species and, as a consequence, post-harvesting stands can support copious coppice on the cut rootstocks. Thinning the coppice to obtain a desired density of multiple benefits is one management option. A decision matrix based on resource proxies derived from earlier studies has been developed to assist managers in prescribing coppice thinning treatments to optimize one or more resource benefits.*

Introduction

Options for thinning coppice in Emory oak (*Quercus emoryi*) stands following earlier fuelwood harvesting can be oriented toward minimizing on-site water losses through transpiration, maximizing fuelwood production, sustaining livestock production, maintaining structural diversity for wildlife habitats, or optimal combinations of these options. Because of the ecosystem-based, multiple-use orientation of managing Emory oak stands in the Madrean Archipelago, the latter option is a common management goal. A decision matrix based on resource proxies derived from earlier studies is presented to assist managers in attaining this goal.

Resource Proxies

Water loss through transpiration by thinned coppice has been estimated by Ffolliott and others (2003). Knowledge of these transpiration rates is a key to selecting a coppice thinning treatment that minimizes water loss on a site and, therefore, is the proxy for water. Average daily transpiration rates for thinned Emory oak rootstocks ranged from lowest to highest in thinned clumps of one, two, and three sprouts, respectively, while unthinned rootstocks transpired the highest amount of water.

Growth and volume of Emory oak coppice is the proxy for wood. When the management objective focuses on utilizing the coppice for fuelwood and a decision must be made to thin the coppice resulting from earlier harvesting activities, thinning to retain one residual sprout is recommended (Farah and others 2003). Growth and volume are concentrated in the single stem, and, as a consequence, that stem will attain a desired volume for fuelwood in a shorter time period. The next "best options" are thinning the coppice to two sprouts and then to three sprouts. Growth and volume are comparatively minimal in the absence of thinning.

The proxy for livestock production is annual herbage production. Earlier studies suggest that increasing densities of Emory oak overstories does not reduce the production of herbaceous plants (Gottfried and Ffolliott 2002). It has been assumed, therefore, that the thinning of Emory oak coppice will have little effect on herbage production.

The abundance of foliage in the tree crowns is the proxy for wildlife habitats. A decision not to thin Emory oak coppice might be the preferred management option when maintaining the structural diversity of wildlife habitats is the management objective. Harvesting removes the taller trees that provide a greater number of habitat niches for non-game bird species and other wildlife than shorter trees (Sharman and Ffolliott 1992). Thinning also eliminates much of the structural diversity by removing many of the intermediate trees. Ordering of the options to maintain structure diversity of wildlife habitats from most to least preferred is no thinning treatment, thinning to three residual sprouts, thinning to two sprouts, and thinning to one sprout.

Incorporating the resource proxies into a decision matrix for selecting thinning options for Emory oak coppice results in table 1. While other management options are likely, those displayed are the basis for solving the decision-making problem illustrated below.

Information on the cost of thinning Emory oak stands following earlier fuelwood harvesting is not available. This cost is assumed less than the multiple resource benefits that can be obtain by thinning and, therefore, has not considered a decision variable in this problem. Reliable information on thinning costs will be necessary if managing this coppice by thinning becomes an operational option and, depending on its magnitude, another decision criterion.

Decision-Making Problem

A manager is faced with the decision-making task of obtaining a fair and equitable solution to problems of integrated resource management. This task can be viewed in the sequential steps of problem recognition, specification of strategies, specification of decision criterion or criteria, and selection of the optimum management strategy. To illustrate this process in the thinning of Emory oak coppice, it is assumed that the problem confronted is minimizing water loss on a site while optimizing fuelwood production, livestock production, and structural diversity of wildlife habitats. Strategies available for solving this problem are thinning the coppice to one, two, or three of the dominant sprouts or retaining the coppice as it evolves naturally following a fuelwood harvest. The decision criterion is to optimize the water, wood, livestock, and wildlife benefits of a selected thinning practice. Methods available to solve this problem include the use of a simplistic approach (which is used here) or more rigorous optimization approaches.

The simplistic approach requires knowledge of the "values" that stakeholders place on the resources considered. There are two cases to consider in applying this approach. All of the resources have equal benefit to stakeholders in the first case, while stakeholders place preferential values on the resources in the second case. As these latter values reflect the "collective biases" of the stakeholders; the stakeholders with "decision-making advantages" will dominate when collective bargaining becomes necessary.

Solution to Problem

The decision outcome for this problem is based on all of the resources being weighed equally. This being the case, thinning rootstocks of Emory oak coppice to one residual sprout is the best compromise (table 1). Water losses to the transpiration process are minimized and the growth and yield of the residual sprout are maximized by thinning to one residual sprout. Herbage production is likely not to change regardless of thinning treatment and, therefore, is not a decision variable. While the structural diversity of wildlife habitats is reduced by this thinning treatment relative to the other options, the need for non-game bird habitat niches might still be met at "some acceptable level" with this thinning prescription. Solution to this problem involved making a decision among ordinal rankings of benefits, and, therefore, managers should be aware of "interpretative guidelines" commonly associated with decision-making through the use of ordinal rankings of benefits (Kenney and Raiffa 1976).

Conclusions

Knowledge of how hydrological and ecosystem processes are affected by thinning Emory oak coppice is necessary in selecting a thinning treatment that meets ecosystem-based, multiple-use management objectives. The information presented in this paper can contribute to this management. The decision matrix should be useful to managers planning to optimize water, wood, livestock, and wildlife habitat benefits. However, incorporating other resources (settings for recreational opportunities, etc.) into the decision matrix is necessary before truly holistic stewardship is possible.

Table 1—A decision matrix for selecting thinning options for Emory oak coppice.

	Alternative thinning treatments[a]			
Criteria	**One**	**Two**	**Three**	**No Thinning**
Water	4	3	2	1
Wood	4	3	2	1
Livestock	-	-	-	-
Wildlife	1	2	3	4

[a] Ranking: 4 = most preferred; 1 = least preferred.

Acknowledgment

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Vascular Plants and Vertebrate Inventories in Sonoran Desert National Parks

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Abstract—*Biological inventories are important for natural resource management and interpretation, and can form a foundation for long-term monitoring programs. We inventoried vascular plants and vertebrates in nine National Parks in southern Arizona and western New Mexico from 2000 to 2004 using repeatable designs, commonly accepted methods, and standardized protocols. At Tumacácori National Historical Park alone, we recorded 378 species of plants and 213 species of vertebrates, including a total of 273 species that were previously undocumented in the park. Data collected in all nine parks will be used in developing monitoring plans for National Parks in the Madrean Archipelago, and for the Sonoran Desert ecoregional monitoring effort.*

Introduction

Species inventories can provide a baseline for monitoring biological resources and a foundation for species checklists. Preventing species loss is a fundamental goal of many land-management agencies (NPS 2000), yet losses do occur (e.g., Drost and Fellers 1996; Newmark 1995). Managers often lack species inventories that could be used to identify potential losses and indicate the need for further research or management action to prevent further loss (NPS 1992). In recognition of a general lack of natural resource information, the National park Service initiated the Vital Signs Inventory and Monitoring Program to increase scientific research in National Parks and detect long-term changes in biological or physical resources (NPS 1992). Knowledge of which species are present, particularly sensitive species and where they occur, is critical for making management decisions such as locating new facilities and developing fire management plans.

We inventoried vascular plants and vertebrates in nine National Parks in Arizona and western New Mexico from 2000 to 2004 (table 1). Our objectives were to: (1) compile historical data; (2) complete field surveys using standardized methods and repeatable study designs to document at least 90% of plant and vertebrate species present; (3) provide park managers with products that are useful for interpretation and management; and (4) provide data to inform National Park Service and regional monitoring initiatives.

In this paper we describe sampling designs, field methods, and results from Tumacácori National Historical Park (NHP), the first park for which we have completed inventories. Tumacácori NHP is representative of several small National Parks in the Madrean Archipelago region that were created to protect cultural resources but which also possess significant natural resources that had not been inventoried.

Methods

Sampling Design

We search for species using both quantitative, plot-based surveys (e.g., trapping grids for nocturnal rodents) and a form of unbounded, visual and auditory encounter surveys (Crump and Scott 1994: 84). Plot-based surveys are repeatable and allowed us to estimate relative abundance or density of all species we detected. We used a combination of random and non-random spatial sampling designs for plot-based surveys. Our visual and auditory encounter surveys were not plot-based and allowed field crews to search areas that they thought, based on their experience, would add species to our list. We recorded UTM coordinates for all survey plots and for all animals that we observed.

Field Methods

Primary field methods that we used at Tumacácori NHP are listed below; see Powell et al. (2004) for a detailed description:

- Plants: modular plots, random walking surveys/incidental sightings
- Fish: electrofishing, dip netting
- Amphibians and reptiles: time-area constrained search, drift-fence pitfall arrays, unbounded surveys
- Birds: variable-circular plots (point counts), taped-playback, line transects
- Mammals: Sherman live traps set in grids, pitfall traps, infrared-triggered cameras

Assessing Inventory Completeness

We used a variety of methods to assess our goal of 90% species detection, including comparison of our results to sources

Table 1—Summary of vascular plant and vertebrate inventories in National Park Service Units in Arizona (AZ) and New Mexico (NM), 2000-2004.

		Taxon group					
Park	**State**	**Plants**	**Fish**	**Amphibians**	**Reptiles**	**Birds**	**Mammals**
Casa Grande National Monument	AZ	X		X	X	X	X
Chiricahua National Monument	AZ	X		X	X	X	X
Fort Bowie National Historic Site	AZ	X				X	X
Gilla Cliff Dwellings National Monument	NM	X		X	X	X	X
Saguaro National Park	AZ	X		X	X	X	X
Tonto National Monument	AZ	X		X	X	X	X
Tumacácori National Historical Park	AZ	X	X	X	X	X	X
Tuzigoot National Monument	AZ	X	X	X	X	X	X

that would predict species presence at the park. These sources included published and unpublished reports, range maps, and additional expert opinions. We also plotted results of our surveys as species-accumulation curves; asymptotic curves can indicate whether most species present have been detected (Hayek and Buzas 1997: 314-316).

Results

We recorded 378 species of plants and 213 species of vertebrates at Tumacácori NHP, including 273 species that were previously undocumented in the park. We recorded a number of notable species including six species that are protected or have conservation status under the Endangered Species Act. Of these six species, Gila topminnow (*Poeciliopsis occidentalis*), yellow-billed cuckoo (*Coccyzus americanus occidentalis*), and southwestern willow flycatcher (*Empidonax traillii trailli*), and gray hawk (*Asturina nitida maxima*) were recorded on private land adjacent to the park that had been identified as an area for possible park expansion. We also documented the second record in Arizona of muster John Henry (*Tagetes minuta*) listed as a Class A noxious weed in California (California Department of Food and Agriculture 2003). We recorded a total of 76 non-native species, many of which represent management concerns, including one species of amphibian, four species of mammals, three species of birds, and four species of fish (Powell et al. 2004).

Based on historical records, expert opinion, and examination of species-accumulation curves, we believe that we recorded all species of native fish present at Tumacácori NHP; that we likely recorded at least 90% of the plants, amphibians, breeding-season birds, and rodents; but that we recorded less than 90% of winter birds, reptiles, and other mammals (Powell et al. 2004).

Discussion

Inventory data can have immediate conservation application for land managers. Our documentation of Federally-protected species on adjacent land that had been proposed for inclusion in the park, together with the help of private land owners, supported congressional legislation expanding the park area by almost 700% to include biologically rich riparian areas. Data from the project also are being used to support the nomination of the Santa Cruz River Basin as a National Heritage Site.

Inventory data can be used to create a baseline for monitoring changes in natural resources; monitoring can provide natural resource managers with the information necessary for management decisions and conservation planning (Elzinga et al. 2001). We will use the inventory data from Tumacácori NHP and other parks to inform the Sonoran Desert Ecoregional Monitoring Framework, a multi-agency and multi-national initiative directed at monitoring a wide range of natural and human indicators across the region.

Once our inventories are complete, each park will receive reports (e.g., Powell 2004) detailing methods and results used for all surveys, species lists (species we recorded, historical records and species possibly present but not documented), recommendations for management and additional inventorying, relevant information on non-native species, maps of study sites, and hard copies of all raw data. In reports to larger parks (e.g., Saguaro National Park) we will also provide distribution maps of species of management concern. All parks will also receive databases developed for entering and storing data, protocols for collecting data, and high-quality digital photographs of some species we found in the park. Original data from this effort will be housed at the Sonoran Desert Network Office in Tucson, Arizona.

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Short-Term Effects of Fire on Sky Island Ant Communities

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Abstract—*Few studies investigating effects of fire on ant communities have been conducted worldwide, and none in the biologically diverse and fire prone region of the Sky Islands. Ant genera richness and total abundance are significantly higher in burned areas. Ant community structure changes between unburned and burned sites, implying that disturbance may influence the role of ant communities in Sky Island ecosystems.*

Introduction

Ants are known to have a significant affect on the terrestrial environment. Competing effectively with vertebrates for seed resources (Agosti et al. 2000), ants are notably responsible for the seed dispersal of 35% of all herbaceous plants. Moving the same amount of soil as earthworms in some locations, ants similarly transport plant and animal matter, and can increase the flow of 13 elements 16-98 times over areas without ants (Hölldobler and Wilson 1990). Ants are among the leading predators of other insects and small invertebrates and play an important role in regulating their populations (Hölldobler and Wilson 1990; Jeanne1979). When combined with their global distribution, these factors make ants ubiquitous and essential members of most ecosystems (Hölldobler and Wilson 1990). Likewise, disturbance plays a crucial role in the structuring of biological communities, and a study investigating the effects of disturbance on ant communities would be of interest considering the important roles ants play in ecosystems.

Fire is a common disturbance of biological communities that affects insolation, vegetation, and ground humidity level (see Hoffmann 2003 and included references). Fire changes the structure of the plant habitat and reduces living area for ants to the soil surface. Studies in Australia show a marked increase in ant species richness and abundance after fire (Andersen and Yen 1985). The effects of fire are also indirect; fire induces modifications to habitat, food supplies, and interspecific competition (Andersen and Yen 1985). To our knowledge, the effect of fire on ant communities has never been studied in the Americas or in such highly diverse habitats as the Chihuahuan Desert.

Methods

This study was conducted over two years in the high elevation Chihuahuan Desert (approximately 1,500 m) of Senora, Mexico, on the ranches of Joe and Valer Austin. We established four pairs of plots in adjacent burned and unburned habitat at the sites of two different fires (figure 1). Burned/unburned habitats were 50-100 m apart while each paired plot was at least 200 m apart. The different fires were separated by at least one kilometer. We attempted to control for plant community composition, slope, and aspect between burned and unburned habitats. Ant species richness, abundance, and diversity did not differ significantly between 3 of the 4 plots at both fire sites. Because these plots were separated by at least 200 m, our paired control and burned habitats are likely to contain similar ant species assemblages (as they were only 50-100 m apart). Ants were sampled using arrays of 6 pitfall traps (7 cm diameter Dixie cups) that were lined with flouon. Traps were partially filled with a mixture of propylene glycol, ethanol, soap, and water. Pitfall traps were set 15 m apart and kept

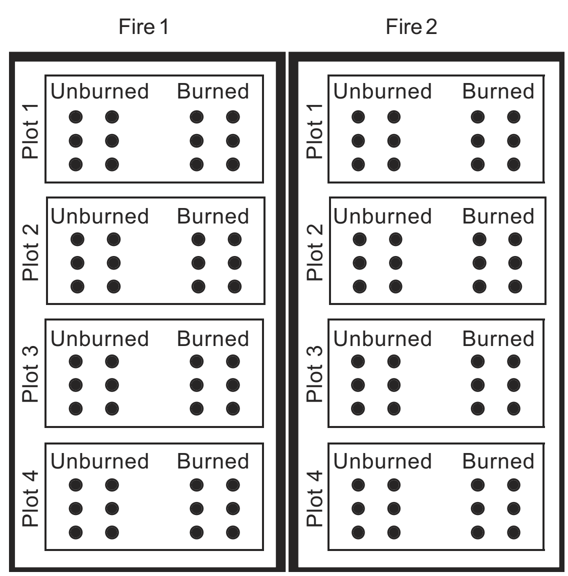

Figure 1—Experimental design.

open for five days at the beginning of the 2002 and 2003 monsoon seasons.

Measurements of vegetation height and richness within 1 m, distance to nearest shrub and tree, and coverage of nearest shrub and tree were taken at each sample point in year two. Common plant genera included: *Agave*, *Mimosa*, *Nolina, Prosopsis*, *Yucca, Quercus*, *Juniperus*, *Guterrezia*, *Opunita*, and *Alhagi* . The only vegetative parameter to differ significantly between plots was distance to nearest tree, indicating that any vegetative differences seen between burned and unburned habitats within plots is likely due to effects of fire, and not to underlying variation in the vegetative community.All insects were removed from pitfalls using salt-water extraction (according to Lattke 2000) and sorted to genus. Ant genera were then assigned to functional groups that have ecological significance in ant communities. Our functional groups were based on Andersen's (2000) assignments that classify ants based on a combination of dominance level, response to stress, and tolerance to disturbance. Differences in generic richness, abundance, and diversity (H') between treatments were analyzed using ANOVA.

Results

Overall ant genera richness (figure 2a) and total abundance (figure 2b) were significantly higher in burned plots than in unburned plots in the first year, but not in the second year (Treatment X Year interaction-richness: F = 7.16, P < 0.01; abundance: F = 3.871, P = 0.051). This pattern indicates recovery of overall ant community richness and abundance to unburned levels within one year after burning, and is similar to patterns observed in other studies investigating the effects on fire on ant communities in Australia (Hoffmann and Andersen 2003).

The relative abundance of specialist herbivores was significantly higher in burned habitats ($F_{1,126}$ = 4.055, P = 0.046), while the relative abundances of both generalist myrmicinae and subordinate camponotini were lower in burned habitats, but non-significantly (Gen-$F_{1,126}$ = 2.960, P= 0.088, Sub-$F_{1,126}$ = 1.859, P = 0.175) (figure 3). Hot climate specialists showed no significant difference between burned and unburned habitats in the first year, but were more abundant in burned plots in the second year (Treatment by year interaction: $F_{1,126}$ = 4.029, P = 0.047).

Three of the six vegetation parameters showed differences between burned and unburned habitat in year two. Distance to the nearest shrub was significantly higher in burned habitats (figure 4a: F = 4.657, P < 0.05), while tree coverage was significantly lower in burned habitats (4b: F = 4.979, P < 0.05). Vegetation height within 1 m of traps was also lower in burned habitats, but this difference was not significant (4c: F = 2.971, P = 0.091). In general burned habitats exhibited lower vegetation density, coverage, and height.

Discussion

Initial increases in the overall richness and abundance of ant communities after fire have so far been explained by the role of fire in reducing habitat complexity (see Hoffmann and Andersen 2003 and included references). Consumption of vegetation and litter by fire effectively concentrates all foraging into two dimensions and drastically decreases surface area in the habitat. Simplifying the habitat in this way is expected to result in increased trapping success (abundance) and increased likelihood of trapping rare species. As a result, ant community recovery to pre-fire or control levels is understood to be a function of vegetative recovery.

However, multiple vegetative parameters show differences between burned and unburned habitats in the second year in our study, and the vegetative community was not observed to have recovered significantly as a whole (Wilkinson, personal observation). Recovery of the ant community to unburned levels in the second year is independent of vegetative recovery in our study. Therefore, it is unlikely that greater ant community richness and abundance in newly burned habitats (year 1) is due solely to decreases in habitat complexity caused by fire. Unmeasured resource pulses after fire may be partially responsible for the observed trends.

Although overall richness and abundance of burned habitats return to unburned levels by year two, functional group composition, and therefore ant community structure, has changed. These structural changes may have implications for the roles that ant communities play in Chihuahuan Desert ecosystems.

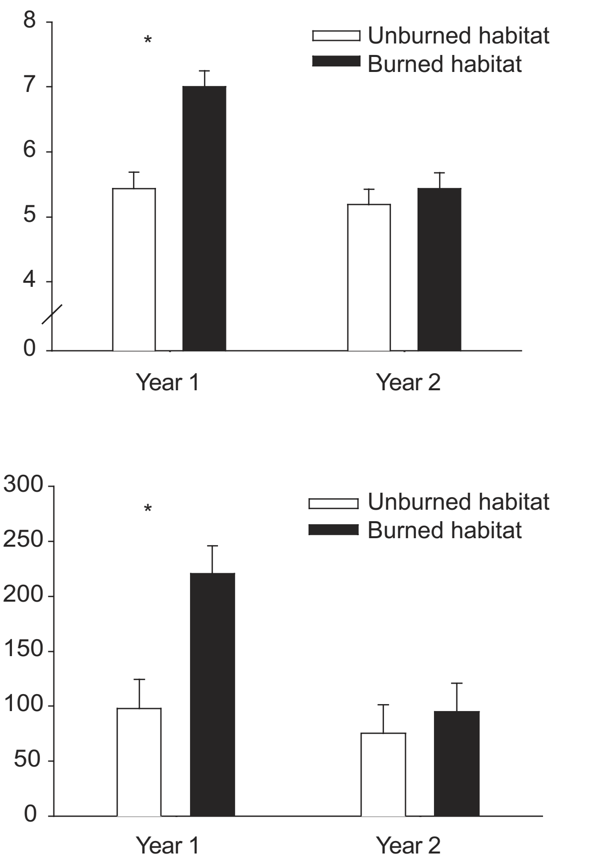

Figure 2—The effect of fire on (a) generic richness and (b) total abundance across study years.

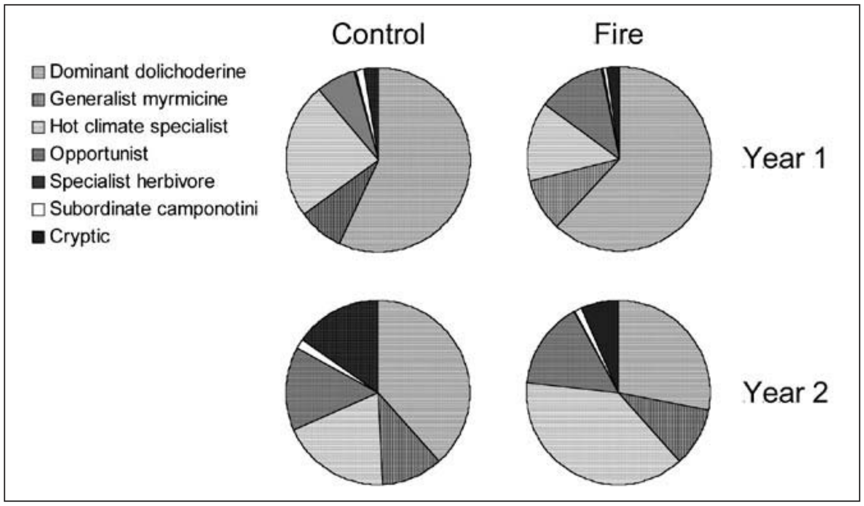

Figure 3—Relative abundance of dominant dolichoderines, generalist myrmicines, hot climate specialists, opportunists, specialist herbivores, subordinate camponotini, and cryptic species in control and fire habitats over both study years.

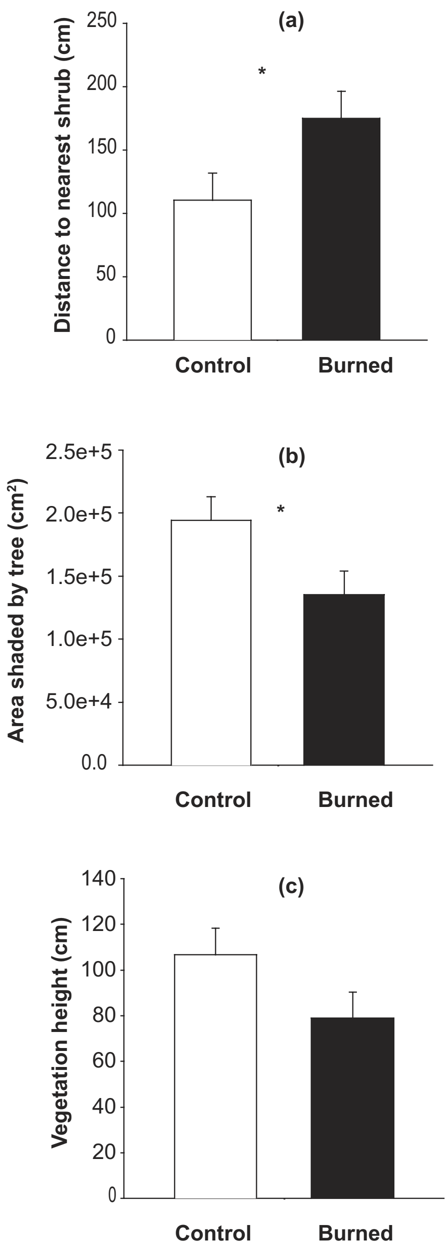

Figure 4—The effect of fire on vegetation parameters. (a) distance to nearest shrub, (b) area shaded by nearest tree, and (c) highest vegetation within 1 m of sample point.

Acknowledgments

We wish to thank Sigma Xi, the American Museum of Natural History, University of Utah ASUU, and the Biology Department at the University of Utah for support. We are especially grateful to Joe and Valer Austin for the use of their ranches as well as Robert L. Minckley for assistance with this project. Students from the Universidad Autonoma de Queretaro made key suggestions to the methodology. Don Feener and Lissy Coley provided useful critiques.

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Abstracts and Resúmenes

Posters and Pre-Reviewed Abstracts Presented at the Conference: English and Spanish (*some titles and authors are different from the finalized versions*)

Carteles y Resúmenes Prerrevisados Presentados en la Conferencia: Inglés y Español (*algunos títulos y autores son diferente al de las versiones completadas*)

ALBRECHT, ERIC W.[1], Brian F. Powell[2], Don E. Swann[3], and William L. Halvorson[2]. [1]Deceased September 20, 2004; [2]USGS Sonoran Desert Research Station and School of Natural Resources, 125 Biological Sciences East, University of Arizona, Tucson, AZ 85721; [3]National Park Service, 3693 South Old Spanish Trail, Tucson, AZ 85730; bpowell@ag.arizona.edu.

Species richness as an avian community monitoring parameter. Species richness is rarely used as a long-term ecological monitoring parameter, yet it represents many characteristics that are recommended for consideration in parameter selection: it is relevant to most land-management goals, has low natural and sampling variability, and is cost effective. While species richness is less sensitive to environmental change than is abundance, it often responds to significant changes (e.g., habitat fragmentation or loss), and methods used to estimate richness allow estimation of other useful parameters (species distribution, species composition). We used data collected in five national parks in southern Arizona and New Mexico to evaluate the potential of avian species richness as a parameter to detect trends in breeding bird communities. Parks surveyed represent gradients in factors such as elevation, vegetation communities, and park size. We used power analysis to determine the amount of effort required to detect change at a specified level over a given period of time (e.g., a 10% loss in species richness over 5 years). We believe that species richness has strong potential for monitoring birds and other taxa throughout the Madrean Archipelago region, and offer specific monitoring recommendations.

La riqueza de especies como parámetro de monitoreo de comunidades de aves. La riqueza de especies rara vez es utilizada como parámetro de monitoreo ecológico de largo plazo, aunque ésta representa muchas características que se recomiendan para ser consideradas durante la selección de parámetros, por ejemplo: es relevante en la mayoría de los propósitos de manejo de suelos, presenta una baja variabilidad natural y de muestreo y tiene un costo razonable. Mientras que la riqueza de especies es menos sensible a los cambios ambientales que la abundancia, a menudo responde a cambios significativos (e.g., pérdida o fragmentación del hábitat) y los métodos utilizados para estimar riqueza permiten estimar otros parámetros útiles (distribución y composición de especies). Utilizamos datos obtenidos en cinco Parques Nacionales del sur de Arizona y New Mexico para evaluar el potencial de la riqueza de especies de aves como un parámetro para detectar las tendencias de reproducción en comunidades de aves. Los parques estudiados representan gradientes en diversos factores como elevación, comunidades vegetales y tamaño del parque. Utilizamos un análisis de fuerza para determinar la cantidad de esfuerzo necesario para detectar cambios a un determinado nivel por algún periodo de tiempo (e.g., pérdida del 10% en riqueza de especies en un periodo de cinco años). Creemos que la riqueza de especies tiene un fuerte potencial para el monitoreo de aves y otros taxa en la región del Archipiélago Madrense y ofrecemos, también, recomendaciones específicas de monitoreo.

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The effects of fire on Sonoran Desert plant communities. An upward trend in the number of fires has occurred during the past 45 years in the Sonoran Desert on the Tonto National Forest. The effects of fire on Sonoran Desert plant communities were determined by analyzing the influence of anthropogenic and climatic factors on fire regimes, and by measuring the recovery of plants on a time-since-fire gradient. Native species most impacted by fire were saguaro (*Carnegiea gigantea*) and foothill paloverde (*Cercidium microphyllum*). Repeated fires caused an increase in density for purple three-awn (*Aristida purpurea*) and desert senna (*Cassia armada*) and a decrease in native species such as saguaro, foothill paloverde, white ratany (*Krameria grayi*), wolfberry (*Lycium* spp.), and creosote bush (*Larrea tridentada*).

Los efectos del fuego en las comunidades vegetales del Desierto Sonorense. Durante los últimos 45 años, se ha observado un aumento en los incendios ocurridos en el Desierto Sonorense dentro de la reserva conocida como Tonto National Forest. Los efectos del fuego en las comunidades vegetales del Desierto Sonorense, fueron determinados por medio de un análisis de la influencia de factores antropogénicos y climáticos en los regimenes de incendios y midiendo la recuperación de plantas en un gradiente de tiempo desde la ocurrencia de un incendio. Las especies nativas más impactadas por el fuego fueron el sahuaro *(Carnegiea gigantea)* y palo verde *(Cercidium microphyllum)*. Incendios sucesivos causaron un aumento en la densidad del zacate tres barbas púrpura *(Aristida purpurea)* y el dais del desierto *(Cassia armada)*, así como una reducción de las especies nativas como el sahuaro, palo verde, cósahui *(Krameria grayi)*, salicieso *(Lycium* spp.) y gobernadora *(Larrea tridentada)*.

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Natural landscape as cultural landscapes: the power of place and tradition. The natural landscape of the Madrean Archipelago is a mosaic of cultural landscapes. Throughout human history, people have imbued the natural landscape with meaning. Each culture ascribes meaning to a natural landscape in its own unique way: cultural values and historic cultural context are layered onto the natural world, allowing people to situate themselves in time and space. In southern Arizona, American Indians, Hispanics, and Euro-Americans have all sought to order the natural landscape in their own unique ways. Cultural landscapes contain special places that have power because of their association with important events, people, or critical resources. Some places have importance to a number of cultures, albeit often times for different reasons, while other places may have importance to only one culture. To effectively conserve and protect the Madrean Archipelago, we must understand the complexities and intricacies of the many-storied cultural landscapes layered upon the natural world. This paper, based on research compiled for the Sonoran Desert Conservation Plan, examines natural landscape as cultural landscapes and addresses the implications for natural resources research and management. Specific examples of significant convergent natural and cultural landscapes are provided to illustrate the concepts under discussion.

Paisaje natural como paisajes culturales: el poder del lugar y de la tradición. El paisaje natural del Archipiélago de Madrense es un mosaico de paisajes culturales. A lo largo de la historia, la gente ha infundido un significado al paisaje natural. Cada cultura atribuye su propio significado al paisaje natural: los valores culturales y el contexto cultural histórico son colocados sobre el mundo natural, permitiendo que la gente se sitúe asimisma en el tiempo y en el espacio. En el sur de Arizona, los Indios Americanos, los Hispanos, y los Euro-Americanos, han intentado ordenar el paisaje natural bajo sus propias maneras. Los paisajes culturales contienen lugares especiales que tienen poder debido a su asociación con acontecimientos importantes, con la gente, o con recursos críticos. Algunos lugares tienen importancia para un cierto número de culturas, a menudo debido a diversas razones, mientras que otros lugares pueden tener importancia solamente para una sola cultura. Para conservar y proteger con eficacia el Archipiélago Madrense, debemos entender las complejidades y las complicaciones de los muchos paisajes culturales colocados sobre el mundo natural. Esta ponencia, basada en la investigación compilada para el Plan de Conservación del Desierto Sonorense, examina a los paisajes naturales como paisajes culturales, y trata las implicaciones para la investigación y manejo de los recursos naturales. Se proporcionan ejemplos específicos de paisajes naturales y culturales significativamente convergentes para ilustrar los conceptos bajo discusión.

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An overview of the floristic richness and conservation of the arid regions of northern Mexico. The arid and semiarid regions of Northern Mexico harbor diverse, highly endemic, and geographically complex ecosystems. These share topographic and biogeographic similarities that can be used as an analytical framework to assess biodiversity patterns. This study presents the current status of vascular plants inventories for the Mexican portion of Aridamerica. The spatial distribution of the floristic records obtained for different vegetation types were analyzed for a 171 year period of field inventories. Floristic curatorial records were obtained from the National Biodiversity Information System (CONABIO) belonging to 10,772 species. Likewise, an analysis of the vegetation types protected within the Mexican National System of Natural Protected Areas (SINAP) was done. Results show that sampling efforts are insufficient to characterize the vascular plant diversity of the natural ecosystems of Northern Mexico. The lowest sampling efforts were recorded for the central region of the Chihuahuan Desert. The highest species richness was obtained for current disturbed areas, since most of the analyzed floristic records are historical ones. Results also show the major vegetation types of the continental arid and semi-arid regions of Northern Mexico are not represented within the SINAP, while those ecosystems covering the Baja California Peninsula and the surrounding islands are almost fully represented.

Una descripción de la riqueza florística y conservación de las regiones áridas del norte de México. Las regiones áridas y semiáridas del norte de México albergan ecosistemas diversos, altamente endémicos y geográficamente complejos, que comparten similitudes topográficas y biogeográficas utilizables como marco de referencia para evaluar patrones de biodiversidad. Este estudio presenta el estado actual de los inventarios de plantas vasculares para la porción mexicana de Aridamérica, analizándose el patrón de distribución espacial de los registros florísticos en función de 171 años de inventarios de campo. Los registros curatoriales de 10,772 especies se obtuvieron del Sistema Nacional de Información sobre Biodiversidad (CONABIO). Asimismo, se presenta un análisis sobre los tipos de vegetación incluidos en el Sistema Nacional de Áreas Naturales Protegidas (SINAP) de México. Los resultados muestran que los esfuerzos de colecta han sido insuficientes para caracterizar la diversidad de plantas vasculares del norte de México. Los esfuerzos de colecta más bajos se registraron para la región central del Desierto Chihuahuense, mientras que la mayor riqueza de especies se obtuvo para áreas actualmente perturbadas. Los resultados muestran que los principales tipos de vegetación de la parte continental del norte de México no están representados en el SINAP; en tanto que los ecosistemas de la península de Baja California e islas que la rodean están sobre representados.

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Ecosystem changes at the Pinacate Reserve: invasion of non-native plants. The Sonoran Desert ecosystem has been altered year after year by humans and the introduction of invasive plants that prosper in disturbed and undisturbed habitats. The disappearance of native vegetation has had a high cost in ecosystem dynamics as changes in diversity can result in radical changes to habitat and food for wildlife. As such, the Pinacate Reserve is a Sonoran Desert ecosystem where the nature landscape is being altered by invasive plants. In accordance with a study completed by CDC, the Pinacate Reserve registers 97 invasive plant species of which 18 are altering the natural ecosystems. Examples are the saltcedar, buffel grass, and the Sahara mustard, among others. One of the sites that underwent significant changes to the ecosystem is the Rio Sonoyta riparian zone near the United States border. This site experienced an extensive invasion of saltcedars (*Tamarix ramosissima*) that have displaced native plants such as the cottonwood, willow, and mesquite. Also, the riparian zone is habitat for endemic species such as the killifish (*Cyprinodon eremus*), sonoyta mud turtle (*Kinosternon sonoriensis longifemorale*), and longfin dace (*Agosia chrysogaster*), among others. The creation of a Management Area in the Pinacate Reserve currently integrates local communities into the programs of control and management of invasive species.

Cambios en los ecosistemas de la Reserva el Pinacate: invasión de plantas no nativas. El ecosistema del Desierto Sonorense ha sido modificando a través de los años por el hombre y por la introducción de plantas invasoras que prosperan en hábitats perturbados y no perturbados. La desaparición de la vegetación nativa a tenido un alto costo en la dinámica de los ecosistemas ya que los cambios en la diversidad pueden ocasionar cambios radicales en el hábitat y la alimento de la fauna silvestre. Como tal, la Reserva El Pinacate es uno de los ecosistemas del Desierto Sonorense en que el paisaje natural está siendo modificado por plantas invasoras. De acuerdo a un estudio realizado por el CDC, la Reserva El Pinacate registra 97 especies de plantas invasoras de las cuales 18 son las que están modificando los ecosistemas naturales. Algunos ejemplos son el pino salado, el pasto buffel y la mostaza del Sahara, entre otros. Uno de estos sitios en los que se ha observado un cambio significativo en su ecosistema es en el cauce del Río Sonoyta, cerca de la línea fronteriza con los Estados Unidos. Este sitio presenta una fuerte invasión de pino salado (Tamarix ramosissima) que ha eliminado la presencia de plantas nativas como el álamo, el sauce y el mezquite. Asimismo, el cauce del Río es hábitat de especies endémicas como el pupo (Cyprinodon eremus), tortuga (Kinosternon sonoriensis longifemorale), y charalito (Agosia chrysogaster), entre otros. Actualmente la creación de un Área de Manejo en la Reserva el Pinacate ha integrado a las comunidades locales en los programas de control y manejo de especeis invasivas.

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Invasion of Arizona's natural areas: plants that threaten wildlands. Hundreds of non-native plant species exist in Arizona yet only several dozen are on the state noxious weed list and a majority of these are species that affect agricultural production or have negative impacts on human economy or health. What about plants that have detrimental impacts to natural habitats and biological diversity? To determine which of these plants are truly invasive in the ecological sense, a risk assessment criteria was developed by a tri-state committee to provide a transparent, repeatable, and credible process to identify which introduced plants invade natural areas and threaten biodiversity and ecological processes.

An Arizona committee, representing over 15 federal, state, and local entities, has been meeting for the past year to identify, evaluate, and rank invasive plants that threaten natural areas. In addition to ecological impact, the criteria assess each plant's invasive potential, ecological amplitude, and distribution. The criteria, progress of the committees' effort, and the status of the plants evaluated and categorized will be presented. The purpose of the list is to draw attention to those species having adverse impacts on native species and natural communities and to provide information to a variety of stakeholders to assist in appropriate decision-making and prioritization of strategies.

Invasión de las áreas naturales de Arizona: plantas que amenazan las áreas silvestres. Existen centenares de especies vegetales exóticas en Arizona, aunque solamente varias docenas están en la lista de plantas nocivas y una mayoría de éstas son especies que afectan la producción agrícola o tienen impactos negativos en la economía o en la salud humana. ¿Qué hay sobre las plantas que tienen impactos perjudiciales sobre los hábitats naturales y la diversidad biológica? Para determinar cuáles de estas plantas son verdaderamente invasoras en el sentido ecológico, un comité tri-estatal desarrolló un criterio de gravamen de riesgo para proporcionar un proceso transparente, repetible y creíble para identificar cuales de las plantas introducidas invaden áreas naturales y amenazan la biodiversidad y los procesos ecológicos.

Un comité de Arizona, representando poco más de 15 entidades federales, estatales y municipales, se ha estado reuniendo durante el último año para identificar, evaluar, y categorizar a las plantas invasoras que amenazan las áreas naturales. Además del impacto ecológico, los criterios determinan el potencial invasor de cada planta, su amplitud ecológica, y distribución. Los criterios, el progreso del esfuerzo del comité, y el estado de las plantas evaluadas y categorizadas, serán presentados. El propósito de la lista es enfocar la atención hacia las especies que tienen impactos adversos sobre las especies nativas y las comunidades naturales y proporcionar información a una variedad de planificadores para que contribuyan en la toma de decisiones apropiadas y en la prioritizasión de estrategias.

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Madrean pine-oak forest in Arizona's Sky Islands: altered fire regimes, altered communities. In presettlement times, Madrean pine-oak forests of the Sky Islands region supported frequent, low-severity surface fires. In response to this regime, pines were fire resistant, exhibiting high top-survival, whereas oaks were fire resilient, exhibiting lower top-survival but pronounced resprouting. Thus, low-severity fire favored pines, but resprouting allowed oaks to rebound during inter-fire periods. Altered fire regimes have modified these ecosystems. Age structures reveal large increases in stand density, especially for oaks, as a result of fire suppression, suggesting more open conditions and higher pine:oak ratio during presettlement times. Frequent fires also apparently excluded less fire tolerant species (e.g., Douglas-fir, border pinyon), which have invaded some pine-oak sites. In recent anomalous stand-replacing crown fires, seedling establishment was very low for pines and oaks, but most oaks resprouted. *Pinus leiophylla* also resprouted but at low levels, which might nonetheless be an important source of future pines. Recent drought has apparently exacerbated the low levels of seedling establishment, further shifting dominance to oaks in these post-fire environments. These results suggest that anomalous high-severity fires, especially those associated with multi-year droughts, can transform Madrean pine-oak forests into more homogeneous oak woodlands.

Bosque madrense de pino-encino en las Islas del Cielo de Arizona: regímenes de fuego alterados, comunidades alteradas. Previo a la presencia de asentamientos humanos, los bosques madrenses de pino-encino de la región de Islas del Cielo sufrieron frecuentes fuegos superficiales de la baja-severidad. En respuesta a este régimen, los pinos se mostraron resistentes al fuego, exhibiendo una alta sobrevivencia, mientras que los robles fueron resistentes al fuego, con una sobrevivencia más baja pero con una rebrotación pronunciada. Así, el fuego de bajo severidad favoreció a los pinos, pero el rebrote permitió que los encinos resaltaran durante los períodos entre incendios. Los regímenes alterados del fuego han modificado la estructura y la dinámica de estos ecosistemas. Las estructuras de edad revelan grandes incrementos en la densidad de los rodales, especialmente para los encinos, como resultado de la supresión moderna de incendios, sugiriendo más condiciones abiertas y una proporción pino:encino más alta previo a la presencia de asentamientos humanos. Los incendios frecuentes también excluyeron, al parecer, a especies menos tolerantes al fuego (e.g., pinabete, pino piñonero de la frontera), que han invadido algunos sitios de pino-encino. En fuegos anómalos recientes del tipo substituyente de rodal, el establecimiento de plántulas fue muy bajo para los pinos y los encinos, pero la mayoría de los encinos rebrotaron. *Pinus leiophylla* también rebrotó pero en niveles bajos, lo cual puede no obstante ser una fuente importante de pinos futuros. La sequía reciente ha exacerbado al parecer los niveles bajos de establecimiento de plántulas, desviando la dominancia hacia los encinos en esos ambientes de post-fuego. Estos resultados sugieren que los fuegos anómalos de la alta severidad, especialmente los asociados a sequías multianuales, pueden transformar los bosques Madrenses de pino-encino en bosques más homogéneos de encino.

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The effects of fire events on soil geochemistry in semi-arid grasslands. Throughout the Southwest, vegetation in what historically was grassland has changed to trees and shrubs; exotic grass species and undesirable shrubs have also invaded at the expense of native grasses. The availability and amount of soil nutrients influence the relative success of plants, but few studies have examined fire effects on soil in a temporal, spatial, and species group-specific fashion. Our research investigates the effects of fire events on selected soil characteristics (pH, NO_3-, PO_4-^{3}, TOC) on native grass-, exotic grass-, and mixed grass-dominated plots distributed on four different geological surfaces. Post-burn results indicate the dominant plant type was a significant factor only for pH. Recovery to pre-burn levels varies with characteristic: there were no significant initial differences between vegetation types, but significant differences in NO_3-, PO_4-^{3} and TOC occur as a result of fire events, geological characteristics, and time. The research helps identify the soil response to fire and the recovery times of soil characteristics, further defines optimal fire frequency to maximize soil macronutrient contents, and illustrates the role geology plays in grassland ecosystems. Poster.

Los efectos de los acontecimientos de fuego en la geoquímica del suelo en pastizales semiáridos. A través del suroeste de los Estados Unidos, la vegetación que históricamente fue un pastizal, ha cambiado a una mezcla de árboles y arbustos; especies exóticas de gramíneas y de arbustos indeseables, también han invadido los pastizales a expensas de los pastos nativos. La disponibilidad y cantidad de nutrientes del suelo influyen en el éxito relativo de las plantas, pero pocos estudios han examinado los efectos del fuego sobre las características del suelo de manera temporal, espacial y para un grupo específico de especies. Nuestro estudio investiga los efectos de acontecimientos de fuego sobre características seleccionadas del suelo (pH, NO_3-, PO_4-^{3}, TOC) en cuadrantes dominados por pastos nativos, pastos exóticos, y pastos mezclados, distribuidos en cuatro superficies geológicas diferentes. Los resultados post-incendio indican que el tipo de planta dominante resultó un factor significativo solamente para el pH. La recuperación de los niveles de pre-incendio varía con la característica: no hubo diferencias iniciales significativas entre los tipos de vegetación, pero si hubo diferencias significativas en NO_3-, PO_4-^{3} y el TOC ocurre como resultado de acontecimientos de fuego, las características geológicas y el tiempo. El estudio ayuda a identificar la respuesta del suelo al fuego, así como el tiempo de recuperación de las características del suelo; además define cual es la frecuencia óptima de incendio como una estrategia de manejo para maximizar el contenido de macronutrientes del suelo, e ilustra el papel que juega la geología en los ecosistemas de pastizal. Póster.

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Aquatic insect diversity and community structure in Madrean Sky Island streams. Streams act as islands of aquatic habitat isolated both within and between mountain ranges of the Madrean Sky Islands (MSI). Despite the rarity and isolation of perennial stream habitats, MSI streams support a diverse insect fauna. Our study, currently in progress, examines the insect diversity and community structure of 40 isolated streams in the MSI region. We are examining habitat type, size, and water quality. Additionally, we are performing biotic surveys for fish and amphibians. We hypothesize that diversity is maintained by multiple factors including (1) steep elevation gradients that provide a broad range of habitats over short distances, (2) interannual baseflow variability that favors lotic vs. lentic community types in different years, (3) severe floods and droughts that maintain habitat heterogeneity. Community structure is likely influenced by dispersal ability of individual species, habitat type, and paleohydrologic connectivity. From initial surveys, data suggests that exotic fish and amphibians may also alter insect community structure. This work provides an important baseline dataset for aquatic insect distribution; these data will also be utilized to test a number of ecological theories, including the equilibrium theory of island biogeography.

Diversidad y estructura de comunidades de insectos acuáticos en las corrientes de las Islas del Cielo Madrense. Las corrientes actúan como islas de hábitats acuáticos aislados tanto dentro como entre las cadenas montañosas de las Islas del Cielo Madrense (ICM o MSI, por su significado en inglés). A pesar de la rareza y el aislamiento de los hábitats de corrientes perennes, las corrientes de las ICM presentan una fauna diversa de insectos. Nuestro estudio, actualmente en desarrollo, examina la diversidad y la estructura de las comunidades de insectos de cuarenta corrientes aisladas en la región de las ICM. Estamos examinando el tipo de hábitat, tamaño, y calidad del agua; además, estamos realizando estudios bióticos en peces y anfibios. Presumimos que la diversidad es mantenida por factores múltiples incluyendo (1) gradientes de elevación pronunciada, los cuales proporcionan una amplia gama de hábitats en distancias cortas, (2) la variabilidad interannual del flujo basal que favorece los tipos de comunidades lóticas vs. lénticas en diferentes años, (3) las inundaciones y sequías severas que mantienen la heterogeneidad del hábitat. La estructura de la comunidad es influenciada probablemente por la habilidad de dispersión de especies individuales, tipo de hábitat, y por la conectividad paleohydrológica. De acuerdo a estudios iniciales, los datos sugieren que los peces y anfibios exóticos también pueden alterar la estructura de las comunidades de insectos. Este trabajo proporciona una serie de datos básicos importantes sobre la distribución acuática de insectos; estos datos también serán utilizados para probar un número de teorías ecológicas, incluyendo la teoría del equilibrio de la biogeografía de islas.

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Habitat connectivity for northern jaguars (*Panthera onca*). Although jaguars have been extirpated from the United States, there have been infrequent sightings in Arizona. These jaguars probably originated from the nearest population which is 215 km south of the US-Mexico border, but their routes of travel are unknown. Therefore, we developed a potential jaguar range map using GARP (Genetic Algorithm for Rule Set Production) modeling. GARP utilizes occurrence data to predict the fundamental ecological niche of a given species. A survey of northern Mexico and the southwestern U.S. yielded 127 occurrence records for jaguars in Arizona, Chihuahua, New Mexico, and Sonora for 1900-2000. From these records, we modeled the potential ranges of males and females. We assumed that records of females were more likely to represent established home ranges and that records of males probably included dispersal movements. Range predictions based on occurrences of males were larger than ranges based on female occurrences, and included a broader array of habitats and environmental conditions. Arizona and Sonora appeared capable of supporting male and female jaguars, while New Mexico and Chihuahua contained environmental characteristics primarily limited to the male niche. The Sky Islands region provides an important habitat linkage for jaguars dispersing to the United States.

Conectividad del hábitat para jaguares del norte *(Panthera onca)*. Aunque los jaguares han sido extirpados de los Estados Unidos, ha habido observaciones infrecuentes en Arizona. Estos jaguares probablemente se originaron de la población más cercana que está a 215 kilómetros al sur de la frontera E.E.U.U.-México, aunque sus rutas de migración son desconocidas. Por lo tanto, desarrollamos un mapa potencial de distribución de jaguar usando el modelo GARP (Genetic Algorithm for Rule Set Production ó Algoritmo Genético para Reglas de Producción en Serie). El GARP utiliza datos de ocurrencia para predecir el nicho ecológico fundamental de una especie dada. Un estudio en el Norte de México y el suroeste de los E.E.U.U. resultó en 127 lecturas de ocurrencia de jaguares en Arizona, Chihuahua, New Mexico y Sonora entre 1900-2000. A partir de estos expedientes, modelamos los rangos potenciales de machos y hembras. Asumimos que las lecturas para hembras fueron más confiables para representar rangos de madrigueras establecidas y que las observaciones para machos incluyeron probablemente movimientos de dispersión. Las predicciones de rangos basadas en ocurrencias de machos fueron más grandes que los rangos basados en ocurrencias de hembras, e incluyeron un arreglo más amplio de condiciones ambientales y de hábitat. Arizona y Sonora parecen ser capaces de soportar jaguares masculinos y femeninos, mientras que New Mexico y Chihuahua presentaron características ambientales limitadas al nicho de los machos. La región de las Islas del Cielo proporciona un acoplamiento importante del hábitat para los jaguares que se dispersan hacia los Estados Unidos.

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Predicting habitat suitability for wildlife in southeastern Arizona using Geographic Information Systems: scaled quail, a case study. Several studies have used Geographic Information Systems (GIS) to evaluate habitat suitability for wildlife on a landscape scale, yet few have established the accuracy of these models. Based on documented habitat selection patterns of scaled quail, we produced appropriate GIS covers for: elevation, slope, precipitation patterns, land-use, and vegetation type. We used these covers to create a map of "potential scaled quail habitat" in southeastern Arizona. We found scaled quail coveys on 36% of conducted surveys inside of "potential scaled quail habitat." We failed to find scaled quail on 90% of surveys conducted outside of "potential scaled quail habitat." Eighty percent of the scaled quail coveys found during random surveys occurred within the "potential scaled quail habitat map"; whereas 85% occurred within areas considered within historic scaled quail range estimates. Potential causes for the lack of precision of our model include inherent inaccuracies of available habitat covers, localized differences in habitat selection patterns of scaled quail, and bias in our survey methods. Future research designed to refine the localized habitat selection patterns of scaled quail may be more useful in evaluating habitat suitability in Arizona.

Predicción del hábitat idóneo para la fauna silvestre en el suroeste de Arizona usando Sistemas de Información Geográfica: la codorniz escamosa, un estudio de caso. Varios estudios han utilizado los Sistemas de Información Geográfica (SIG) para evaluar la idoneidad del hábitat para la fauna silvestre a una escala de paisaje, aunque pocos han establecido la exactitud de estos modelos. De acuerdo con los patrones existentes sobre la selección del hábitat por la codorniz escamosa, creamos coberturas apropiadas de SIG para: elevación, pendiente, patrones de precipitación, uso del suelo y tipos de vegetación. Utilizamos esas coberturas para crear un mapa del "hábitat potencial de la codorniz escamosa" en el sureste de Arizona. Encontramos nidadas de codornices escamosas en el 36% de muestreos conducidos dentro del "hábitat potencial de la codorniz escamosa". No pudimos encontrar codornices escamosas en el 90% de los muestreos realizados fuera del "hábitat potencial de la codorniz escamosa". Ochenta por ciento de las nidadas de codornices escamosas encontradas durante los muestreos al azar, ocurrieron dentro del "mapa del hábitat potencial de la codorniz escamosa", mientras que el 85% ocurrió en áreas consideradas dentro del rango de estimaciones históricas de las codornices escamosas. Las causas potenciales de la carencia de precisión de nuestro modelo, incluyen las inexactitudes inherentes a las cubiertas disponibles del habitat, las diferencias en los patrones de selección del hábitat por las codornices escaladas y el sesgo en nuestros métodos de muestreo. Investigación futura diseñada para refinar los patrones de selección del hábitat de la codorniz escamosa, puede ser más útil para evaluar la idoneidad del hábitat en Arizona.

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Assessing indicators of rangeland health with remote sensing. Recent interest in rangeland health has led to the development of a plot-scale assessment methodology with 17 specific indicators of rangeland health. The goal of this study was to design and evaluate a method to cost-effectively scale up the field-based assessment to a landscape level using remote sensing products and other spatial data layers. Remotely sensed metrics representing health indicators were derived from multi-spectral satellite imagery, including canopy cover, biomass and mesquite composition. Canopy cover, including both green and senescent vegetation was used to derive an estimate of bare ground as an assessment of soil and site stability. Biomass and mesquite composition were used to estimate invasive species, structural plant groups, and production as an assessment of biotic integrity. These metrics were combined in a GIS with other spatial data to produce a preliminary map of areas that exhibit a significant departure from expected or reference ecological conditions. The model was calibrated using ground-based assessments of semi-desert grasslands in southeastern Arizona. Results of the model design and its evaluation by rangeland researchers, land managers and remote sensing specialists will be presented. Poster.

Evaluación de indicadores de la salud del pastizal por percepción remota. El interés reciente en la salud del pastizal ha conducido al desarrollo de una metodología de evaluación con 17 indicadores específicos de la salud del pastizal. Esta metodología fue diseñada para realizar evaluaciones a escala de parcela. El propósito de este estudio fue diseñar y evaluar un método rentable para llevar una evaluación de campo a un nivel de paisaje usando productos de percepción remota y otros datos espaciales. A partir de imágenes multiespectrales de satélite se derivaron mediciones de percepción remota que representan indicadores de salud, incluyendo cobertura vegetal, biomasa y composición de mezquite. La cobertura vegetal, que incluye tanto vegetación verde como senescente, fue utilizada para derivar una estimación del suelo desnudo, como una evaluación de la estabilidad del suelo y del sitio. La composición de biomasa y de mezquite fue usada para estimar especies invasoras, grupos estructurales de plantas y producción, como una evaluación de la integridad biótica. Estas mediciones fueron combinadas en un SIG con otros datos espaciales para producir un mapa preliminar de las áreas que presentan una diferencia significativa en cuanto a condiciones ecológicas esperadas o de referencia. El modelo fue calibrado usando mediciones en campo de pastizales semidesérticos en el sureste de Arizona. Se presentarán resultados del diseño del modelo y su evaluación por investigadores de pastizales, manejadores de suelos y especialistas en percepción remota. Póster.

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Land use changes in central Sonora: ecological consequences in the Sky Islands' desert seas. Land use changes and exotic grass planting and potential invasion over the last 30 years have increased pressure on the functional and structural ecological relationships of native plant communities in the region. As found by modeling approaches, spread of buffel grass may become a major threat in the future for most of the region, while important consequences are already present to the biodiversity and nutrient relationships because of the rate of change in the structure plant communities at the southern edge of the Sonoran Desert. Poster.

Cambios en los tipos de uso del suelo en la parte central de Sonora: consecuencias ecológicas en los mares del desierto de las Islas del Cielo. Los cambios en el uso del suelo y el sembrado e invasión potencial de pastos exóticos, en los últimos 30 años, ha incrementado la presión en las relaciones ecológicas funcionales y estructurales de las comunidades de plantas nativas de la región. Según lo estipulado por programas de modelaje, la propagación del pasto buffel puede convertirse, en un futuro, en una amenaza importante para gran parte de la región, mientras que ya existen consecuencias importantes en la biodiversidad y en las relaciones de los nutrientes, debido a la velocidad de cambio en la estructura de las comunidades de plantas en el extremo sur del Desierto de Sonora. Póster.

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Status of black-tailed prairie dog (*Cynomys ludovicianus*) in Sonora, México. The prairie dog is a keystone species though the habitat where it occurs but its populations have declined in about 98% in the last century. This species has been considered of international importance for the United Stated of America, Canada and Mexico. Only two populations are recorded for Mexico, and the westernmost (isolated by Sierra Madre Occidental from the other) remains basically unknown in the Upper San Pedro River Watershed in Mexico. This species has been eradicated from Arizona. The closest population is hundreds of kilometers away, in New Mexico. Since July 2003 we have been working to collect basic information that is needed for this species conservation: actual distribution, population parameters, habitat and threats. Methodology being used is standardized to those under way in other places. Geographic Information Systems and Remote Sensing are being used as tools in range, habitat, and threats analysis. Poster.

Estado del perro de la pradera de cola negra (*Cynomys ludovicianus)* en Sonora, Mexico. El perro de la pradera en una especie clave, a lo largo del hábitat donde ocurre, pero sus poblaciones han declinado en un 98% en el último siglo. Esta especie se ha considerado de importancia internacional en los Estados Unidos de América, Canadá y México. Sólo se han registrado dos poblaciones en México, siendo la población más occidental (aislada de la otra por la Sierra Madre Occidental) sobre la cual básicamente se conoce muy poco, en la Cuenca Superior del Rió San Pedro en México. Esta especie ha sido erradicada en Arizona. La población más cercana se encuentra a cientos de kilómetros de distancia, en Nuevo México. A partir de julio del 2003, hemos estado colectando información básica para la conservación de esta especie: su distribución actual, parámetros de población, hábitat y amenazas. La metodología utilizada esta estandarizada con otras que están siendo usadas en otros lugares. Se han utilizado utilizando Sistemas de Información Geográfica y Detección Remota como herramientas para el análisis de rango, hábitat y amenazas. Póster.

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A regional framework for ecosystem monitoring in the Sonoran Desert. The Sonoran Desert is changing; urbanization and the loss of natural habitats, population growth, exotic species, global warming, and other influences affect the region. To better understand these changes and inform management decisions, we propose to create a bi-national ecosystem monitoring framework to assess the state of the Sonoran Desert. The creation of an ecosystem monitoring framework for the Sonoran Desert is a partnership; and, we hope, that the framework will be implemented by multiple agencies and institutions in coordination. The Sonoran Institute and The Nature Conservancy have long advocated a bi-national ecosystem monitoring program for the Sonoran Desert and have gained wide-spread support of agencies and organizations in the United States and Mexico. The National Park Service is mandated to identify "vital signs" as a basis for monitoring natural resources. This presentation will provide an update on the process and progress to create a science-based, peer-reviewed framework for ecosystem monitoring in the Sonoran Desert. This framework will provide the structure for following steps of developing parameters and protocols, linking monitoring to adaptive management, data management, and reporting on the condition of the region.

Un marco regional para el monitoreo de ecosistemas en el Desierto Sonorense. El desierto sonorense esta cambiando; la urbanización y la pérdida de hábitats naturales, el crecimiento demográfico, las especies exóticas, el calentamiento global y otras influencias afectan esta región. Para entender mejor estos cambios e informar decisiones de manejo, nos proponemos a crear un marco binacional de monitoreo de ecosistemas para evaluar el estado del Desierto Sonorense. La creación de un marco de monitoreo de ecosistemas para el Desierto Sonorense es una asociación: y esperamos que el marco sea implementado por una coordinación de múltiples agencias e instituciones. Desde hace tiempo, The Sonoran Institute y The Nature Conservancy han abogado por un programa binacional de monitoreo de ecosistemas para el desierto sonorense y han obtenido gran apoyo por parte de las agencias y organizaciones en los Estados Unidos y México. Se le ha asignado al Nacional Park Service que identifique "muestras vitales" como una base pare el monitoreo de recursos naturales. Esta presentación proporcionará una actualización del proceso y el progreso de la creación de un marco, basado en la ciencia, revisado por contemporáneos, de monitoreo de ecosistemas en el Desierto Sonorense. Este marco proveerá la estructura para seguir los pasos de parámetros y protocolos de desarrollo, vinculando el monitoreo al manejo adaptante, al manejo de información y a la divulgación sobre la condición de la región.

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Revising the Land and Resource Management Plan for the Coronado National Forest. The Forest and Rangeland Renewable Resources Planning Act of 1974, as amended by the National Forest Management Act of 1976, specifies that all units of the National Forest System will have a land and resource management plan (LRMP). The purpose of the plan is to guide all natural resource management activities for 10-15 year period. The Coronado National Forest LRMP, which was completed in 1986, is now due for revision. Because of a widely recognized need to increase the relevance and utility of the LRMP there will be basic differences between land management planning in the 1980's and in 2004. Planning in the new century will focus on outcomes, not outputs. Compared with the 1986 plan, the revised plan will be more programmatic in nature and provide for adaptive changes as needed. The planners will emphasize early collaboration with the public and incorporation of science. The plan will have three basic parts: vision (desired conditions and monitoring), strategy (acceptable practices to move toward or maintain those conditions) and design criteria (technical and scientific specifications bounding those practices). These three parts can be thought of as the why, what and how for future management of the Coronado National Forest.

Revisión del Plan de Manejo de Tierra y Recursos del Coronado National Forest. El Forest and Rangeland Renewable Resources Planning Act de 1974, según la enmienda prevista por el National Forest Management Act de 1976, especifica que todas las unidades del Sistema Nacional de Bosques tendrán un plan de manejo de tierra y de recursos (PMTR). El propósito de este plan es guiar todas las actividades de manejo de los recursos naturales por un periodo de 10 a 15 años. Por lo que se necesita efectuar una revisión del PMTR del Coronado Nacional Forest, el cual fue completado en 1986. Debido a la extensamente reconocida necesidad de incrementar la pertinencia y la utilidad del PMTR habrán diferencias básicas entre el planeamiento del manejo de la tierra de los 1980 y del 2004. La planeación en el nuevo siglo se enfocará en los resultados, no en los productos. Comparado con el plan de 1986, el plan revisado será más programático y proveerá cambios adaptables conforme éstos se vayan necesitando. Los planificadores enfatizarán una colaboración temprana con el público y la incorporación de la ciencia. El plan consistirá de tres partes: visión (condiciones deseadas y supervisión), estrategia (prácticas aceptables para alcanzar o mantener esas condiciones) y los criterios de diseño (especificaciones técnicas y científicas para limitar esas prácticas). Estas tres partes se pueden considerar como el porqué, qué y cómo del futuro manejo del Coronado National Forest.

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The tectonic evolution of the Madrean Archipelago and its impact on the geoecology of the Sky Islands. The Madrean Archipelago bridges the gap between the Northern Sierra Madre Occidental and the Southern Rocky Mountains and thus allows biotic "mixing" of two major floristic provinces (the Neotropic and Holarctic) and two faunal realms (the Neotropic and Nearctic) within a convergence region of three climatic zones (tropical, subtropical, and temperate). This geography is often cited as one of the principal explanations for the exceptional biodiversity of the Sky Island region. Here, I explore an additional geoecological factor of equal importance (but less often cited): namely, the unique tectonic location of the Madrean Archipelago within the actively deforming zone produced by the relative motion between the North American and Pacific plates. The tectonic history of the archipelago has played a fundamental role in determining the topography, bedrock geology, and soil types. Of particular interest is how the complex geologic history of the region (characterized by a number of mountain building events over the past 200 million year varying from compressional thrusting to present-day extensional tectonics) has resulted in a heterogeneous ensemble of bedrock types which vary throughout the mountain ranges making up the Sky Islands. Just as elevated biodiversity is associated with "mixing" of flora and faunal regimes, the "mixing" of tectonic environments has played a critical role in the elevated biodiversity of the Madrean Archipelago.

La evolución tectónica del Archipiélago Madrense y su impacto en la geoecología de las Islas del Cielo. El Archipiélago Madrense sirve de puente sobre el espacio entre la parte norte de la Sierra Madre Occidental y la parte sur de las Rocallosas, permitiendo el "intercambio" biótico de dos provincias florísticas importantes (la Neotropical y la Holártica) y dos reinos faunísticos (el Neotropical y el Neoártico) dentro de una región de convergencia de tres zonas climáticas (tropical, subtropical y templada). Esta localización geográfica única es citada constantemente como uno de los factores responsables de la biodiversidad excepcional de la región Isla del Cielo. En este lugar, estoy explorando otro factor geoecológico de gran importancia (aunque citado con menos frecuencia): principalmente, la localización tectónica única del Archipiélago Madrense dentro de una zona activamente deformante producida por el movimiento relativo entre las placas Norte Americanas y del Pacifico. La historia tectónica del Archipiélago ha jugado un papel fundamental al controlar el carácter y la distribución de la topografía, la geología de la roca de fondo y los tipos de suelo. Es de particular interés conocer como la compleja historia geológica de la región (caracterizada por varios eventos creadores de montañas en los últimos 200 millones de años que varían desde eventos de empuje compresional hasta los tectónicos extensionales en el presente) ha dado lugar a un conjunto heterogéneo de tipos de roca de fondo que varían a lo largo de las cordilleras que conforman la Isla del Cielo. Siendo así como una biodiversidad elevada está asociada a la "mezcla" de regímenes de flora y fauna, la "mezcla" de ambientes tectónicos también ha jugado un papel principal en la gran biodiversidad del Archipiélago Madrense.

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A quantitative topographic analysis of the Sky Islands: a closer examination of the topography-biodiversity relationship in the Madrean Archipelago. The well-documented relationship between topography and biodiversity is particularly profound in the Madrean Archipelago. However, despite this recognition, most studies of the Sky Island biogeography have used only a first-order *qualitative* description of the topography (e.g., average vertical relief and mean elevation). Exploiting the availability of high-resolution DEMs (digital elevation models), we have undertaken a rigorous *quantitative* analysis of the topographic fabric of the region and explored its utility for evaluating the relationship between topography and biodiversity. Using a surface-normal eigenvector analysis of a 1-km-resolution DEM, topographic roughness, strength, orientation, and organization were used for characterization of the topographic fabric. Building on the assumption that land cover diversity is a plausible first-order measure of biodiversity, we compare "predicted" biodiversity (based on weighted topographic quantities) and the "observed" biodiversity (based on land cover information extracted from satellite imagery). We find good fit throughout much of the Madrean Archipelago (in contrast to the neighboring provinces) supporting the conclusion that topography plays a critical role in the biodiversity of sky-island regions.

Un análisis topográfico cuantitativo de las Islas del Cielo: una examinación más cercana a la relación entre topografía y biodiversidad en el Archipiélago Madrense. La relación bien documentada entre topografía y biodiversidad es particularmente predominante en el Archipiélago Madrense. Sin embargo, a pesar de este reconocimiento, la mayoría de los estudios de biogeografía de Islas del Cielo solamente han utilizado una descripción cualitativa del primer orden de la topografía (el promedio del relieve vertical y elevación media). Gracias a la disponibilidad de MDE (modelos digitales de elevación) de alta resolución, hemos emprendido un análisis *cuantitativo* riguroso de la tela topográfica en la región y exploramos su utilidad para evaluar la relación entre topografía y biodiversidad. Mediante el uso de un análisis eigenvector de superficie normal de un MDE con una resolución de un km, se utilizaron aspereza topográfica, fuerza, orientación y organización para caracterizar la tela topográfica. Empezando con la suposición que la diversidad de la cubierta de la tierra es una medida plausible de primer orden de la biodiversidad, evaluamos el ajuste entre la biodiversidad "predecida" (basada en el producto pesado de las cantidades topográficas medidas) y la biodiversidad "observada" (basada en información de la cubierta de la tierra extraída de imágenes de satélite). Encontramos un buen acuerdo en el ajuste del Archipiélago Madrense (en contraste con las provincias vecinas), lo que apoya la conclusión que la topografía desempeña un papel crítico en la biodiversidad de las regiones caracterizadas por telas insulares de montaña (es decir, Islas del Cielo).

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Chich'il (acorn soup): dissolution of traditional culture resulting from regulatory control of the landscape. To a great extent, Western Apache culture is geographically defined by the Madrean Archipelago and the resources contained within it: water, deer, birds, acorn, mescal, plant medicines, basket materials, mineral pigments and so on. This region, with its widely variable climate and geomorphology, provided the means to sustain traditional Apachean life. As much as the initial wars of conquest, it has been the multiplicity of twentieth century federal agencies and their regulatory biases that have had the greatest negative impact on Apachean traditions. Because of the modification of surface resources due to the stewardship of extractive-friendly bureaucracies, Apaches who still practice their traditional skills in modern times have become an endangered species. Nothing illustrates this alienation from the landscape better than the demise of Emory Oak acorns as a major food source.

Chich'il (sopa de bellota): disolución de la cultura tradicional como resultado del control regulador del paisaje. En gran parte, la cultura Apache Occidental está definida geográficamente por el Archipiélago Madrense y los recursos que se encuentran en este lugar: agua, venados, aves, bellotas, mezcal, plantas medicinales, materiales para cestas, pigmentos minerales, etc. Esta región, con una geomorfología y un clima altamente variable, proveía los medios con los que la vida Apache tradicional podía sostenerse. Al igual que las primeras guerras de conquista, la multiplicidad de agencias federales del siglo veinte y sus prejuicios regulatorios han tenido el mayor impacto negativo en las tradiciones Apaches. Gracias a la modificación de los recursos superficiales debido al manejo de burocracias a favor de la extracción, en el presente los Apaches que aún practican habilidades tradicionales se han convertido en una especie en peligro de extinción. No existe una mejor ilustración de la enajenación del paisaje como la desaparición de las bellotas del roble de Emory como una fuente alimenticia importante.

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High-resolution climate monitoring on a mountain island: the Saguaro National Park pilot study. The National Park Service is undergoing a comprehensive inventory effort under the Natural Resource Challenge program. Under this challenge, the Inventory and Monitoring (I&M) Program of the National Park Service is charged with acquiring information needed by national park managers in their efforts to maintain park ecosystem integrity. Climate data comprises one category of basic information required through this effort. However, the climate data typically collected in parks consist only of basic parameters such as precipitation and daily temperature, and are often collected at a single location within the park. A pilot project to identify climate monitoring needs and options within Saguaro (East) National Park began in fall, 2003. Eight temporary weather stations have been deployed across the complex topography of the park to provide insight into the spatial and temporal patterns of climate within the park management unit. This project will provide a valuable baseline for park management and may highlight unique spatial and temporal patterns that deserve further investigation. Project findings will help dictate long-term climate monitoring strategies for the park and other park units within the I&M Sonoran Desert Network. This paper will highlight findings and data collected to-date.

Monitoreo de alta resolución en una isla de montaña: el estudio piloto del Saguaro National Park. El National Park Service está efectuando un inventario comprehensivo bajo el programa de Desafío del Recurso Natural (Natural Resource Challenge). Bajo este desafío, el Programa de Monitoreo e Inventario (M&I) del National Park Service está encargado de adquirir la información que les hace falta a los directores para mantener la integridad de los ecosistemas de los parques nacionales. Bajo este esfuerzo, se requiere como categoría básica la información sobre el clima. Sin embargo, la información climática que normalmente se colecta en los parques solamente consiste de parámetros básicos como precipitación y temperatura diaria, que a menudo se colecta en una sola localización dentro del parque. Se inició un proyecto piloto, en otoño del 2003, para identificar las necesidades y opciones de monitoreo del clima dentro del Saguaro National Park. Se han desplegado ocho estaciones meteorológicas temporales a lo largo de la topografía compleja del parque para hacerse una idea de los patrones climáticos espaciales y temporales dentro de la unidad de manejo del parque. Este proyecto proporcionará una referencia base para el manejo de parques y posiblemente podrá hacer énfasis en patrones espaciales y temporales únicos que merezcan estudios adicionales. Los resultados del proyecto ayudarán a dictar estrategias de monitoreo climático a largo plazo para éste y otros parques dentro de la red de M&I del Desierto de Sonora. Este trabajo destacará los resultados y la información colectada hasta ahora.

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Collaboration and complexity: adaptive management experiments in the borderlands. Long-term large-scale studies developed in collaboration with ranchers and researchers of the borderlands are beginning to document the interaction of driving processes in these arid and semi arid rangelands. The process demonstrates that developing and sustaining research at scales relevant to management often requires innovative institutional frameworks as much as a solid foundation of science. The application of science to the collaborative conservation process supports basic research, but also helps sustain communities by giving credibility to rancher based conservation efforts. The results show that when working at the landscape level that conventional wisdom on the effects of fire, and grazing developed through small-scale short-term studies are frequently not supported. Two key points emerge from the analysis. First, when examining scale dependent processes such as fire or grazing one must first get the scale right if the results are to be truly applicable to conservation and management. Second, the action is in the interaction. Studies that examine single variables in isolation can often be misleading or at best miss much of the inherent complexity and dynamics of borderlands ecosystems.

Colaboración y complejidad: experimentos de manejo adaptable en las tierras fronterizas. Los estudios de gran escala y largo plazo, desarrollados con la colaboración de rancheros y los investigadores, han comenzado a documentar la interacción de la conducción de procesos en estas praderas áridas y semiáridas. El proceso demuestra que para desarrollar y mantener una investigación en escalas relevantes al manejo se necesitan marcos institucionales innovadores, al igual que una base sólida en la ciencia. La aplicación de la ciencia al proceso de conservación de colaboración no sólo apoya la investigación básica, sino que ayuda a sostener comunidades al darle credibilidad a los esfuerzos de conservación de los rancheros. Los resultados muestran que cuando uno trabaja a un nivel de paisaje la sabiduría convencional sobre los efectos del fuego y pastoreo, obtenida a partir de pequeños estudios de corto plazo, generalmente no está apoyada. Emergen dos puntos clave en el análisis. Primero, al examinar los procesos dependientes de escala como el fuego o el pastoreo, uno debe aplicar la escala correcta para que los resultados sean verdaderamente aplicables a la conservación y al manejo. Segundo, la acción está en la interacción. Los estudios que se basan en variables aisladas muchas veces pueden ser engañosos o en el mejor de los casos pasan por alto la complejidad inherente y las dinámicas de los ecosistemas de las tierras fronterizas.

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Characterization of Mexican spotted owl habitat in Madrean Sky Island ecosystems. Mexican spotted owls (*Strix occidentalis lucida*) (MSO) are widely distributed throughout the Southwest. Although several studies have been conducted to characterize habitat variability throughout their range, few of these studies have focused on Sky Island habitats. This project was undertaken to describe Protected Activity Center (PAC) and Inventory Area (IA) habitat variability on Fort Huachuca Military Reservation, in southeastern Arizona, using existing information from various studies conducted within the last decade. These studies included annual MSOW surveys, a wildland fuel inventory, and fire history. It has been suggested that the potential for catastrophic wildfire is the biggest threat to owl habitat in Madrean ecosystems. Eight PACs and three IAs were created based on MSO surveys. Owl nest/roost sites were concentrated in steep canyons dominated by oak encinal (averaging 73%) followed by a mixed conifer component (averaging 25%). Although fire most likely burned through most of the Huachuca Mountains in 1899, only three PAC/IAs have been partially affected by fire since, and that was in the early 1970s. Canyons have the highest tree density, and fuels, and most likely the highest potential for catastrophic fire.

Caracterización del hábitat del búho moteado Mexicano en los ecosistemas de la Isla del Cielo Madrense. Los búhos moteados mexicanos *(Strix occidentalis lucida)* (BMM) están extensamente distribuidos en el suroeste de los Estados Unidos. A pesar de que se han realizado varios estudios para caracterizar la variabilidad de hábitat a lo largo de su rango, pocos se han enfocado en los hábitats de las Islas del Cielo. Este proyecto se emprendió para describir el Centro Protegido de Actividad (CPA) y la variabilidad del hábitat del Área de Inventario (AI) en la Reservación Militar Fort Huachuca, en la parte sureste de Arizona, al utilizar información disponible de diversos estudios realizados en la última década. Estos estudios incluyen encuestas anuales MSOW, un inventario del combustible en áreas silvestres y la historia de incendios. Se ha sugerido que un incendio catastrófico potencial es la mayor amenaza para el hábitat de los búhos en los ecosistemas Madrenses. Se crearon ocho CPA y tres AI basándose en encuestas MSOW. Los nidos y sitios de percha de los búhos se concentraban en los cañones empinados dominados por pino-encino (alrededor del 73%) seguido de un componente mixto de coníferas (alrededor del 25%). A pesar de que en 1899 hubo incendios en la mayoría de las Montañas Huachuca, desde entonces sólo tres CPA/AI han sido afectados parcialmente por incendios, y eso fue a principios de los años 1970. Los cañones tienen la densidad de árboles más alta, y de combustibles, y por lo tanto tienen el potencial más alto de un incendio catastrófico.

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Occurrence, structure, and function of the nitrogen-fixing microsymbiont *Frankia* from nodules of Arizona alder. Actinorhizal plants are nodulated by the symbiotic, nitrogen-fixing actinomycete *Frankia.* The genus *Alnus* in the family Betulaceae is one of the 25 genera in 8 families of angiospermous plants that are actinorhizal. Arizona alder (*Alnus oblongifolia* Torr.) occurs in isolated populations associated with the watersheds of Madrean Sky Islands in the southwestern United States between 4,500 and 7,500 ft in elevation. We have found root nodules on alder trees from Oak Creek Canyon and from the Santa Catalina Mountains (southeastern and central Pima County to Oak Creek in Coconino County, Arizona). We describe the occurrence of nodules at two locations at opposite longitudinal ends of their range together with nodule anatomy and quantification of nodular nitrogenase activity in order to confirm symbiotic function of this actinorhizal system.

Distribución y diversidad de microsimbiontes fijadores de nitrógeno *Frankia* presentes en los nódulos del aliso de Arizona. El actinomicete simbiótico, fijador de nitrógeno *Frankia* forma nódulos en las plantas actinorizoidales. El género Alnus de la familia Betulaceae es uno de los 25 géneros en ocho familias de plantas angiospermas que son actinorizoidales. El aliso de Arizona (*Alnus oblongifolia* Torr.) crece en poblaciones aisladas asociadas a corredores ribereños de las islas del cielo Madrenses en la parte suroeste de los Estados Unidos entre los 4,500 7,500m pies de altura. Hemos encontrado nódulos de raiz en árboles de aliso en Oak Creek Canyon y en las Montañas Santa Catalina (sureste y centro de Pima County hasta Oak Creek en Coconino County, Arizona). Describimos la ocurrencia de nódulos en dos localidades en extremos longitudinales opuestos de su habitat junto con la anatomía del nódulo y una cuantificación de actividad nodular nitrogenasa para confirmar la función simbiótica de este sistema actinorizal.

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Ecosystem management in the Madrean Archipelago: a 10-year (1994-2004) historical perspective. The conceptual basis of ecosystem management has existed for several decades. However, the concept and its implementation evolved from one concerned mainly with physical and biological processes to a more holistic system which includes economic, social, and political dimensions in the late 1980s. This broader concept was implemented by the USDA Forest Service in the early 1990s and led to the formation of several ecosystem programs throughout the western U.S. The program that concerns this conference was development of the research work in the Rocky Mountain Research Station on "Achieving Ecosystem Management in the Borderlands of the Southwestern U.S. through Research and Management Partnerships." This program involved the establishment of partnerships among researchers, land and resource managers, conservationists, private landowners, and other local interests concerned about an area of 800,000 acres in the San Bernardino-Animas area of southeastern Arizona and southwestern New Mexico. Concurrent with development of this ecosystem program was the planning and presenting of the first conference on the "Sky Islands of the Madrean Archipelago," which was held in Tucson, Arizona, in September 1994. This conference on biodiversity and ecosystem management became the initial forum for subsequent local, national, and international conferences and symposia which have brought together scientists, managers, and other interested parties from government agencies, universities, and private organizations in the U.S. and Mexico. This paper describes the sequence of activities involved in the earlier planning phases along with the initial implementation of ecosystem principles in the management of the borderlands of the U.S. and Mexico. A review of several milestone activities in the 10 years (1994-2004) since the first conference is also presented in the paper.

Manejo de ecosistemas en el Archipielago Madrense: una perspectiva histórica de 10 años (1994-2004). La base conceptual sobre el manejo de los ecosistemas ha existido desde hace varias décadas. Sin embargo, el concepto y su implementación evolucionó de uno enfocado pricipalmente con los procesos físicos y biológicos hacia un sistema holístico que incluye dimensiones económicas, políticas y sociales a finales de 1980. Este concepto más amplio fue implementado a principios de los 90s por el Servicio Forestal de los Estados Unidos de América (USDA Forest Service) que llevó a la formación de varios programas sobre ecosistemas a lo largo de la región occidental de los E.E.U.U. El programa que concierne a esta conferencia, fue desarrollado por la inestigación en Rocky Mountain Research Station sobre "Logrando el Manejo de Ecosistemas en las Tierras Fronterizas del Suroeste de los Estados Unidos a través de la Investigación y Manejo Compartidos." Este programa involucró la colaboración entre investigadores, manejadores, conservacionistas, propietarios y otros intereses locales concernientes a un área de 800,000 acres de San Bernadino-Animas en la región sereste de Arizona y suroeste de Nuevo México. En concurrencia con la iniciación de este programa, aconteció la primera conferencia sobre "Islas del Cielo del Archipiélago Madrense" en la ciudad de Tucson, Arizona en septiembre 1994. Esta conferencia sobre biodiversidad y manejo de ecosistemas se convirtió en el forum para las siguientes conferencias y reuniones a nivel local, nacional e internacinal que congregó a participantes interesados de agencias de gobierno, universidades de la región y organizaciones privadas. Esta ponencia describe la implementación inicial de los principios ecosistémicos en el manejo de las Tierras Fronterizas del Suroeste de los Estados Unidos y México. También, en esta ponencia se describen varias actividades sobresalientes en los 10 años (1994-2004) desde que se realizó la primera conferencia.

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Conservation of genetic variation in Sky Island populations of Douglas-fir. Genetic variation of Sky Island populations of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) from southwestern North America and northern Mexico was analyzed. The numbers of Douglas-fir have been decreasing in the Sky Islands, and genetic diversity in small, isolated populations such as these is expected to be low. Results of this study showed relatively high within-population variation but not as much among populations, despite small population sizes and isolation of populations from each other. The high genetic diversity was attributed to low frequency alleles which tend to be more common at the edges of a species' range, and often result from adaptation to environmental extremes characteristic of these edges. Low frequency alleles are important to maintaining genetic diversity of these populations and may also have adaptive significance, thus efforts to conserve them are important. A significant relationship between genetic diversity and stand density suggests gene flow is maintaining genetic diversity and thus helps conserve low frequency alleles. Therefore, genetic diversity will be more effectively conserved if the current stand densities are maintained. Finally, a significant relationship between genetic diversity and latitude is consistent with the idea that these southern populations are older than more northerly populations due to patterns of glacial retreat. Poster.

Conservación de la variación genética de las poblaciones de abeto Douglas en las Islas del Cielo. Se analizó la variación genética de la poblaciones de abeto Douglas (*Pseudotsuga menziesii* [Mirb.] Franco) del suroeste de Norteamérica y norte de México. El número de abetos Douglas en las Islas del Cielo ha ido disminuyendo y se espera que la diversidad genética sea baja en pequeñas poblaciones aisladas como éstas. Los resultados de este estudio mostraron una variación relativamente alta dentro de la población, pero no entre las poblaciones, a pesar de los pequeños tamaños de población y el aislamiento de una población de otra. La alta diversidad genética se atribuyó a alelos de baja frecuencia que tienden a ser más comunes en los bordes del rango de las especies, y muchas veces resultan como adaptación a los extremos ambientales característicos de estos bordes. Los alelos de baja frecuencia son importantes para mantener la diversidad genética de estas poblaciones y también pueden tener una importancia adaptativa, por lo que son importantes los esfuerzos para conservarlos. Una relación significativa entre la diversidad genética y la densidad de soporte sugiere que el flujo de genes mantiene la diversidad genética y con ello ayuda a conservar los alelos de baja frecuencia. Por lo tanto, la conservación de la diversidad genética será más efectiva si se mantienen los soportes actuales. Finalmente, una relación significativa entre biodiversidad genética y latitud es consistente con la idea que las estas poblaciones sureñas son más antiguas que las poblaciones más al norte debido a los patrones del retiro glacial. Póster.

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A cultural resource overview of the Santa Rita Experimental Station: a representation of the necessity of cultural and natural resource collaboration. Cultural Resource Specialists function as interpreters of past and present human behavior through the analysis of cultural/natural resources vital to human ecological sustainability. When developing short and long-term preservation strategies for cultural resources, it is more current and innovative for Cultural Resource Specialists to think of past human populations as occupiers of broad ranges of landscapes and not limit our interpretive spheres to site-specific locales only. Cutting edge Cultural Resource Specialists are expanding their knowledge through integrated research, public interaction and state-of-the-art preservation techniques. The current paper and presentation are an effort to contribute to this expansion. Cultural Resource Specialists must begin to articulate the similarities (and differences) of Cultural and Natural Resource Specialists and to use this collaborative force to contribute, scientifically, to the preservation of cultural and natural resources. We must begin to combine our scientific efforts in an endeavor to confront, collectively, the future of the overall innovative and emergent management strategies of cultural/natural resources. The current paper will address these concerns in the context of cultural resource management strategies in the Santa Rita Experimental Station. Poster.

Una descripción de los recursos culturales de la Estación Experimental Santa Rita: una representación de la necesidad cultural y la colaboración de los recursos naturales. Los Especialistas de Recursos Culturales funcionan como interpretadores del pasado y presente del comportamiento humano a través del análisis de recursos culturales/naturales vitales para la sustentabilidad ecológica humana. Al desarrollar estrategias de conservación, de corto y largo plazo, de los recursos culturales, es más actual e innovador que los Especialistas de Recursos Culturales piensen en las poblaciones humanas pasadas como ocupantes de amplios rangos de paisaje y no limitar nuestros ámbitos interpretativos sólo a lugares específicos. Los Especialistas de Recursos Culturales vanguardistas están ampliando su conocimiento a través de la investigación integrada, la interacción con el público y modernas técnicas de preservación. El trabajo y la presentación que se muestran ahora son un esfuerzo para contribuir a esta expansión. Los Especialistas de Recursos Culturales deben empezar a articular las similitudes (y diferencias) de los Especialistas de Recursos Culturales y Naturales y así utilizar esta fuerza colaboradora para contribuir científicamente a la conservación de recursos naturales y culturales. Debemos empezar a combinar nuestros esfuerzos científicos para procurar la confrontación colectiva de las futuras e innovadoras estrategias de manejo de los recursos culturales/naturales. Este trabajo tratará sobre estas preocupaciones en el contexto de las estrategias de manejo de recursos culturales de las Estación Experimental Santa Rita. Póster.

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Community-based conservation in the upper San Pedro watershed, Sonora, Mexico: a case study. Proyecto Corredor Colibrí (PCC) is a binational collaboration that works with communities in the Upper San Pedro Watershed of Sonora in natural and cultural resource conservation. Specific organization goals include capacity-building of local residents, conservation of biodiversity, and the development of ecologically, economically, and socially sustainable projects that stand as examples to communities throughout the watershed. PCC accomplishes its goals through environmental education and community outreach, research and monitoring, and economic diversification, seeking win-win situations for both communities and conservation. This paper provides an overview of PCC's grassroots projects at two upper tributaries to the San Pedro River in Sonora: Villa Verde and Los Campitos. Villa Verde encompasses the three most endangered habitats in the Upper San Pedro Watershed and provides a link between Sierra de Los Ajos and Sierra de San José. Los Campitos is located in the madrean evergreen woodland of Sierra La Mariquita and Sierra La Elenita. Both Villa Verde and Los Campitos provide critical habitat to Neotropical migratory birds and other wildlife. We highlight PCC's innovative, bottom-up efforts at conservation through habitat restoration and outreach projects with landowners, community leaders, and teachers. We also discuss lessons learned and make recommendations for future successes.

Conservación a base de comunidades en el línea superior de aguas superior de San Pedro, Sonora, México: un estudio de caso. El Proyecto Corredor Colibrí (PCC) es una colaboración bi-nacional que trabaja con las comunidades en el Línea Divisoria de Aguas Superior de San Pedro de Sonora en la conservación de los recursos culturales y naturales. Las metas específicas de esta organización incluyen la capacitación de los residentes locales, la conservación de la biodiversidad y el desarrollo ecológico, económico y social de proyectos sustentables que sirvan de ejemplo a las demás comunidades a lo largo de las líneas divisorias de aguas. PCC logra sus metas a través de la educación ambiental y comunicación con las comunidades, investigación y monitoreo y diversificación económica, en la búsqueda de situaciones donde ganen tanto las comunidades como la conservación. Este trabajo provee una perspectiva de los proyectos grassroot de PCC en los dos tributarios superiores del Rió San Pedro en Sonora: Villa Verde y Los Campitos. El diverso medio ambiente de Villa Verde incluye los tres hábitats en mayor peligro de extinción en el Línea Divisoria de Aguas Superior de San Pedro y provee una conexión entre la Sierra de Los Ajos y la Sierra de San José. Los Campitos se localiza en los bosques perennifolios madrenses de la Sierra la Mariquita y la Sierra la Elenita. Tanto Villa verde como Los Campitos proporcionan un hábitat crítico para las aves migratorias neotropicales y otros tipos de vida silvestre. Hacemos énfasis en los esfuerzos innovadores de conservación de un nivel local a federal a través de la restauración de los hábitats y proyectos de comunicación con los terratenientes, los líderes de las comunidades y los maestros. También discutimos acerca de las lecciones aprendidas y hacemos recomendaciones para futuros éxitos.

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Safe harbor: a tool to help recover topminnow and pupfish in Arizona. The Arizona Game and Fish Department (AGFD) is developing a Safe Harbor Agreement for the Gila and Yaqui topminnow, and desert and Quitobaquito pupfish. Safe Harbor Agreements are an Endangered Species Act tool for non-federal landowners. The AGFD Safe Harbor for topminnow and pupfish will be a proactive tool that will promote the conservation and recovery of these endangered species. The topminnow was listed as endangered in 1967 and the pupfish in 1986. Since then, many conservation efforts have been attempted, but the status of all four species is only marginally better than when the species were listed. The Safe Harbor will assist recovery by: creating duplicate populations; creating partnerships between state, federal, and other groups; minimizing the use of mosquitofish and other nonindigenous species; providing for mosquito control; and educating those outside the native fish community. The arrival of West Nile Virus in Arizona may actually be beneficial to topminnow and pupfish. Since both topminnow and pupfish are known to prey on mosquito larvae as effectively as mosquitofish, a tremendous marketing opportunity has presented itself. Making these fish available for release in suitable habitats to control mosquitos allow us to meet our goals for the Safe Harbor, while creating partnerships essential to species conservation.

Puerto seguro: una herramienta para recuperar el topminnow y el pez perrito en Arizona. El Arizona Game and Fish Department está desarrollando un Acuerdo de Puerto Seguro para el topminnow Gila y Yaqui y el Pez Perrito del desierto y Quitobaquito. Los Acuerdos de Puerto Seguro son una herramienta del Endangered Species Act para terratenientes no federales. El Puerto Seguro AGFD para el topminnow y el pez perrito será una herramienta proactiva que promoverá la conservación y recuperación de estas especies en peligro de extinción. Se enlistó al topminnow como especie en peligro de extinción en 1967 y al pez perrito en 1986. Desde entonces, se han intentado muchos esfuerzos de conservación, pero el estatus de estas cuatro especies no ha mejorado mucho desde que fueron enlistadas. El Puerto Seguro asistirá a la recuperación al crear poblaciones duplicadas, crear acuerdos entre estatal, federal y otros grupos, minimizar el uso de pez mosquito y otras especies no nativas, controlar los mosquitos y educar a aquellos fuera de la comunidad nativa de pesca. La llegada del Virus del Oeste del Nilo a Arizona puede ser benéfica para topminnow y pez perrito. Con el conocimiento que tanto topminnow y pez perrito se alimenta de larvas de mosquito con la misma eficacia que el pez mosquito se ha presentado una enorme oportunidad de comercialización. Al lograr que estos peces estén disponibles para su liberación en hábitats convenientes pare el control de mosquitos, nos permite satisfacer nuestras metas para el Puerto Seguro, mientras que crea las sociedades esenciales para la conservación de especies.

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Kleptoparasitic behavior and species richness at Mt. Graham red squirrel middens. Red squirrels (*Tamiasciurus hudsonicus*) larder hoard conifer cones in cone scale piles known as middens. Middens may provide resources for other small mammals resulting in higher species diversity. Middens also likely facilitate kleptoparasitism (stealing) because they are conspicuous and contain large quantities of high quality food. Introduced Abert's squirrels (*Sciurus aberti*) have been observed to kleptoparasitize cones from endangered Mt. Graham red squirrel middens. We used remote photography to assess the frequency of inter- and intra-specific kleptoparasitism and species richness at Mt. Graham red squirrel middens in the Pinaleño Mountains. Remote cameras and marked conifer cones were placed at occupied and unoccupied middens and random forested sites. By examining photographs, we were able to identify frequency of kleptoparasitism and species richness at different sites. Very few Abert's squirrels were recorded and only at unoccupied middens and random sites. Red squirrels were most common at unoccupied middens, infrequent at random sites, and very rare at occupied middens. These results suggest that inter- and intra-specific kleptoparasitism of Mt. Graham red squirrel middens is uncommon. Territorial behavior exhibited by red squirrels likely deters potential kleptoparasites. Ten species of birds and mammals were detected at red squirrel middens and only 3 species at random sites. Red squirrels may serve as a keystone species that increase species richness and abundance of small mammals.

Conducta clepto-parasítica y riqueza de especies en las madrigueras de la ardilla roja de Mt. Graham. Las ardillas srojas (*Tamiasciurus hudsonicus*) almacenan conos de coníferas en montones de escamas de conos denominadas madrigueras. Las madrigueras proveen de recursos para otros mamíferos pequeños, resultando en una gran diversidad de especies. Las madrigueras también probablemente faciliten el clepto-parasitismo (robo) debido a que son notorias y contienen grandes cantidades de comida de alta calidad. La ardilla introducida de Abert's (*Sciurus aberti*) se ha visto que clepto-parasita los conos en madrigueras de la ardilla roja de Mt. Graham, actualmente en peligro. Estudiamos fotografía remota para establecer la frecuencia de clepto-parasitismo inter e intra-específico y la riqueza de especies en las madrigueras de la ardilla roja de Mt. Graham en las Montañas Pinaleño. Las cámaras remotas y los conos de conífera marcados se ocuparon en madrigueras ocupadas y sin ocupar y en sitios al azar dentro del bosque. Examinando las fotografías, se pudo identificar la frecuencia del clepto-parasitismo y la riqueza de especies en diferentes sitios. Pocas ardillas Abert se registraron y solo en madrigueras desocupadas y en sitios al azar. Las ardillas rojas fueron las más comunes en madrigueras desocupadas, infrecuentes en sitios al azar y muy raras en madrigueras ocupadas. Estos resultados sugieren que el clepto-parasitismo inter e intra – específico de la ardilla roja Mt. Graham es poco común. La conducta territorial que exhibieron las ardillas rojas, muy probablemente evita a cleptoparásitos potenciales. Diez especies de aves y mamíferos se detectaron en madrigueras de ardilla roja y solo 3 especies en sitios al azar. La riqueza de especies de mamíferos pequeños fue mayor en madrigueras de ardilla roja que en sitios al azar. Las ardillas rojas pueden haber servido como especies clave que incrementan la riqueza de especies y la abundancia de mamíferos pequeños.

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An assessment of the spatial extent and condition of grasslands in the Arizona, New Mexico, and Mexico borderlands. Grasslands of the Arizona, New Mexico, and Mexico borderlands have experienced dramatic changes for over a century, including shrub encroachment, loss of perennial grasses, and spread of exotic species. To assess changes and to identify remaining native and restorable grasslands for conservation planning and management, we used a combination of expert consultation, remote sensing, and field verification. Open-native grasslands comprise 16.6% of current and historical grasslands. Shrub encroachment has occurred on 67% of identified grasslands. However, 31.6% are potentially restorable. Conversion from grassland to shrubland has occurred on 36.2% of the study area. Exotic grasses have invaded 12.1% of grasslands on the U.S. side. We found no regional-scale invasion on the Mexico side. Less than 1% of open-native grassland has a moderate to high level of legal protection; 70% has no protection. A moderate to high level of protection occurs on 5% of restorable native grassland. The remainder has low to no protection. Private lands account for 59.4% of open-native grassland; 93.5% of which has no legal protection. In a region experiencing a rapid rate of growth and development pressure, remaining native grasslands of the U.S.-Mexico borderlands are well-positioned to become increasingly fragmented and vulnerable to exotic grass invasion.

Una definición de la extensión espacial y condición de los pastizales de Arizona, New Mexico y la frontera de México. Los pastizales de Arizona, Nuevo México y la frontera con México han experimentado cambios dramáticos por más de un siglo, incluyendo el incremento de arbustos, la pérdida de pastos perennes y el aumento de especies exóticas. Para determinar los cambios e identificar los pastizales remanentes y restaurables para la planeación de la conservación y manejo, utilizamos una combinación de consulta de expertos, percepción remota y verificación de campo. Pastizales nativos y abiertos comprenden el 16.6 % de los pastizales actuales e históricos. Incremento de arbustivas y leñosas ha ocurrido en 67 % de los pastizales identificados. Sin embargo, 31.6 % son potencialmente restaurables. La conversión de pastizal a matorral ha ocurrido en 36.2 % del área de estudio. Los pastos exóticos han invadido 12.1 % de los pastizales en el lado de los E.E.U.U. No encontramos una invasión a nivel regional en el lado de México. Menos de 1 % de pastizales nativos – abiertos tienen estatus de protección legal moderada; 70 % no tienen protección. Un nivel moderado a alto de protección ocurre en 5 % del pastizal nativo restaurable. El resto tiene baja o nula protección. Los terrenos privados constituyen el 59.4 % de los pastizales nativos abiertos, de los cuales 93.5 % de éllos no tienen protección legal. Para una región experimentando rápidas tasas de crecimiento y presión de desarrollo, los pastizales nativos remanentes en la frontera de los E.E.U.U. – México parecen estar en posición de sufrir mayor fragmentación y vulnerabilidad a la invasión de pastos exóticos.

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Mexico's nationwide avian monitoring program. The Comisión Nacional de Áreas Naturales Protegidas, in cooperation with other federal agencies, is developing an inter-institutional proposal for a national program for the evaluation and monitoring of avian populations and their habitats in the Republic of Mexico, particularly in the Áreas Naturales Protegidas and other critical areas. It is important to respond to the concrete needs for information and achieve more efficient management of biodiversity in Mexico, to incorporate the numerous efforts that already exist in the country, and to generate new programs to make use of the existing pools of information in an orderly manner.

The general objective is to foster understanding of avian populations and their habitats in Mexico, thereby achieving their conservation in the short and long term. Specific objectives include: (1) creating a solid institutional platform for a permanent framework with taxonomic and biogeographical coverage at a national scale; (2) empower stakeholders (in government and society) to participate across distinct sectors; (3) increase and improve the understanding of biodiversity in Mexico; and (4) rely on adequate biological information to achieve conservation, management, and sustainable use. Strategic measures will address: institutional mechanisms, cross-sector alliances, identification of appropriate geographic foci and methodologies, public access to information, and evaluation of research.

Programa nacional de evaluación y seguimiento de las poblaciones de aves silvestres en México. La Comisión Nacional de Áreas Naturales Protegidas, en cooperación con otras agencias federales, está desarrollando una propuesta interinstitucional para un programa nacional de evaluación y seguimiento de las poblaciones de aves silvestres y sus hábitats en la República Mexicana, particularmente en las Áreas Naturales Protegidas y otras áreas críticas. Es importante responder a necesidades concretas de información y lograr una gestión más eficiente de la biodiversidad de México, incorporar los numerosos y variados esfuerzos que existen actualmente en el país y generar de manera ordenada, nuevos programas que cubran las lagunas de información existentes.

El objetivo general es fomentar el conocimiento sobre las poblaciones de aves silvestres en México y su hábitat, y así lograr su conservación a corto y largo plazo, con objetivos más específicos de: (1) crear una sólida plataforma institucional para una red permanente, con representatividad taxonómica y biogeográfica a escala nacional; (2) capacitar a los interesados

(gobierno y sociedad) en participar en los esfuerzos entre distintos sectores; (3) incrementar y mejorar el conocimiento de la biodiversidad del país; y (4) contar con información biológica adecuada para lograr su conservación, manejo y uso sustentable. Las lineas estratégicas incluyen: mecanismos institucionales, alianzas con otros sectores, identificación de enfoque geográfica y de las metodologías, acceso público de información, y evaluación de investigaciones.

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Viva taxonomy! Viva Sky Island trees! This presentation explores botanical changes in the forests between the southern and northern limits of the Sky Island region, and celebrates the significance of taxonomy and field-oriented biologists and conservationists. The biological changes are largely from subtropical affiliations in the south to temperate affiliations in the north, giving the region unique qualities. The diverse taxa of tropical affinity have their northward extensions generally limited by increasing wintertime minimum temperatures as the northward march of the Sky Islands veers inland away from ameliorating maritime influence and towards increased aridity. Much of this northward march of southern montane tropical diversity halts in the mountains of Sonora where one even finds epiphytic orchids and bromeliads growing on "southern" oaks and pines, or at southern-northern meeting places one can find an intermingling of maples, oaks, palms, and organ pipe cacti. The transitions of southern and northern taxa bring a welter of fascinating and perplexing taxonomic problems — the stuff of botanical intrigue and biological reality. What are the real southern limits of so many of the northerners? Are some geographic limits being obscured by taxonomic problems as well as changes due to human activities? And lastly, as card-carrying biologists what more can we do than just witness mega-destruction of the forests?

!Viva la taxonomía! !Vivan los arboles de las Islas del Cielo! Esta presentación explora los cambios en los bosques entre los límites sur y norte de la región de las Islas del Cielo y celebra lo significativo de la taxonomía y a los biólogos y conservacionistas orientados hacia el campo. Los cambios biológicos son principalmente de afiliaciones subtropicales en el sur a afiliaciones templadas en el norte, dando cualidades únicas a la región. Los diversos taxa de afinidad tropical tienen sus extensiones hacia el norte generalmente limitadas por temperaturas mínimas que se incrementan en la estación de invierno conforme la marcha de las Islas del Cielo vira hacia tierras continentales alejándose de la influencia marina y hacia una aridez mayor. Mucho de esta marcha hacia el norte de la diversidad tropico-montana se interrumpe en las montañas de Sonora donde uno puede encontrar orquideas y bromelias epífitas creciendo sobre encinos y pinos "sureños", o hacia el sur-norte alcanzando lugares en que uno puede encontrar una mezcla de alisos, encinos, palmas y pitahayas. Las transiciones de los taxa del sur y norte traen una confusión con problemas taxonómicos fascinantes y perplejos – un atestamiento de intriga botánica y realidad biológica. Cuales son los límites reales hacia el sur de los muchos elementos norteños? Existen algunos límites geográficos que están siendo obscurecidos por problemas taxonómicos así como por cambios ocasionados por las actividades humanas? Y, finalmente, que podemos hacer como biólogos en vez de ser testigos de la mega destrucción de los bosques?

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International Arid Lands Consortium contributions to Madrean Archipelago stewardship. The International Arid Lands Consortium (IALC) was established in 1990 to promote research, education, and training activities related to the development, management, and reclamation of arid and semi-arid lands worldwide. The IALC supports ecological sustainability and development of these lands. Building on a decade of experience, the IALC continues to increase the knowledge-base for managers by funding research, development, and demonstration projects and special initiatives. The results from these scientific and technical efforts enhance management of arid and semi-arid ecosystems for sustainable use within the framework of maintaining the integrity of the ecological processes. This paper reviews the contributions of the IALC's scientific and technical programs to Madrean Archipelago stewardship through a synopsis of the projects and initiatives pertaining to this region. These efforts have been grouped into soil and water resources development and conservation, land use and reclamation, processes enhancing the management of ecological systems, and inventorying and measurement techniques and monitoring for presentation purposes. Poster.

Contribuciones del Consorcio Internacional de Tierras Aridas a la representacion archipielago madrense. El consorcio internacional de tierras áridas (IALC, por sus siglas en inglés), fue establecido en 1990 para promover la investigación, educación, y actividades de entrenamiento relacionadas con el desarrollo, manejo y recuperación de tierras áridas y semiáridas en todo el mundo. El IALC proporciona sostenibilidad ecológica y desarrollo de esas tierras. Construyendo una década de experiencias, el IALC continua incrementando el conocimiento básico para manejadores patrocinando proyectos de investigación, de desarrollo y de demostración, así como iniciativas especiales. Los resultados de estos esfuerzos científicos y técnicos mejoran el manejo de los ecosistemas áridos y semiáridos para un uso sostenible, dentro de un marco de mantenimiento de la integridad de los procesos ecológicos. En esta ponencia, se describen brevemente estudios de la IALC que han contribuido a una mejor representación de la tierra en el Archipiélago Madrense en término de las implicaciones de su manejo. Póster.

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Vegetative characteristics of oak savannas in the southwestern United States: a comparative analysis with oak woodlands in the region. Much has been learned about the oak (encinal) woodlands of the southwestern United States in recent years. Ecological, hydrologic, and environmental characterizations have been obtained through collaborative efforts involving a large number of collaborators. This state-of-knowledge has been presented in a variety of publications and presentations. However, comparable characterizations of the companion oak savannas are needed to help in enhancing the knowledge of all oak ecosystems in the Madrean Archipelago region. Oak savannas differ from oak woodlands in that they are more open in their structure with fewer trees and, as a consequence, a higher level of herbaceous development and production is attained. Species compositions, densities, and growth rates of tree overstories and species composition, production, and utilization of herbaceous understories in representative oak savannas are presented in this paper with comparisons of these characterizations to the more densely stocked oak woodlands. Information such as this is prerequisite to planning for more holistically conceived, ecosystem-based management of these fragile plant communities.

Características vegetativas de sabanas de encinos en el suroeste de los estados unidos: un análisis comparativo con los bosques de encino en la región. Mucho a sido aprendido en relación a los bosques de encino del suroeste de los Estados Unidos en los años recientes. Se han obtenido caracterizaciones ecológicas, hidrológicas y ambientales a través de esfuerzos colaborativos implicando a un gran número de personas. Este estado del conocimiento ha sido presentado en una variedad de publicaciones y ponencias. Sin embargo, caracterizaciones comparables a las de la sabana de encino son necesarias para ayudar a mejorar el conocimiento de todos los ecosistemas de encinos en la región del Archipiélago Madrense. Las sabanas de encinos difieren en los bosques de encino en que ellas son más abiertas en su estructura, con más pocos árboles y, por consecuencia, un alto nivel de desarrollo herbáceo y de producción es alcanzado en ellas. En esta ponencia se presentan las composiciones de especies y las densidades de los estratos superiores arboreos así como la producción de pastos, hierbas y arbustos en los estratos inferiores o herbáceos en las sabanas de encinos representativas, con comparaciones de estas caracterizaciones en relación a los más densamente poblados bosques de encinos. Este tipo de información es un prerequisito para la planeación de un manejo holístico, basado en ecosistemas de estas fragiles comunidades de plantas.

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Distribution of birds and plants at the western and southern edges of the Sky Island region in Sonora, Mexico. The western and southern edges of the Sky Island Region in Sonora, Mexico are poorly defined and have received little study. In these areas, isolated stands of oak woodland occur on mountains separated by vast lowlands of Sonoran Desertscrub or Semidesert Grasslands in the west and by Sinaloan Thornscrub in the south. I explored the distribution of birds and woody plants in these mountain “islands” and in the intervening lowlands at the western and southern fringes of the Sky Island region in Sonora. I documented range expansions and additional records for several species of management and conservation interest. Many of these new records can likely be attributed to the lack of past field work in these areas rather than recent colonization events. Although many of these disjunct mountains have not been considered as part of the Sky Island region, they have Madrean affinities. Therefore, I suggest their biota indicate they require inclusion as part of the Sky Island region. Organisms in the more xeric regions of the Arizona-Sonora borderlands should be carefully inventoried while the region remains relatively unaltered from human actions.

Distribución de aves y plantas en los límites poniente y sur de la región de las Islas del Cielo en Sonora, México. Los límites poniente y sur de la Región de las Islas del Cielo en Sonora, México están pobremente definidos y han sido poco estudiados. En esas áreas ocurren “stands” aislados de bosques de encino en montañas separadas en el oeste por bastas planicies de matorrales desérticos y pastizales semidesérticos y por matorral espinoso sinaloense en el sur. Exploré la distribución de aves y plantas leñosas en esas “islas” montañosas y en las planicies de las franjas sur y oeste de la región de las Islas del Cielo en Sonora. Documenté las expansiones y registros adicionales para varias especies de interés en conservación y manejo. Muchos de estos nuevos registros pueden seguramente ser atribuidos a la ausencia en el pasado de trabajos de campo en esas áreas, más bien que eventos de reciente colonización. Aunque muchas de esas montañas disjuntas no han sido consideradas como parte de región de las Islas del Cielo, ellas tienen afinidades Madrenses. Por lo tanto, sugiero que su biota indica que requieren su inclusión como parte de la región de las Islas del Cielo. Los organismos de las regiones más xéricas de las tierras fronterizas de Arizona-Sonora deberían ser cuidadosamente inventariadas mientras la región permanezca relativamente inalterada por las acciones humanas.

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Inbreeding in Mexican wolves: evaluating the consequences of merging wolf lineages. Inbreeding in small populations of endangered species can reduce fitness of individuals and populations, making recovery more difficult. In Mexican wolves, available data suggest that inbreeding has lead to reduced body size in the most numerous lineages. To better manage the extant genetic diversity of Mexican wolves, three captive lineages were merged beginning in 1997. These lineages were founded from unrelated individuals and prior to 1997 there was no interbreeding between them. While each of the lineages has accumulated substantial inbreeding, offspring resulting from crosses between lineages should be free of inbreeding. They should also be free of the negative phenotypic effects of inbreeding, if any. We use body size to evaluate the effects of merging the three lineages of Mexican wolves. First we reexamine the relationship between inbreeding and body size using larger samples of past McBride lineage wolves. Next we compare the weights of cross-lineage wolves with contemporary and past wolves from the McBride lineage to look for an effect of the reduction in inbreeding among the cross-lineage wolves. The consequences of these results to management of the captive and reintroduced populations of Mexican wolves will be discussed.

Consanguinidad en lobos mexicanos: evaluando las consecuencias de la mezcla de linajes de lobos. La consanguinidad en pequeñas poblaciones de especies en peligro de extinción puede reducir la aptitud de individuos y poblaciones, haciendo más difícil su recuperación. En lobos mexicanos, la información disponible sugiere que la consanguinidad ha llevado a la reducción del tamaño corporal en la mayoría de los híbridos. Para manejar mejor la diversidad genética existente de los lobos mexicanos, tres linajes en cautiverio fueron mezclados a inicios de 1997. Esos linajes fueron provenientes de individuos no relacionados entre sí y, antes de 1997, no existía consanguinidad entre ellos. Mientras que cada uno de los linajes ha acumulado consanguinidad substancial, las descendencias resultantes de las cruzas entre linajes deberían estar libres de consanguinidad. Ellas deberían también estar libres de efectos fenotípicos negativos de la consanguinidad. Nosotros usamos el tamaño corporal para evaluar los efectos del mezclado de los tres linajes de lobos mexicanos. Primero nosotros reexaminamos las relaciones entre la consanguinidad y el tamaño corporal usando grandes muestras de antiguos lobos de linaje McBride. Enseguida comparamos los pesos de lobos con linaje cruzado proveniente de lobos contemporáneos con lobos antiguos de linaje McBride tratando de buscar un efecto de reducción en la consanguinidad entre lobos de linaje cruzado. Las consecuencias de estos resultados para el manejo de las poblaciones de lobos mexicanos cautivos y reintroducidos serán discutidas.

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Greater Huachuca Mountains Fire Management Group. The Greater Huachuca Mountains Fire Management Group brings together public and private partners to manage fire activities over roughly 500,000 acres of mountains and valleys in southeast Arizona. Partner land managers include Arizona State Parks, Arizona State Lands, Audubon Research Ranch, Coronado National Forest, Coronado National Memorial (NPS), Fort Huachuca, The Nature Conservancy, San Pedro Riparian National Conservation Area (BLM), and private ranches. The group is preparing a fire management plan to guide cross-jurisdiction collaborations on wildland fire use, suppression of unwanted wildfires, prescribed burns, and use non-fire means to reduce fuels around developed and other sensitive areas. To complete the plan, subgroups have taken on such tasks as ecological mapping, compilation of fire history and fire ecology data, condition class assessment, formulation of prescriptions for sensitive sites and resources, and development of outreach programs. Group field exercises contribute needed new data and provide opportunities for members of this diverse group to become better acquainted. Key benefits of managing for fire on this broad landscape scale include (1) increased public and fire crew safety, (2) improvement in ecosystem function, and (3) economical execution of fire activities. The Huachuca group collaboration also addresses border issues and is soliciting Mexican partners.

El grupo de manejo de incendios de las Montañas Huachuca. El Grupo de Manejo de Incendios de las Montañas Huachuca reúne a socios tanto públicos como privados para realizar actividades sobre incendios en aproximadamente 250,000 hectáreas de montañas y valles en el Sureste de Arizona. Esas asociaciones incluyen al Arizona State Parks, Arizona State Lands, Audubon Research Ranch, Coronado National Forest, Coronado National Memorial (NPS), Fort Huachuca, The Nature Conservancy, San Pedro Riparian National Conservation Area (BLM), además de ranchos privados. El grupo está preparando un plan de manejo de incendios para guiar las colaboraciones a lo largo de la jurisdicción en relación al uso de fuego en terrenos naturales, supresión de incendios no deseados, fuegos prescritos y el uso del no-fuego como medio para reducir materiales incendiables alrededor de áreas pobladas y otras áreas sensibles. Para complementar el plan, algunos subgrupos participan en distintas faenas realizando mapeos ecológicos, compilando información sobre historia y ecología de incendios, evaluando clases de condición, en la formulación de prescripciones para sitios y recursos sensibles y en el desarrollo de programas de extensionismo. Los ejercicios en campo del grupo, contribuyen con nueva información necesaria y proporcionan oportunidades para que los miembros de este grupo tan diverso se vean mejor capacitados. Algunos beneficios claves del manejo del fuego en este escenario de gran escala incluyen (1) incremento en la seguridad pública y de equipos contra incendios, (2) mejoramiento en el funcionamiento de los ecosistemas y (3) ejecución económica de actividades sobre acerca del fuego. La colaboración del grupo Huachuca también considera asuntos fronterizos y está solicitando participantes mexicanos.

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Response of semi-desert grasslands dominated by non-native perennial grass to fire season. In the Madrean Archipelago, semi-desert grasslands rise above the desert seas to meet the Sky Islands. The elevational gradient lends itself to a unique assemblage of grasslands hosting a rich diversity of species, some at their southern-most or northern-most extent. Since the arrival of Anglos, grasslands have experienced significant shifts in community structure and are currently dominated by woody species and non-native perennial grasses. Land managers are restoring fire, contrary to historic fire regimes and into vastly altered systems, in an effort to recreate semi-desert grasslands. A perennial grass introduced from southern Africa, *Eragrostis lehmanniana*, is of primary concern because of its adaptation to fire and association with declines in diversity across guilds. We designed a large-scale experiment in southeastern Arizona to quantify changes in plant community structure following fire treatments (spring, summer, no fire) across a gradient of dominance by *E. lehmanniana*. Although the biomass of *E. lehmanniana* decreased significantly and remained low for at least two years after fire, the relative abundance of *E. lehmanniana* to native species did not change. In a system limited by moisture, response of native plant communities to fire treatments and presence of *E. lehmanniana* was linked to climatic variability.

Respuesta de pastizales semidesérticos dominados por un pasto perenne no nativo a la estación de incendios. En el Archipiélago Madrense, los pastizales semidesérticos emergen por arriba de los mares de desierto hasta alcanzar las islas del cielo. El gradiente elevacional se presta para que se de un ensamblaje único de pastizales que alojan una rica diversidad de especies, algunas hacia su parte más al sur o más al norte. Desde la llegada de los Anglos, los pastizales han experimentado desplazamientos significativos en la estructura de las comunidades y actualmente son dominados por especies leñosas y pastos perennes no nativos. Los manejadores de tierras están restaurando los incendios, lo cual es contrario a los regímenes históricos de fuegos y en sistemas bastante alterados, en un esfuerzo por recrear los pastizales semidesérticos. Un pasto perenne introducido del sur de Africa, *Eragrostis lehmanniana*, es de importancia primaria debido a su adaptación al fuego y su asociación con descensos en la diversidad a lo largo de las comunidades. Nosotros diseñamos un experimento a gran escala en el sur de Arizona para cuantificar los cambios en la estructura de las comunidades vegetales después de tratamientos con fuego (primavera, verano, no fuego) a lo largo de un gradiente de dominancia por *E. lehmanniana*. Aunque la biomasa de *E. lehmanniana* disminuyó significativamente y permaneció baja por al menos dos años después del fuego, la abundancia relativa de *E. lehmanniana* contra las especies nativas no cambió. En un sistema limitado por la humedad, la respuesta de las comunidades vegetales nativas a tratamientos con fuego, y a la presencia de *E. lehmanniana*, fue ligada a la variabilidad climática.

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Building effective international, multicultural alliances for restoration of ejido forests in the Sierra Madre Occidental. Effective NGO-government-community alliances are the key to overcoming the complex socio-political obstacles to conservation in the Sierra Madre Occidental. Over 80% of the territory in the Sierra Madre Occidental is communally owned. A variety of land tenure arrangements present both opportunities and obstacles to conservation. Social conditions characterized by extreme poverty, unemployment, *cacicazgo*, corruption, violence, and illiteracy all contribute to the spiral of environmental and socio-economic decline. Conservation, environmental justice, and community development are inseparable components of effective conservation in the communal lands of the Sierra. Case studies from the Sierra Tarahumara and Madera regions reveal the effectiveness of interdisciplinary, multi-cultural strategies, participatory planning and diagnostic processes in weaving the social fabric for environmental protection and restoration. Other cases show the pitfalls of inadequate social participation in failed mega-projects. Specific examples of effective alliances, and guidelines for international partners provide the framework for realizing a bioregional vision for preserving the biological and cultural diversity, building restorative economic alternatives, and providing hope to Mexico's poorest regions.

Construyendo alianzas multiculturales, internacionales y efectivas para la restauración de bosques ejidales en la Sierra Madre Occidental. Las alianzas efectivas de tipo comunidad-gobierno-ONG, son la clave para superar los complejos obstáculos socio-políticos para la conservación de la Sierra Madre Occidental. Más del 80% del territorio de la Sierra Madre Occidental es propiedad comunal. La variedad de convenios sobre la tenencia de la tierra presenta oportunidades y obstáculos para la conservación. Las condiciones sociales caracterizadas por extrema pobreza, desempleo, *cacicazgo*, corrupción, violencia y analfabetismo, contribuyen a la formación de una espiral descendente en el deterioro ambiental y socio-económico. La conservación, la justicia ambiental y el desarrollo comunitario son componentes inseparables de la conservación efectiva en las tierras comunales de la Sierra. Estudios de casos en las regiones de la Sierra Tarahumara y Madera, revelan la efectividad de los procesos interdisciplinarios, las estrategias multiculturales, y la planificación y diagnóstico participatorio, para tejer el manto social para la protección y restauración ambiental. Otros casos muestran los escollos de una participación social inadecuada en mega proyectos fallidos. Ejemplos específicos de alianzas efectivas y las guías para socios internacionales proporcionan el marco de trabajo para realizar una visión bioregional para preservar la diversidad biológica y cultural, creando alternativas económicas de restauración y ofreciendo esperanzas a las regiones más pobres de México.

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Conservation through community support: a functioning coalition in the Sierra Madre. Sierra Madre Alliance supports a network of Mexican organizations and community partners dedicated to conservation, community development, environmental and agrarian justice. A poster display and revolving power point presentation demonstrate how an international alliance of grassroots organizations and traditional indigenous communities organize and cooperate to build ethno-ecological management maps and plans, research migratory birds and ethno-ornithology, build regional coalitions, protect endangered forests and indigenous lands, and advance watershed restoration and development alternatives in the face of sometimes overwhelming obstacles. Poster.

Conservación a través del apoyo comunitario: una coalición funcional en la Sierra Madre. La Alianza Sierra Madre brinda asesorías a una red de organizaciones mexicanas y socios comunitarios dedicados a la conservación, desarrollo comunitario, justicia ambiental y agraria. Un despliegue de poster y una presentación en Power Point demuestran como una alianza internacional de organizaciones rústicas y comunidades indígenas tradicionales se organizan y cooperan para construir mapas y planes de manejo etno-ecológico, estudios de aves migratorias y etno-ornitología, crean coaliciones regionales, protegen bosques en peligro y terrenos indígenas y avanzan en restauración de cuencas hidrológicas y desarrollan alternativas en tal forma que en ocasiones salvan obstáculos. Póster.

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Phylogenetic analysis of Chiricahua and Ramsey Canyon leopard frog populations in Arizona. Ramsey Canyon Leopard Frogs *(Rana subaquavocalis*), formerly classified as Chiricahua Leopard Frogs (*R. chiricahuensis*), are found only in the Huachuca Mountains of southern Arizona. These two species are difficult to distinguish phenotypically and field observations indicate that described diagnostic characteristics may not be reliable. We collected tissue samples from throughout the Arizona range of these species to investigate their genetic distinctiveness. We sequenced 1344 base pairs of the mitochondrial control region from 92 samples collected from 7 Ramsey Canyon Leopard Frog and 14 Chiricahua Leopard Frog populations. All Ramsey Canyon Leopard Frog samples shared a single haplotype and differed from Chiricahua Leopard Frogs in the Canelo Hills and Altar Valley by 1-2 base pairs. In both parsimony and maximum-likelihood phylogenetic analyses, Ramsey Canyon Leopard Frogs were within the well-supported southern Arizona clade of Chiricahua Leopard Frogs. Our mitochondrial analyses support previous findings of distinctiveness between southern Arizona and Mogollon Rim forms of the Chiricahua Leopard Frog. We found no evidence that the Ramsey Canyon Leopard Frog is a species distinct from the Chiricahua Leopard Frog. Poster.

Análisis filogenético de poblaciones de ranas leopardo de Chiricahua y Ramsey Canyon en Arizona. Las Ranas Leopardo de Ramsey Canyon (*Rana subaquavocalis*), anteriormente clasificada como Ranas Leopardo de Chiricahua (*R. chiricahuensis*), se encuentran únicamente en las Montañas Huachuca del sur de Arizona. Las dos especies son difíciles de distinguir fenotípicamente y observaciones de campo indican que las características de diagnóstico descritas pueden no ser confiables. Nosotros colectamos muestras de tejido en toda el área de distribución de esta especie en Arizona para investigar su variabilidad genética. Secuenciamos 1344 pares base de la región mitocondrial control de 92 muestras colectadas de 7 poblaciones de Ranas Leopardo de Ramsey Canyon y de 14 poblaciones de Ranas Leopardo de Chiricahua. Todas las muestras de Ranas Leopardo de Ramsey Canyon compartieron un simple haplotipo y difirieron de las Ranas Leopardo de Chiricahua en las Canelo Hills y Altar Valley por 1-2 pares base. En análisis filogenéticos de parsimonia y máxima probabilidad, las Ranas Leopardo de Ramsey Canyon estuvieron dentro del abundante grupo de Ranas Leopardo de Chiricahua del sur de Arizona. Nuestros análisis mitocondriales respaldan previos hallazgos de diferenciación en formas de Ranas Leopardo de Chiricahua entre el sur de Arizona y el Mogollon Rim. Nosotros no encontramos evidencia de que las Ranas Leopardo de Ramsey Canyon pertenecen a una especie diferente a la de las Ranas Leopardo de Chiricahua. Póster.

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Watershed improvement using prescribed burns as a way to restore aquatic habitat for native fish. The Muleshoe Ranch Cooperative Management Area is located in the Galiuro Mountains of southeastern Arizona and has 4 streams that support 2-5 species of native fish, including Gila chub (*Gila intermedia*). The Nature Conservancy and the Bureau of Land Management are using large-scale prescribed burns to increase the abundance and cover of perennial grasses and reduce shrubs in the Hot Springs Creek watershed. I present a conceptual model relating these watershed vegetation changes to improvements in aquatic habitat. Results to date are consistent with the model and show a significant decrease in shrub cover and a relative increase in perennial grass cover on burn vs. controls plots. Since 1994, stream cover and the amount of undercut bank have increased dramatically in Hot Springs Creek. In addition, the mean maximum depth of aquatic habitats has increased as has the number of deep pools. Associated with these aquatic habitat changes, the density of Gila chub and the density of native fish have also increased significantly. Although primarily a monitoring study, the results suggest that prescribed fire and grazing rest are important tools for managing upland vegetation and restoring aquatic habitat and native fish populations.

Mejoramiento de cuencas hidrológicas usando fuegos prescritos como una manera de restaurar hábitats acuáticos para peces nativos. El Área de Manejo Cooperativo Muleshoe Ranch está localizado en las Montañas Galiuro del sureste de Arizona y tiene cuatro corrientes que albergan 2-5 especies de peces nativos, incluyendo el cacho del Gila (*Gila intermedia*). The Nature Conservancy y el Bureau of Land Management están usando fuego prescrito a gran escala para incrementar la abundancia y cobertura de pastos perennes y reducir los arbustos en la cuenca hidrológica Hot Springs Creek. Yo estoy presentando un modelo conceptual en el que relaciono los cambios en la vegetación de la cuenca con el mejoramiento en el hábitat acuático. Los resultados a la fecha son consistentes con el modelo y muestran una disminución significativa en la cobertura de arbustos y un incremento relativo en la cobertura de los pastos perennes en parcelas quemadas contra parcelas control. Desde 1994, la cobertura en las corrientes y la cantidad de ribera rebajada se han incrementado dramáticamente en el Hot Springs Creek. Adicionalmente, la profundidad máxima promedio de los hábitats acuáticos ha aumentado, así como el número de estanques profundos. Asociado con esos cambios en los hábitats acuáticos, la densidad del cacho del Gila y de otros peces nativos, también se ha incrementado significativamente. Aunque este es un estudio primeramente de monitoreo, los resultados sugieren que el fuego prescrito y el descanso en el pastoreo son herramientas importantes para manejar la vegetación de las tierras altas y restaurar el hábitat acuático y las poblaciones de peces nativos.

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The Forest Service, Rocky Mountain Research Station's Southwestern Borderlands Ecosystem Management Project: building on ten years of success. The USDA Forest Service initiated the Southwestern Borderlands Ecosystem Management Project in 1994. The Project concentrates on the unique, relatively unfragmented landscape of exceptional biological diversity in southeastern Arizona and southwestern New Mexico. Its mission is to: "Contribute to the scientific basis for developing and implementing a comprehensive ecosystem management plan to restore natural processes, improve the productivity and biological diversity of grasslands and woodlands, and sustain an open landscape with a viable rural economy and social structure in the region." The Project works closely with partners from federal and state agencies, universities, non-governmental organizations, and private landowners. The original effort was designed to accumulate and synthesize existing information from the region, conduct a comprehensive inventory and monitoring of existing conditions to provide a basis for research and management, and to conduct research to fill gaps in knowledge. A recent review indicated that more than 180 research and resource publications, academic theses and dissertations, and reports have resulted from this cooperation since 1994. Future research will determine the effects of rangeland restoration techniques and fire at landscape levels on Borderlands ecosystem components, and develop and evaluate integrated, cost-effective monitoring methodologies.

Proyecto de la Estación Experimental Rocky Mountain del Servicio Forestal sobre Manejo de Ecosistemas de las Tierras Fronterizas del Suroeste: construyendo en base a diez años de éxito. El Servicio Forestal del USDA inició el Proyecto sobre Manejo de Ecosistemas de las Tierras Fronterizas del Suroeste en 1994. Las actividades del proyecto están concentradas en el sureste de Arizona y el suroeste de New Mexico en un paisaje único, relativamente no fragmentado y con una diversidad biológica excepcional. Su misión es: "Contribuir con una base científica para desarrollar e implementar un plan comprensivo de manejo de ecosistemas para restaurar procesos naturales, mejorar la productividad y la diversidad biológica de los pastizales y los bosques y sustentar un paisaje abierto en la región con una economía rural y una estructura social viables." El Proyecto trabaja muy estrechamente con sus numerosos miembros, investigadores y manejadores de agencias federales y estatales, universidades, organizaciones no gubernamentales y propietarios de terrenos. El esfuerzo original fue diseñado para acumular y sintetizar información existente sobre la región, realizar un inventario exhaustivo y monitorear las condiciones existentes con el fin de proporcionar una base para la investigación y el manejo y conducir estudios para llenar vacíos en el conocimiento. Una revisión reciente indica que, a través de esta cooperación, desde 1994 se han generado más de 180 investigaciones y publicaciones sobre los recursos, tesis y disertaciones académicas, así como reportes técnicos. Investigaciones futuras determinarán los efectos de las técnicas de restauración de pastizales y uso del fuego a nivel de paisaje sobre los componentes de los ecosistemas de las Tierras Fronterizas y desarrollar y evaluar metodologías de monitoreo integradas y con un costo efectivo.

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Designing and implementing regional biodiversity conservation plans. Planning for biodiversity conservation is taking place at a range of spatial scales by a variety of public and private organizations. The ecoregional planning projects of The Nature Conservancy and The Wildlands Project, and the development of statewide comprehensive conservation strategies, illustrate the range of planning activities. There is growing consensus that the most important steps in conservation planning include: (1) identifying biological/ecological entities as conservation targets, (2) establishing explicit goals for targets, (3) gathering information from all possible sources about targets, (4) assessing the ecological integrity and viability of targets, (5) identifying areas with the aid of site-selection algorithms that will conserve targets, and (6) measuring the degree to which implementing these plans will conserve the regional biodiversity. Steps concerned with (7) conserving the underlying ecological processes that maintain biodiversity and (8) measuring planning effectiveness have long been overlooked. Various measures are being explored for assessing how well these planning efforts are being implemented. Proposed measures include the structural intactness of the region, maintenance of disturbance regimes, progress toward specific conservation target goals, degree of legal land protection, and the vulnerability of the region to threats.

Diseñando e implementando planes regionales para la conservación de la biodiversidad. La planificación para la conservación de la biodiversidad está tomando lugar en un rango de escalas espaciales en una variedad de organizaciones públicas y privadas. Los proyectos de planificación ecoregional de The Nature Conservancy y The Wildlands Project y el desarrollo de estrategias de conservación comprensiva a nivel estatal, son ilustraciones de las actividades de planificación. Existe un creciente consenso en que las etapas más importantes en la planificación de la conservación incluyen: (a) la identificación de las entidades biológicas/ecológicas (ejemplo, objetos de conservación) a ser conservadas, (b) el establecimiento de propósitos explícitos para esos objetos, (c) obtención de información de todas las fuentes posibles acerca de esos objetos, (d) determinar la integridad y viabilidad ecológica de esos objetos, (e) identificar áreas con la ayuda de algoritmos para selección de sitios que conservarán a esos objetos y (f) medir el grado al cual la implementación de esos planes conservarán la biodiversidad regional. Las etapas relacionadas con la conservación de los procesos ecológicos que sirven de base para mantener la biodiversidad (etapa d) y la medición de la efectividad de esos esfuerzos de planificación (etapa (f) han sido bastante vigilados. Varias mediciones están siendo exploradas para evaluar que tan bien están siendo implementados los esfuerzos de planificación. Las mediciones propuestas incluyen la integridad estructural de la región, el mantenimiento de los regímenes de perturbación, el progreso hacia las metas de conservación de objetos, el grado de protección legal de la tierra y la vulnerabilidad de la región a las amenazas.

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Between the Sky Islands: historic land uses in cross-border valleys—Arizona-Sonora, New Mexico-Chihuahua. This paper examines the history of land use and land tenure in four cross-border valleys of the Madrean Archipelago region. The valleys under consideration include three that extend across the Arizona-Sonora boundary and one that crosses the New Mexico-Chihuahua boundary. From west to east, they are the Santa Cruz River valley, the San Pedro River valley, the San Simon-San Bernardino valley, and the Animas valley. Each of these valleys, with a roughly north-south axis, has provided a significant corridor for the movement of flora, fauna, and culture groups. Each is bounded by mountain ranges, several of which meet the criteria for Sky Islands.

This paper presents a brief summary of land tenure in the four valleys during the past 250 years. It examines the relationship between tenure and land use, and the consequent ecological impacts for the valleys and the surrounding Sky Islands. The discussion centers on contrasting systems of land tenure in the Mexican and United States portions of the cross-border valleys and questions long-held assumptions concerning the significance of economic and public policy practices of each nation.

Entre las Islas del Cielo: usos históricos de tierra en valles transfronterizos de Arizona-Sonora, New Mexico-Chihuahua. Esta ponencia examina la historia de usos y tenencia de la tierra en cuatro valles transfornterizos de la región de las Islas del Cielo. Tres de ellos se extienden a lo largo de la frontera entre Arizona y Sonora y uno entre New Mexico y Chihuahua. De oeste a este ellos son: el valle del río Santa Cruz, el valle del río San Pedro, el valle de San Simón-San Bernandino y el valle de las Animas. Con una orientación aproximada de norte a sur, cada uno ha servido como corredor importante para el movimiento de flora, fauna y grupos culturales y varios de los grupos montañosos que los rodean cumplen con los criterios para ser catalogados como Islas del Cielo.

En esta ponencia se presenta un breve resumen sobre la tenencia de la tierra en los cuatro valles durante los últimos 250 años. Se examina la relación entre tenencia y uso de la tierra, así como los impactos ecológicos a los valles e Islas del Cielo que los rodean. La discusión se centra en contrastar los sistemas de tenencia de la tierra entre las respectivas porciones de los cuatro valles en México y de Estados Unidos, cuestionando suposiciones mantenidas durante mucho tiempo sobre el significado de las políticas económicas y públicas que se practican en cada país.

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Effects of the chytrid fungus on the Tarahumara frog (*Rana tarahumarae*) in Sonora, Mexico. A chytrid fungus, *Batrachochytrium dendrobatidis*, has been linked to recent anuran population declines in Australia, tropical America, and North America. The disease (chytridiomycosis) is known in several frogs in Arizona, where it may have aided the 1983 extirpation of the Tarahumara frog. We tested for the pathogen using histological examination of museum specimens of Tarahumara frogs collected from six Sonoran sites during 1982-1999. In the field, infected frogs displayed severe neurological symptoms, which were often exacerbated by handling, and some died. Population responses in the early 1980s ranged from extirpation to no observed decline. A 1999 re-survey of these populations indicated apparent extirpation at one site, near extirpation and subsequent recovery at another, and neurological symptoms without apparent decline at four sites, two of which had confirmed chytridiomycosis in both 1982 and 1999. Differential effects of chytrid fungus at different localities suggest an additional stressor, such as winter cold or pollution, may influence disease virulence. Frogs further south or near winter-warm springs may survive chytrid infection better than those in higher elevation and northern populations where lower temperatures prevail, which is consistent with expectations based on physiology of the pathogen.

Efectos de hongos chytridos en ranas Tarahumaras *(Rana tarahumarae)* de Sonora, México. El hongo chytrido, *Batrachochytrium dendrobatidis* ha sido relacionado recientemente con disminuciones de poblaciones de anúridos en Australia, América tropical y Norteamérica. La enfermedad (chytridiomycosis) afecta varias ranas en Arizona y puede haber jugado un papel importante en la extirpación de la rana Tarahumara en 1983. Usando técnicas histológicas se buscó la presencia del patógeno en especimenes de ranas Tarahumaras pertenecientes a museos y colectados en seis sitios en Sonora entre 1982 y 1999. Ranas infectadas colectadas en el campo mostraron varios síntomas neurológicos severos, los cuales empeoraron al ser manipuladas y resultaron en la muerte de varias de ellas. Respuestas de las poblaciones a principios de los años ochentas variaron entre la desaparición total y ninguna disminución observada. Una nueva inspección a estas poblaciones en 1999 reveló un sitio donde habían aparentemente desaparecido, otro donde tras casi desaparecer se recuperaron, y cuatro sitios en los que se observaron síntomas neurológicos pero sin disminuciones poblacionales aunque en dos de ellos se había confirmado la presencia de chytridiomycosis en 1982 y 1999. Variación en los efectos del hongo chytrido entre diferentes localidades sugiere la presencia de otros factores estresantes como bajas temperaturas durante el invierno o contaminación, cuyos efectos pueden influenciar la virulencia de la enfermedad. Ranas con distribuciones más sureñas o cercanas a ojos de agua templada durante el invierno pudieran sobrevivir mejor a las infecciones de chytridos que aquellas con distribuciones poblacionales más norteñas o en altas elevaciones donde prevalecen temperaturas más bajas, lo cual sería consistente con las expectativas basadas en la fisiología del patógeno.

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Challenges to managing information. Numerous efforts are underway by both public and private groups to assess the status of biodiversity on the landscape. Other efforts to gather data about natural resources have come and gone, leaving behind shelves, drawers, and boxes of information that are now not accessible by anyone. As scientists and managers we now have more information then we ever have, yet we struggle. In order to do proper assessments and make appropriate management decisions, we have to apply the best scientific understanding possible. The ability to provide top quality, integrated information depends on our solving problems associated with scale, format, classification systems, hardware, software, and currency of data. A cultural shift needs to be made in our business of science. That is to hire people who know electronic systems – from a mechanic's perspective and from an operator's perspective – in order to handle the great volume of data that now needs to be dealt with. We need to develop information management systems that will allow researchers and managers to obtain natural resource information for the state, for a county, for a federal management unit etc., and be able to update that information and get it back into the system.

Retos para el manejo de la información. Grupos públicos así como privados se encuentran realizando numerosos esfuerzos para evaluar el estado de la biodiversidad en el paisaje. Esfuerzos realizados anteriormente para generar datos sobre recursos naturales han dejado estantes, cajones y cajas llenos de información que no son accesibles para nadie. Aunque científicos y manejadores contamos hoy con más información que nunca, continuamos sufriendo. Para realizar análisis adecuados y tomar decisiones de manejo apropiadas es necesario utilizar el mejor conocimiento científico disponible. La provisión de información integrada y de la mejor calidad depende de nuestra habilidad de resolver problemas asociados con la escala, formato, sistemas de clasificación, sistemas operativos y programas, así como la compatibilidad de los datos. Es necesario un cambio cultural en este negocio de la ciencia. Es necesario contratar gente que conozca de sistemas electrónicos desde una perspectiva mecánica y operativa para poder procesar los grandes volúmenes de información que es necesario manejar hoy en día. Es necesario desarrollar sistemas de manejo de la información que permitan a investigadores y manejadores obtener información de recursos naturales para los estados, condados, unidades de manejo federal, etc. Además de tener la capacidad de actualizar la información y reintegrarla al sistema.

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Bringing back the lower San Pedro River. The San Pedro River is a migratory corridor of international importance for neotropical birds, bats, and insect pollinators. The San Pedro River was formerly perennial from Fairbanks to Redington and from upstream of Mammoth to the Gila River. The perennial flow and associated wetlands supported a diverse array of riparian and aquatic communities. Groundwater development for agriculture and mining has resulted in loss of perennial flow from substantial reaches of the river downstream from Fairbanks.

In an effort to return perennial flow to formerly perennial reaches of the lower San Pedro River (downstream from "The Narrows"), The Nature Conservancy has embarked on an ambitious program of flow management. The program consists of retirement of agricultural pumping in key locations along the lower San Pedro River. Selection of agricultural lands for acquisition and retirement of pumping is based on results from groundwater-surface water modeling and hydrologic analysis.

Following acquisition of a property, hydrologic and ecological monitoring is conducted to better understand the relationship between groundwater, surface water flow, and riparian vegetation. Results from hydrologic monitoring will be reported herein.

Trayendo de regreso el curso bajo del río San Pedro. El río San Pedro es un corredor migratorio de importancia internacional para aves neotropicales, murciélagos e insectos polinizadores. En el pasado el río San Pedro fluía de forma perenne de Fairbanks a Redington y río arriba de Mammoth al río Gila. El flujo perenne y los humedales asociados a él proveían de soporte a una gran diversidad de comunidades ribereñas y acuáticas. La explotación de los mantos acuíferos subterráneos para agricultura y minería han resultado en la pérdida del flujo perenne del río en varios puntos río abajo de Fairbanks.

En un esfuerzo para reestablecer a su antiguo nivel el flujo perenne del curso bajo del río San Pedro (río abajo de "The Narrows"), la organización The Nature Conservancy ha iniciado un ambicioso programa de manejo del caudal. El programa consiste en la eliminación del bombeo de agua para la agricultura en sitios clave a lo largo del curso bajo del río San Pedro. La selección y compra de tierras agrícolas para eliminar el bombeo se basa en los resultados obtenidos a partir de modelos de agua subterránea y superficial así como de análisis hidrológicos.

Una vez que se ha adquirido la propiedad, se realizan monitoreos hidrológicos y ecológicos para continuar mejorando el entendimiento de la relación entre el flujo de agua subterránea y superficial y la vegetación ribereña. En esta ponencia también se reportan los resultados de los monitoreos hidrológicos.

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Citizens' council protecting Sky Island wildlife corridor. The Cienega Corridor, at the eastern edge of Tucson, represents 93,000 acres of State, County, and private land linking Las Cienegas National Conservation Area and the Whetstone and Santa Rita Mountains to national park and forest lands in the Rincon Mountains. Growth projections for Pima County indicate that in the next twenty years nearly half a million people will move to the region, and these lands lie in the path of much of that growth. The Cienega Corridor warrants immediate protection because of its value as a riparian wildlife corridor, its rare and endangered plants and animals, open spaces, recreational opportunities, and importance to groundwater recharge. In tandem with recommendations for federal legislative actions, a 2003 report to Congress recommended that local partners launch a community-based, collaborative management approach to protecting the Cienega Corridor, including creation of an ad hoc organization comprising land managers, landowners, ranchers, recreationists, and other land users. The Cienega Corridor Conservation Council, formed in response to this need, has drafted a charter, hosts speakers on topics relevant to Cienega Corridor protection, has working groups to address specific needs, and has hired a land use planner to help draft long term solutions for this critical wildlife corridor.

Un consejo ciudadano protege el corredor silvestre de las Islas del Cielo. Al lado este de Tucson se encuentra el corredor de la Ciénega conformado por 93,000 acres de tierra estatal, privada y municipal que une al Área Nacional de Conservación de Las Ciénegas y las montañas Whetstone y Santa Rita con tierras forestales y de parque nacional en las montañas Rincón. Según proyecciones de crecimiento para el municipio de Pima se espera que dentro de veinte años casi medio millón de nuevos habitantes residan en la región y las tierras antes mencionadas se encuentran dentro de la trayectoria esperada de este crecimiento. El corredor de la Ciénega requiere de protección inmediata por su valor como corredor ribereño de vida silvestre, sus especies raras y en peligro de extinción, espacios abiertos, oportunidades de recreación e importancia como áreas de recarga para el manto acuífero. En conjunto con recomendaciones para acciones legislativas en el ámbito federal, se recomendó al congreso, en un reporte del año 2003, que socios locales iniciaran un esfuerzo de manejo de base comunitaria y colaborativo para la protección del corredor de la Ciénega. También se recomendó que se creara una organización ad hoc con la participación de administradores de tierras, propietarios, ganaderos, usuarios con fines recreativos y otros usuarios. En respuesta a estas necesidades se formó el Consejo para la Conservación del Corredor de la Ciénaga, el cual ya ha elaborado un anteproyecto con estatutos, invitado oradores para que expongan temas relevantes para la protección del corredor de la Ciénega, creado grupos de trabajo que puedan dar respuesta a necesidades específicas, así como contratado a un planificador de usos de la tierra que ayude a esquematizar soluciones de largo plazo para este importantísimo corredor para la vida silvestre.

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Biological values of BLM managed lands in the Sky Island region of southern Arizona. Plant and animal communities on BLM managed lands are valuable elements in a matrix of federal, private, and state lands. Lands managed by the BLM encompass a wide variety of biotic communities impacted by federal, private, and state actions. To identify the biological resources and values of BLM land and their management status Sky Island Alliance analyzed and will present data from varied sources. These sources include Sky Island Alliance information from road surveys in 2001-4, Arizona Game and Fish Department Heritage Data Management System, New Mexico Department of Game and Fish BISON-M, expert opinion, and local knowledge. The varied and unique vegetation associations on BLM lands not only are habitat for sensitive species but they provide important corridors for both the movement of wide-ranging animals and genetic interchange in populations of less fragile organisms. Poster.

El valor biológico de las tierras administradas por la Agencia del Manejo de Tierra (BLM) en la región de las islas del cielo del sur de Arizona. Las comunidades de plantas y animales en tierras administradas por el BLM son elementos valiosos en la matriz de tierras federales, privadas y estatales. Las tierras administradas por el BLM abarcan una gran variedad de comunidades bióticas que han sido alteradas por acciones federales, privadas y estatales. Para identificar los recursos biológicos y valor de las tierras administradas por el BLM así como su estado de manejo, la Alianza para las Islas del Cielo analizó datos de varias fuentes. Entre ellas se incluye información que la Alianza colectó en sondeos de caminos del año 2000 al 2004, datos del sistema de manejo de información del Departamento de Pesca y Caza de Arizona, del Departamento de Pesca y Caza de Nuevo México, opinión de expertos y conocimiento local. La gran variedad y extraordinarias asociaciones vegetales en tierras del BLM no solo son hábitat para especies delicadas pero también proveen de importantes corredores para su movimiento y el intercambio genético con poblaciones menos frágiles. Póster.

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History, extent, and future of roadless BLM managed lands in the Sky Island region of southern Arizona. Roadless areas of Southeastern Arizona managed by the Bureau of Land Management (BLM) are becoming rare. Fragmentation by roads and development, all-terrain vehicle use, erosion, and altered hydrology are a few of the causes of loss and degradation of roadless areas. The history of BLM and publically identified roadless areas includes the passage of the Wilderness Act of 1964, the Federal Lands Policy and Management Act of 1976, the development and passage of the Arizona Deserts Wilderness Act of 1990, the efforts of the Arizona Wilderness Coalition (AWC) in the 1980's, and Sky Island Alliance's survey work in the late 1990s and 2001-4. Analysis of BLM and AWC wilderness studies, findings, and recommendations along with data from road surveys indicates the potential to protect many high-quality areas of roadless areas. Many of these areas are threatened by policy shifts, continued all-terrain vehicle abuse, road building, and other impacts.

Historia, extensión y futuro de tierras sin caminos administradas por el Agencia de Manejo de Tierras (BLM) en la región de las islas del cielo del sur de Arizona. Son raras las tierras administradas por el BLM que no tengan caminos. Algunas de las causas de la degradación o pérdida de áreas sin caminos son precisamente la fragmentación causada por el desarrollo y construcción de caminos, uso de vehículos todo terreno, erosión y alteración hidrológica. La identificación histórica del BLM con áreas públicas sin caminos incluye la aprobación del Acta de Áreas Naturales en 1964, el Acta Federal de Política y Manejo de Tierras de 1976, el desarrollo y aprobación de la Coalición de Áreas Naturales de Arizona (AWC) en los años 80s y los sondeos realizados por la Alianza para las Islas del Cielo a finales de los años 90s y del año 2000 al 2004. Estudios realizados por el BLM y la AWC ilustran el potencial para proteger muchas zonas de alta calidad en estas tierras sin caminos. Muchas de estas áreas continúan amenazadas por cambios en las políticas, el abuso continuo de vehículos todo terreno, la construcción de caminos y otros impactos.

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A GIS-based model of potential jaguar habitat in Arizona. The jaguar (*Panthera onca)* is an endangered species that occasionally visits the southwestern United States from Mexico. The number of jaguar sightings per decade has declined over the last 100 years in Arizona, raising conservation concerns for the species at a local and national level. The objectives of our analysis were to identify and characterize potential jaguar habitat in Arizona from historic sighting records and create a statewide habitat suitability map. We used a Geographic Information System (GIS) to characterize potential jaguar habitat by overlaying historic jaguar sightings (57) and landscape/habitat features believed important (vegetation biomes and communities, elevation, terrain ruggedness, proximity to perennial/intermittent water sources, and human density). The amount of Arizona (%) identified as potentially suitable jaguar habitat ranged from 21 to 30% depending on the input variables. The majority of jaguar sightings were in scrub grasslands between 1,220 and 1,829-m elevation in southeastern Arizona, in intermediately to extremely rugged terrain, and within 10 km of a water source. Conservation efforts should focus on protecting the most suitable jaguar habitat in southeastern Arizona, travel corridors within and outside Arizona, and jaguar habitat in the Sierra Madre of Sonora, Mexico. Poster.

Un modelo de hábitat potencial para el jaguar en Arizona basado en un sistema de información geográfica (GIS). El jaguar (*Panthera onca*) es una especie amenazada proveniente de México que ocasionalmente visita el suroeste de Estados Unidos. En Arizona, el número de avistamientos por década ha disminuido en los últimos 100 años despertando preocupación en el ámbito local y nacional sobre la conservación de la especie. El objetivo de nuestro análisis fue identificar y caracterizar el hábitat potencial para el jaguar en Arizona y crear un mapa del hábitat estatal adecuado para jaguar basado en avistamientos históricos. Para caracterizar el hábitat potencial para jaguar usamos un Sistema de Información Geográfica (SIG) donde sobrepusimos los avistamientos históricos (57) con las características del hábitat que se consideran importantes (biomas de vegetación y comunidades, elevación, lo escabroso del terreno, la proximidad a fuentes de agua perenne o intermitente y densidad humana). El porcentaje del estado de Arizona identificado como hábitat potencialmente adecuado para jaguar osciló entre el 21 y 30% dependiendo de la cantidad de variables incluidas en el modelo. La mayoría de los avistamientos de jaguar se realizaron en pastizales de matorral de 1,220 a 1,829 m de elevación en el sureste de Arizona en terreno moderadamente a extremadamente escabroso y 10 km a la redonda de las fuentes de agua. Los esfuerzos de conservación deben de enfocarse en proteger el hábitat mas adecuado para Jaguar en el sureste de Arizona, los corredores de desplazamiento dentro y fuera de Arizona y el hábitat localizado en la Sierra Madre de Sonora, México. Póster.

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Wild cats of the Sky Islands: a summary of monitoring efforts using noninvasive techniques. In this presentation we will review and summarize a variety of efforts which are taking place to detect, inventory, and monitor the wild felids (pumas, bobcats, jaguars, and ocelots) of the Madrean Archipelago. Researchers are using a suite of noninvasive methods, including infrared-triggered photography, DNA analysis of scat and hair (collected from "hair snares"), and old-fashioned tracking and sign searches. In northern Mexico, these techniques have yielded data on the presence and distribution of rare cats, such as jaguars and ocelots. This information has, in turn, created the impetus for the purchase of land to protect these populations and now serves as a land-based germination point for future conservation efforts in the area. In the United States, researchers have documented the presence of possibly-resident jaguars in southern Arizona. In addition, with IR-triggered cameras and molecular genetics techniques, we are often able to identify individuals, estimate home ranges, determine gender, and derive rough population estimates without invasive and expensive animal capture and radio telemetry—heretofore the only way to gather such information. These data provide managers with valuable information with respect to land use, landscape connectivity, and ecosystem function.

Los gatos salvajes de las Islas del Cielo: un resumen sobre esfuerzos de monitoreo usando técnicas no-invasivas. En esta ponencia revisaremos y resumiremos los diversos esfuerzos para detectar, inventariar y monitorear a felinos salvajes (pumas, linces, jaguares y ocelotes) que se están realizando en el Archipiélago Madrense. Investigadores están utilizando un diverso portafolio de métodos no invasivos que incluyen fotografías tomadas con disparadores infrarrojos, análisis del ADN de las excretas y pelo (colectado en trampas para pelo) y métodos tradicionales de rastreo. En el norte de México estos métodos han resultado útiles para determinar la presencia y distribución de gatos raros como el jaguar y el ocelote. Como consecuencia esta información ha generado un ímpetu por comprar tierras que protejan a estas poblaciones y que sirvan como punto focal para futuros esfuerzos de conservación en esta área. En los Estados Unidos, investigadores han documentado la presencia de jaguares que posiblemente residen en el sur de Arizona. Además, utilizando cámaras accionadas con disparadores infrarrojos y técnicas genéticas moleculares es posible identificar individuos, estimar sus áreas de acción, determinar el sexo y hacer estimaciones generales sobre la población sin que sea necesario utilizar técnicas de captura y telemetría, que son la alternativa para obtener la misma información, aunque invasivas y más caras. Estos datos proveen a manejadores de vida silvestre con información valuable sobre el uso de la tierra, conectividad del paisaje y funcionamiento del ecosistema.

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Monitoring and introduction of Huachuca water umbel, an endangered wetland plant. The ecology of the Huachuca water umbel, an endangered wetland plant, is little understood. Monitoring plots were established at Bingham Cienega Preserve in order to document phenology and the role of interspecific competition in a population located within the San Pedro River floodplain. In one half of the monitoring plots potentially competitive vegetation was clipped at the ground surface during fall 2001 and 2002. After fall and spring monitoring in 2001, plants in treatment plots had flowers and many more leaves. However, leaf numbers fell precipitously in fall 2002 and were no longer present in spring and fall 2003, perhaps due to low soil moisture. Additionally, sediment deposited after summer 2003 fires in the Santa Catalina Mountains was removed from three additional monitoring plots in order to expose the original substrate. Seedbank studies were conducted on the overlying sediment and the original substrate in order to determine plant species introduced to the area through sediment deposition. In December 2003, Huachuca water umbel was introduced into Findlay Tank at the Audubon Research Ranch in Elgin, AZ. Poster.

Introducción y monitoreo de una planta amenazada de humedal: el umbel de agua de Huachuca. Se conoce poco sobre la ecología del umbel de agua de Huachuca la cual es una planta amenazada de humedal. En la Reserva de la Ciénega de Bingham se establecieron cuadrantes para monitorear y documentar su fenología así como su rol en la competencia ínter-específica de una población localizada en tierras de inundación del río San Pedro. En el otoño del 2001 y 2002 a la vegetación que potencialmente compite con el umbel se le cortó al ras del suelo en la mitad de los cuadrantes. Después de los monitoreos de otoño y primavera del 2001 las plantas en los cuadrantes de tratamiento tenían flores y muchas más hojas. Sin embargo, el número de hojas disminuyó notablemente en el otoño del 2002 y ya no había ninguna en la primavera y otoño del 2003, posiblemente por la baja humedad en el suelo. Además, a tres cuadrantes de monitoreo les fue removido el sedimento depositado después de los incendios del verano del 2003 en las montañas de Santa Catalina a fin de dejar expuesto el substrato original. Se realizaron estudios de acumulación de semillas en los sedimentos acumulados tras los incendios y en los substratos originales para determinar si la deposición de sedimento resultó en la introducción de especies de plantas. En diciembre del 2003 el umbel de Huachuca fue introducido al Tanque de Findlay del Rancho Audubon en Elgin, Arizona. Póster.

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Late Quaternary vegetation history and paleoclimate of the U.S.A. – Mexico borderlands region from two new packrat midden series. Two packrat midden chronologies reveal glacial to interglacial changes in vegetation and climate in the Playas and San Simon Valleys in the U.S.A.-Mexico Borderlands. Plant macrofossil and pollen assemblages from middens indicate vegetation along pluvial lake margins consisted of open pinyon-juniper communities and a rich understory of C_4 annuals and grasses. Although both lake and pinyon-juniper expansion across the lowlands have been attributed to greater winter precipitation, the summer-flowering understory indicates at least moderate summer precipitation during the late glacial. The U.S.A.-Borderlands may have been the only area in the western half of the United States to “green-up” in July and August, and may explain the concentration of megafauna and paleoindian sites dating from this period in the area. A transition to a warmer, drier climate is inferred from the extirpation of *Pinus edulis* by 10,300 ^{14}C yr B.P. The disappearance of pinyon and change to more xeric oak-juniper communities may have occurred abruptly during the “Clovis-aged Drought.” Few middens in our series dated from the middle Holocene (8000 – 4000 ^{14}C yr B.P.), a period during which middens are scarce across the Southwest. Desertscrub elements begin to appear by about 4000 ^{14}C yr B.P., marking the transition to present-day vegetation.

Historia de la vegetación y paleoclima del Cuaternario Tardío de la región fronteriza E.E.U.U. – México a partir de dos series de paleomadrigueras de roedores. Dos cronologías de paleomadrigueras de roedores revelan cambios de vegetación y clima de glacial a interglacial en los valles de Playas y San Simon de la región fronteriza E.E.U.U. – México. Los conjuntos de macrofósiles de plantas y polen de las paleomadrigueras indican que la vegetación que poblaba los márgenes de los lagos pluviales consistía en comunidades abiertas de pino piñonero y junípero, con un rico estrato arbustivo y herbáceo de anuales C4 y gramíneas. Aunque tanto el lago como la expansión del pino y el junípero a menores altitudes han sido atribuidos a una mayor precipitación de invierno, el tapiz vegetal con floración de verano indica cuando menos una moderada precipitación de verano durante el glacial tardío. La región fronteriza E.E.U.U. – México puede haber sido la única área de la mitad oeste de los Estados Unidos “reverdecida” en julio y agosto, lo que puede explicar la concentración de megafauna y sitios paleoindios que datan de este período en el área. Una transición hacia un clima más cálido y seco se infiere de la extirpación de *Pinus edulis* hace 10,300 años 14C B.P. La desaparición del pino piñonero y el cambio a comunidades más xéricas de encino y junípero puede haber ocurrido de manera abrupta durante el “período de sequía de edad Clovis”. En nuestra serie, pocas paleomadrigueras datan del Holoceno medio (8000-4000 años 14C B.P.), período para el cual las paleomadrigueras son escasas en todo el Suroeste. Los elementos del matorral desértico empiezan a aparecer hace alrededor de 4000 años 14C B.P., marcando la transición a la vegetación actual.

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How do humans restructure the biodiversity of the Sonoran desert? Humans exert a profound effect on the Sonoran desert ecosystem. An extensive integrated field inventory was conducted to study broad-scale patterns of biodiversity across the entire urbanized, suburbanized, agricultural and surrounding desert landscape of the Central Arizona-Phoenix region. We used a probability-based dual-density tessellation stratified design to survey diversity of perennial plants, pollen, birds and sample soil chemistry at 204 sites in 2000, supplemented with geographic and socioeconomic variables from existing databases and the US Census. Dominantly geomorphic controls on spatial variation in perennial plant diversity and soil nitrogen concentrations in undeveloped desert, were replaced by variables such as current and former land use, family income, population density and housing age across urbanized parts of the region. There was widespread deposition of imported exotic pollen taxa across the region, in addition to that from native desert species, with significant variation in abundances - even for taxa with very mobile wind-dispersed pollen. Bird species richness increased with plant species diversity, plant volume, number of new houses and family income (in summer). We conclude that urbanization has resulted in a landscape in which biodiversity reflects social, economic, and cultural influences in addition to those recognized by traditional ecological theory.

¿Cómo los humanos han reestructurado la biodiversidad del Desierto Sonorense? Los humanos tienen una gran influencia sobre el ecosistema del Desierto Sonorense. Para estudiar patrones de gran escala de la biodiversidad del desierto en la región del centro de Arizona y Phoenix se condujo un inventario integral y extensivo de toda el área urbana, suburbana, agrícola y el desierto circundante. Utilizamos un diseño experimental probabilísticamente basado y estratificado de doble densidad para evaluar la diversidad de plantas perennes, polen, aves e hicimos un muestreo de la química del suelo en 204 sitios durante el año 2000. Además estos muestreos fueron complementados con variables geográficas y socioeconómicas disponibles en bases de datos de la oficina del Censo de los E.E.U. Se reemplazaron los controles geomórficos dominantes en la variación espacial de la diversidad de plantas y concentración de nitrógeno del suelo, ingreso por familia, densidad

poblacional y edad de las construcciones habitacionales a lo largo de areas urbanas en la región. Se encontró una gran distribución de deposiciones de taxas exóticos así como de taxas nativos de polen a lo largo de la región, con una variación significativa en su abundancia, aún para los taxas de polen muy móvil cuya dispersión la realiza el viento. La riqueza en las especies de aves incrementó junto con la diversidad de especies de plantas, volumen y número de casas e ingreso por familia (en el verano). Concluimos que la urbanización ha generado un paisaje del cual la biodiversidad es reflejo de influencias sociales, económicas y culturales en adición a aquellas tradicionalmente reconocidas por la teoría tradicional de ecología.

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Relationships between native flora richness and spatial complexity in the northern Madrean Archipelago region. This study investigated the relationships between native flora richness (FR) and spatial complexity (SC) in seven high elevation and five low elevation areas in southeastern Arizona and southwestern New Mexico. FR information was acquired from previous flora studies of these areas. SC attributes were derived from a digital elevation model using a Geographic Information System. Simple linear regression was utilized to study the correlations between FR and SC. The results showed that FR positively correlated with elevation range ($R^2 = 0.73$), elevation coefficient of variation ($R^2 = 0.622$), slope range ($R^2 = 0.495$), and slope standard deviation ($R^2 = 0.405$). Additionally, FR negatively correlated with the proportion of north facing slope ($R^2 = 0.47$) after one flat terrain area was removed. However, these SC variables were strongly correlated with each other. This study thus proposed an alternative spatial metric, the ratio of surface area and planar area (S/P), which provided rich information of terrain roughness not considered in previous SC variables. Although the correlation between FR and S/P was not strong (positive correlation, $R^2 = 0.198$) in this study, it might come from the inconsistency of FR data collection. Future studies in other areas are needed to validate this metric.

La relación entre la riqueza de la flora nativa y la complejidad espacial en la región norte del Archipiélago Madrense. En este estudio se investigaron las relaciones entre la riqueza de la flora nativa (FR) y la complejidad espacial (SC) en siete áreas de gran elevación y cinco de baja elevación en el sureste de Arizona y el suroeste de Nuevo México. A través de estudios previos se obtuvo información sobre la FR mientras que los atributos de la SC se obtuvieron de un modelo digital de elevación generado con un sistema de información geográfica. Los resultados muestran que FR está positivamente correlacionada con el rango de elevación ($R = 0.73$), el coeficiente de variación de la elevación ($R^2 = 0.622$), el rango de la pendiente ($R^2 = 0.495$) y la pendiente de la desviación estándar ($R^2 = 0.405$). Además se encontró a la FN negativamente correlacionada con la proporción de pendiente localizada del lado norte ($R^2 = 0.47$) después de haber removido un área de terreno plano. Sin embargo las variables de SC estaban altamente correlacionadas entre sí. Por lo tanto se propuso utilizar una métrica espacial diferente: el rango de área superficial y planar (S/P), que resultó en el suministró de rica información sobre lo agreste del terreno, lo cual no había sido generado por las variables de SC previamente utilizadas. Aunque la correlación obtenida en este estudio entre FR y S/P no fue muy fuerte (correlación positiva, $R^2 = 0.198$) pudiera ser resultado de la inconsistencia en la colecta de datos de FR. Más estudios en el futuro serán necesarios para validar la métrica utilizada aquí.

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Genetic variation in springsnails of the Lower Colorado drainage. Springsnails of the genus *Pyrgulopsis* are the most diverse group of freshwater gastropods in North America. Though taxonomic relationships within this group are still being investigated, current estimates show that *Pyrgulopsis* contains well over 100 different species. Some factors contributing to their diversity include poor dispersal ability and habitat specificity based on water availability, water chemistry, and depth. Most taxa exhibit high degrees of endemism, with many species occurring in a single spring or seep, making springsnails ideal for studies of allopatric speciation. Here I present data from a survey of genetic variation at the mitochondrial gene cytochrome oxidase I from 36 populations belonging to 16 species of *Pyrgulopsis* distributed throughout the Lower Colorado River Basin. High levels of interspecific sequence divergence indicate that *Pyrgulopsis* may have colonized this region multiple times beginning in the late Miocene; earlier than previous estimates based on fossil evidence. However, geneflow among conspecific populations appears to be high, as indicated by low levels of interpopulation variation. Estimates of nucleotide diversity differ greatly among populations and may reflect differences in demographic processes. These results are used to identify factors contributing to radiation of species in this region, and implications for future management and conservation are discussed.

La variación genética de caracoles de poza en la cuenca baja del Río Colorado. El grupo más diverso de gasterópodos de agua dulce son los caracoles de poza del género Pyrgulopsis. Aunque las relaciones taxonómicas entre individuos del grupo aún se encuentran bajo investigación estimaciones actuales indican que Pyrgulopsis está compuesto por más de 100 especies diferentes. Algunos de los factores que favorecen su diversidad incluyen: baja dispersión y especificidad de hábitat sobre la base de la disponibilidad, química y profundidad de agua. La mayoría de los taxa exhiben un alto grado de endemismo y muchas especies ocurren únicamente en una poza o manantial haciendo de estos caracoles sujetos ideales para el estudio de especiación alopática. En esta ponencia se presentaron datos del estudio de la variación genética del gen mitocondrial cytochromo oxidasa I en 36 poblaciones representando a 16 especies de Pyrgulopsis distribuidos a lo largo de la cuenca baja del río Colorado. Los resultados muestran altos niveles de secuencias interespecíficas divergentes que indican que Pyrgulopsis puede haber colonizado esta región en varias ocasiones desde principios de finales de Mioceno, lo cual resulta anterior a las estimaciones basadas en evidencias fósiles realizadas anteriormente. Sin embargo, los altos niveles de variación inter-poblacional indican que el flujo genético entre poblaciones co específicas pudiera ser extenso. Las estimaciones sobre la diversidad de nucleótidos presentan grandes variaciones entre poblaciones y pudieran reflejar diferencias entre procesos demográficos. Estos resultados son utilizados para identificar factores que contribuyan a la radiación de las especies en esta región así como también se discuten las implicaciones para su manejo y conservación.

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Using cluster analysis and a classification and regression tree model to developed cover types in the Sky Islands of southeastern Arizona. The objective of this study was to develop a rule based cover type classification system for the forest and woodland vegetation in the Sky Islands of southeastern Arizona. In order to develop such system we qualitatively and quantitatively compared a hierarchical (Ward's) and a non-hierarchical (k-means) clustering method. Ecologically, unique groups and plots dominated by multiple species were more appropriately grouped using k-means. When compared numerically using classification and regression tree (CART) model, the classification k-means required fewer nodes or decision rules. Based on these results we developed a detailed cover type classification system for the existing vegetation of the Sky Islands in southeastern Arizona. The final cover types were based on the original k-means clusters, with some minor modifications made using CART analysis to compensate for overlapping values. This allowed us to transform the CART output into a dichotomous identification key for 20 detailed cover types. The final detailed cover types were linked to a flexible three-level hierarchical framework allowing users to aggregate or segregate forest lands as needed. This framework is similar to the natural organization of ecosystems, which will aid our understanding of natural processes in these forest and woodlands.

Utilización de análisis de conjuntos y una clasificación y modelo de regression de árbol para desarrollar tipos de cubierta vegetal en las Islas del Cielo del sureste de Arizona. El objetivo del estudio fue desarrollar un sistema de clasificación de tipos de cobertura vegetal, basado en reglas, para la vegetación de bosque y montes en las islas del cielo del sureste de Arizona. Para desarrollar tal sistema, comparamos cuantitativamente y cualtitativamente un sistema jerárquico (Ward) y uno no-jerárquico (medias k) de análisis de conjuntos. Ecológicamente, grupos únicos y parcelas dominadas por especies múltiples fueron agrupados de mejor manera utilizando medias k. Cuando fueron comparadas en forma numérica utilizando modelos de árboles de clasificación y regresión (CART), la clasificación de medias k requirió menos nodos o reglas de decisión. Basándonos en estos resultados, desarrollamos una clasificación de tipos de cobertura vegetal detallada para la vegetación existente en las islas del cielo del sureste de Arizona. Los tipos de cobertura final se basaron en los conjuntos de medias k originales, con modificaciones menores utilizando análisis CART para compensar por valores sobrepuestos. Esto nos permitió transformar el resultado CART en una identificación dicotómica para 20 tipos de cobertura vegetal. Los tipos de cobertura detallados se relacionaron a un marco jerárquico de tercer nivel, permitiendo a los usuarios agregar o segregar los terrenos forestales según sea necesario. Este marco jerárquico es similar a la organización natural de los ecosistemas, que ayudará a nuestro entendimiento de los procesos naturales en estos bosques y montes.

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Herpetology of the Coronado National Forest: origin of the species. The Coronado National Forest of southeastern Arizona and southwestern New Mexico largely encompasses the Madrean Archipelago in the United States. The Coronado has diverse habitats, ranging from upland desert to subalpine forest, and is an important destination for ecotourism. In the Coronado and adjacent valleys, there are approximately 114 (111 native) species of amphibians and reptiles, including 1 salamander, 20 frogs and toads, 6 turtles, 40 lizards, and 47 snakes. In the United States, 34 of these species are only known from Arizona and/or New Mexico. While 16 of the species are Madrean endemics, the high biodiversity originates from a convergence of Madrean and other biotic communities. The herpetofauna are characteristic of (taxa scored for each community): Sonoran Desert (27%), Chihuahuan Desert (26%), Madrean montane (20%), Great Plains (17%), Petran montane (6%), introduced (2%), and other (2%). The Coronado National Forest is essentially an ecotone for all of these biotic communities, resulting in the highest biodiversity in the western United States. Certain taxa, such as whiptails, spiny lizards, rattlesnakes, and leopard frogs, are particularly well represented in the Madrean Archipelago region.

Herpetología del Bosque Nacional de Coronado: origen de las especies. El Bosque Nacional de Coronado del sureste de Arizona y suroeste de Nuevo México comprende la mayoría del Archipiélago Madrense en los Estados Unidos. El Coronado tiene hábitats diversos, que van de desierto elevado a bosque subalpino, y es un destino importante para el ecoturismo. En el Coronado y sus valles adyacentes, hay aproximadamente 114 (111 nativas) especies de anfibios y reptiles, incluyendo 1 salamandra, 20 ranas y sapos, 6 tortugas, 40 lagartijas y 47 víboras. En los Estados Unidos, 34 de estas especies sólo son conocidas para Arizona y/o New Mexico. Mientras que 16 de las especies son endémicas Madrenses, esta gran biodiversidad se origina por la convergencia de otras comunidades bióticas con la Madrense. La herpetofauna es característica de (taxa contabilizado para cada comunidad): Desierto Sonorense (27%), Desierto Chihuahuense (26%), Madrense montano (20%),

Grandes Planicies (17%), montano Petrense (6%), introducidas (2%) y otras (2%). El Bosque Nacional Coronado es esencialmente el ecotono de todas estas comunidades bióticas, resultando en la mayor biodiversidad en el oeste de los Estados Unidos. Ciertos taxa, tales como whiptails, spiny lizards, víboras de cascabel y ranas leopardo, están particularmente bien representadas en la región del Archipiélago Madrense.

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Characterization of habitat preferences for selected wildlife species in encinal savannas of the Southwest. The encinal savannas of the sub-mogollon southwestern United States are important for livestock grazing and wildlife habitat. Little data have been collected on the ecology of these Sierra Madrean types of woodland land areas, which makes management difficult. Obtaining information such as habitat preferences for selected wildlife species and livestock can be an important piece of information towards the characterization and management of these areas. Habitat preferences of deer and cottontail were determined from repeated measurements of fecal accumulations on a circular 0.01-acre-plot centered over each sampling point in the spring and fall on twelve watersheds on the east slope of the Peloncillo Mountains in southwestern New Mexico. Bird surveys were also conducted in the spring and fall at the observational sites studied to obtain comparative listings of common bird species. Spring bird surveys resulted in 19 different species of birds on the watersheds. Poster.

Caracterización de preferencias de hábitat por especies selectas de fauna silvestre en sabanas de encinal del suroeste. Las sabanas de encinal del suroeste de los Estados Unidos son hábitats importantes para una gran variedad de especies de fauna silvestre y para el pasto de ganado. Se ha colectado poca información sobre la ecología de las áreas arboladas de la Sierra Madrense. Por lo tanto, la obtención de información sobre las preferencias de hábitat de las especies silvestres y el ganado contribuye como una clave para la caracterización y el manejo más efectivo de estas áreas. Las preferencias de hábitat para el venado y el conejo se han estimado en repetidas mediciones de las acumulaciones fecales y en un terreno circular de 0.01 acres centrado sobre cada punto de muestreo, en la primavera y el otoño, en 12 cuencas hidrológicas en la ladera este de las Montañas Peloncillo del suroeste de New Mexico. Listados comparativos de especies comunes de aves se han obtenido mediante muestreo de aves realizadas en las parcelas de muestreo en la primavera y en el otoño. Los muestreos de primavera reportaron 19 especies de aves presentes en estas cuencas. Póster**.**

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Herpetology of the Coronado National Forest: managing our natural heritage. The Coronado National Forest (CNF) is the primary public land management agency of the Madrean Archipelago of Arizona and New Mexico. CNF manages habitat for a biologically diverse herpetofauna. Peripheral Mexican forms constitute most of the species protected by environmental laws and policy, including ranid frogs, montane rattlesnakes, and other taxa rarely encountered in the United States. Although the Forest Service is mandated to maintain viable populations of all species well-distributed throughout their ranges, federally recognized taxa of concern are those primarily addressed in environmental documentation. These are listed as federally threatened (n=2 taxa), endangered (n=1), sensitive (n=13), and management indicators (n= 7). There are currently 18 species on these lists (overlapping designations). The Forest Service works in conjunction with state and federal agencies, academic institutions, and non-government organizations to protect this natural heritage. CNF is involved with habitat management, research support, inventory and monitoring, habitat improvement projects, public education, training programs, and control of exotics. The Forest Service provides input for conservation agreements, recovery plans, and other management plans, and is an affiliate of the Partners in Amphibian and Reptile Conservation consortium.

Herpetología en el Bosque Nacional Coronado: manejo de nuestra herencia natural. El Bosque Nacional Coronado (CNF por sus ciglas en inglés) es la principal organización pública de manejo de la tierra dentro del Archipiélago Madrense de Arizona y New Mexico. CNF maneja el hábitat para una herpetofauna biológicamente diversa. Formas mexicanas poco representadas constituyen la mayoría de las especies protegidas por las leyes y políticas ambientales, incluyendo ranas “ranid”, víboras de cascabel de montaña y otros taxa raramente encontrados en los Estados Unidos. Aunque el Servicio Forestal tiene el mandato de mantener poblaciones viables de todas las especies bien distribuidas a lo largo de su rango de distribución, son aquellos taxa de estatus reconocido federalmente los que son consideracidos de primera instancia en la documentación ambiental. Estos se enlistan a nivel federal como amenazados (n=2 taxa), en peligro (n=1), sensibles (n=13) e indicadores de manejo (n=7). Hay actualmente 18 especies en esas listas (algunas con designaciones sobrelapándose). El Servicio Forestal trabaja en conjunto con agencias estatales y federales, instituciones académicas y organizaciones no gubernamentales para proteger nuestra herencia cultural. CNF esta involucrado en el manejo del hábitat, apoyo a la investigación, inventario y monitoreo, proyectos de mejora del hábitat, educación pública, entrenamiento y control de exóticas. El Servicio Forestal provee las bases para acuerdos de conservación, planes de recuperación y otros planes de manejo, y es un afiliado al consorcio de Socios en la Conservación de Anfibios y Reptiles.

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Preliminary distribution of Upper Respiratory Tract Disease in captive and free-ranging desert tortoises in Greater Tucson, Arizona. Upper Respiratory Tract Disease (URTD), caused by the pathogen *Mycoplasma agassizii*, poses a critical threat to the Mojave population of the desert tortoise (*Gopherus agassizii*), where release of captive tortoises into the wild has been implicated in the spread of the disease. Little is known about URTD in the Sonoran population of the desert tortoise. To determine the distribution of URTD in Greater Tucson, Arizona we used enzyme-linked immunosorbent assay to detect antibodies indicating previous exposure to *M. agassizii* and polymerase chain reaction to detect *M. agassizii* antigens indicating a current infection. Blood and nasal lavage samples were collected in 2002 and 2003 from 52 captive tortoises within Tucson and 117 free-ranging tortoises in 9 mountain ranges along an urban gradient radiating from Tucson. We compared results from captive and free ranging populations to determine if there is an association between urbanization and distribution of *M. agassizii*. Results will shed light on geographic patterns of URTD and may help elucidate the relationship between a large captive population and free-ranging population. This study has implications for other diseases that may be spread into urban wildlife habitat as human development continues to encroach upon mountain foothills. Poster.

Distribución preliminar de la enfermedad del tracto respiratorio superior en Tortugas del Desierto bajo cautiverio y libres, en el Gran Tucson, Arizona. La Enfermedad del Tracto Respiratorio Superior (URTD, por sus siglas en inglés), causada por el patógeno *Mycoplaslma agassizii*, representa un peligro crítico a la población Mojave de la tortuga del desierto (*Gopherus agassizii*), en donde la liberación de tortugas cautivas al hábitat natural ha causado la dispersión de la enfermedad. Poco se conoce acerca de URTD en la población Sonorense de la tortuga del desierto. Para determinar la distribución de URTD en el área del Gran Tucsón, Arizona, utilizamos un ensayo inmunoabsorbente de enzima-ligada para detectar anticuerpos que indicaran exposición previa a *M. agassizii* y reacción en cadena de polimerasa para detectar antígenos de *M. agassizii* indicando infección presente. Durante 2002 y 2003 se colectaron muestras de sangre y fosas nasales en 52 tortugas cautivas en Tucsón y 117 tortugas libres en 9 cordilleras a lo largo de gradientes urbanos con centro en Tucsón. Comparamos los resultados de las poblaciones cautivas y libres para determinar si existe una asociación entre urbanización y distribución de *M. agassizii*. Los resultados de este estudio darán información sobre los patrones geográficos de URTD y podrán ayudar a elucidar la relación entre poblaciones grandes de cautivas y libres. Este estudio tiene implicaciones para otras enfermedades que puedan dispersarse en la fauna de hábitats urbanos conforme el desarrollo humano continúa incrustándose en los piés de montaña. Póster.

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Recent population declines of the Chiricahua leopard frog in the Galiuro Mountains, Arizona. The Chiricahua leopard frog (*Rana chiricahuensis*) was once widespread in aquatic systems throughout east-central Arizona and west-central New Mexico, southeastern Arizona, southwestern New Mexico, and adjacent Mexico. It is one of several native ranid frog species that has undergone significant population declines. Populations have been tracked by state and federal agencies and other interested parties, especially during the past decade, to assess population status; these surveys documented the severity of recent declines and led to federal protection under the Endangered Species Act. Surveys conducted in the mid 1990's demonstrated that frogs were found at numerous localities on the eastern flank of the Galiuro Range, but by the late 1990's many of these were extirpated. Renewed limited surveys in 2002 suggested that some populations still existed. In 2003, the Safford Ranger District conducted extensive surveys of most known Galiuro localities to establish a baseline for annual habitat and population monitoring. Twenty-four of the 27 known sites revealed only two confirmed populations. One of the two sites was a stock tank and the other a nearby lotic system. The lotic site had a moderately sized population and currently represents the best locality for a Galiuro source population, should re-introduction plans be initiated.

Disminución reciente de las poblaciones de rana leopardo de las Chiricahuas en las montañas Galiuro de Arizona. La rana leopardo de las Chiricahuas (*Rana chiricahuensis*) estuvo originalmente distribuída ampliamente en los sistemas acuáticos del este-centro de Arizona y oeste-centro de New Mexico, sureste de Arizona, Suroeste de New Mexico y en las cercanías de México. Es una de varias especies nativas de ranas ranidas que ha sufrido disminuciones significativas en sus poblaciones. Sus poblaciones han sido detectadas por agencias estatales, federales y organizaciones interesadas, durante la última década, para determinar el estado de sus poblaciones; estos inventarios documentaron la severiad de la disminución reciente y llevaron a su protección federal bajo el Acta de Especies en Peligro de Extinccíón. Muestreos durante a mediados de 1990 demostraron que las ranas se encontraban en numerosas localidades en el lado este de las Galiuro, pero para finales de 1990, muchos de estas se habían destruido. Nuevos muestreos parciales en 2002 sugirieron que algunas de las poblaciones aún existían. En 2003, el Distrito de Safford condujo muestreos extensivos de la mayoría de las localidades conocidas en las Galiuro, para establecer una línea base para el monitoreo anual del hábitat y de las poblaciones. Veinticuatro de los 27 sitios conocidos revelaron sólo dos poblaciones confirmadas. Uno de los dos sitios fue un tanque de almacenamiento y el otro un sistema lótico cercano. El sitio lótico tuvo una población de tamaño moderado y actualmente representa la localidad mas representativa de la población Galiuro, en caso de que se iniciara un plan de re-introducción.

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The Research Ranch: what do you do with a grassland besides raise cows? For most of the past 10,000 years, semi-arid grasslands of Southeastern Arizona have not been heavily impacted by large herds of hoofed animals. This began to change in the 1500s with the introduction of domestic livestock, primarily cattle. Impacts of this major ecological force on a naive system were widespread. In 1968, Frank and Ariel Appleton created an outdoor laboratory, the Research Ranch, to examine the consequences of removing that major ecological force. The Audubon Appleton-Whittell Research Ranch is an 8000-acre exclosure and living laboratory where short-term research projects are conducted and repeated, and where long-term study sites can be established. Results of these studies are providing sound scientific information that is being used to formulate policy on regional planning and land management issues. Perhaps the most useful role for the facility continues to be its use as a control for the many 'environmental experiments' going on throughout the Southwest as the human population of the region increases. Impacts of road building, recreational usage, conversion of once open-spaces to exurban home sites, and a shrinking, but usually locally valued, cattle industry can be evaluated with more insight when compared to conditions on the Research Ranch.

El Rancho de Investigación: Que hace usted con un pastizal además de criar vacas? Durante la mayor parte de los últimos 10,000 años, los pastizales semiáridos del sureste de Arizona no han sido fuertemente afectados por las grandes manadas de animales con cascos. Esto empezó a cambiar en los 1500s con la introducción del ganado doméstico, sobre todo bovinos. Los impactos de esta gran fuerza ecológica se extendieron sobre un sistema simple. En 1968, Frank y Ariel Appleton crearon un laboratorio al aire libre, el Rancho de Investigación, para examinar las consecuencias de quitar aquella gran fuerza ecológica. El Rancho de Investigación Audubon Appleton-Whittell es una exclusión de 4000 hectáreas (8000 acres) y un laboratorio viviente donde se conducen y se repiten proyectos de investigación a corto plazo, y donde pueden ser establecidos sitios de estudios a largo plazo. Resultados de estos estudios están proporcionando bastante información científica que se está utilizando para formular políticas de planificación regional y manejo de tierras. Quizás el papel mas útil del rancho es que continúa siendo usado como un control para los muchos "experimentos ambientales" que se están realizando en el suroeste conforme aumente la población humana de la región. Impactos de la construcción caminos, uso recreativo, conversión de lo que antes fueron espacios abiertos en casas suburbanas, y una industria ganadera pequeña, pero localmente valorada, pueden evaluarse con más detalle al compararse con las condiciones del Rancho de Investigación.

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What happens if you just add water? The Santa Cruz River in southern Arizona is now a generally dry streambed, except during brief periods of stormwater runoff and in areas where treated wastewater is discharged and provides surface water. For the past two decades, an effluent stream has been discharged to a reach of river that was historically dry. Along this reach, an incipient riparian community has developed without active restoration planning, intentional planting, or active management efforts. This paper reviews the effects of just adding water to the streambed. Hydrological and biological factors affect the establishment and maintenance of the riparian community. Primary stressors appear to be daily fluctuations of water, channel changes due to flooding, great depth to available soil moisture away from the narrow channel, substrate properties, and invasion by exotic species. Many biological components typically associated with the Sonoran Riparian community have become established, but others appear to be lacking. Lessons learned from this study may be important for planning stream restoration and management in the region and optimizing the use of treated wastewater.

Que pasa si sólo agregas agua? El Río Santa Cruz en el sur de Arizona es en la actualidad una corriente generalmente seca, excepto durante breves periodos de escurrimientos de aguas de lluvia y en áreas donde las aguas tratadas son descargadas y proporcionan agua superficial. En las últimas dos décadas, una corriente derivada a sido descargada hacia un río que estaba históricamente seco. A lo largo de esta corriente una incipiente comunidad ribereña se ha desarrollado sin esfuerzos de una planificación de restauración activa, una plantación intencional o esfuerzos de manejo. Este artículo analiza los efectos de solo agregar agua a la corriente. Los factores hidrológicos y biológicos afectan el establecimiento y mantenimiento de la comunidad ribereña. Los principales estresantes parecen ser las fluctuaciones diarias de agua, los cambios en el canal debido al flujo, gran profundidad para la humedad disponible de suelo lejos del estrecho canal, propiedades del substrato e invasión de especies exóticas. Muchos componentes biológicos típicamente asociados con la comunidad ribereña sonorense ya se han establecido, pero otros parecen estar ausentes. Las lecciones aprendidas en este estudio pueden ser importantes para planificar el manejo y la restauración de las corrientes en la región y optimizar el uso de aguas residuales tratadas.

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Green Sunfish impacts on Gila chub, a natural experiment thanks to a waterfall. Gila chub (*Gila intermedia*) is a medium sized minnow restricted to an irregular patchwork of isolated populations in the Gila River drainage that is federally proposed for endangered status. Green sunfish (*Lepomis cyanellus*) have been implicated in their demise. Natural waterfalls have apparently saved several populations (Turkey Creek, Sycamore Creek, and Silver Creek). At these sites, Gila chub are usually abundant above the waterfalls in the absence of green sunfish, but are rare below when green sunfish are common. We investigated this pattern by sampling fish populations above and below the waterfall on Silver Creek. We found only Gila chub above the waterfall, where they were abundant. Below the waterfall, green sunfish were abundant, and, despite significantly more sampling effort, Gila chub were considerably less abundant. More striking, over half the Gila chub were less than 70 mm above the falls, while none this small were found below, this suggests recruitment is either very low or nonexistent. This difference we attribute to the presence of green sunfish. Any populations of Gila chub that also have an abundance of green sunfish must be renovated and protected with a barrier or Gila chub will eventually be extirpated as green sunfish invade further upstream.

Impactos del pez del sol verde sobre el cacho del Gila, un experimento natural gracias a una cascada. El cacho del Gila (*Gila intermedia*) es un pececillo de tamaño mediano restringido a una distribución irregular de poblaciones aisladas en el drenaje del río Gila y que está propuesto federalmente en un estatus de amenazado. El pez del sol verde (*Lepomis cyanellus*) a sido implicado en su desaparición. Las cascadas naturales han salvado aparentemente varias poblaciones (Turkey Creek, Sycamore Creek, y Silver Creek). En todos estos sitios los cachos del Gila son comúnmente abundantes arriba de las cascadas en ausencia del pez del sol verde, pero son raros debajo de dichas cascadas, cuando el pez del sol verde es común. Nosotros investigamos este patrón muestreando poblaciones de peces arriba y debajo de la cascada en Silver Creek. Encontramos únicamente cachos del Gila arriba de la cascada, donde ellos eran abundantes. Debajo de la cascada los peces del sol verde fueron abundantes y, a pesar de esfuerzos significativos en el muestreo, encontramos que los cachos del Gila fueron considerablemente menos abundantes. Lo más sorprendente es que más de la mitad de los cachos del Gila estaban menos de setenta milímetros por arriba de las cascadas mientras que ninguno de estos fue encontrado abajo, sugiriendo que su reclutamiento es muy bajo o no existe. Nosotros atribuimos esta diferencia a la presencia del pez del sol verde. Todas las poblaciones de cacho de Gila que también tienen una abundancia de pez del sol verde, deben ser renovadas y protegidas con una barrera o el cacho de Gila será eventualmente extirpado conforme el pez del sol verde vaya invadiendo aguas arriba.

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A dearth of data on mammals in the Madrean Archipelago: what we think we know and what we do know. The flora and fauna of the Madrean Archipelago is often noted to be extraordinarily diverse. The borderlands of the southwestern United States and northwestern Mexico are considered to be one the major world centers of diversity for a number of taxa to include the Mammalia. Despite this celebrated level of diversity, our knowledge of the ecology of individual species within the region is often suspected to be low relative to species in other regions of North America. Herein, we examine this 'dearth of data' hypothesis through a literature review that compares the frequency of publications across various mammalian taxa outside the Madrean Archipelago to publication records of species within the region. The results of our analyses support the 'dearth of data' hypothesis and suggest where additional research might be most informative.

Una escasez de datos sobre mamíferos en el Archipiélago Madrense: lo que creemos que conocemos y lo que no conocemos. Se ha notado a menudo que la flora y fauna del Archipiélago Madrense es extraordinariamente diversa. Las tierras fronterizas del suroeste de los Estados Unidos y el noroeste de México son consideradas como unos de los centros del mundo con mayor diversidad en un número de taxa, incluyendo el Mammalia. Fuera de este notable nivel de diversidad, nuestro conocimiento de la ecología de especies individuales dentro de la región, se sospecha que es relativamente bajo comparado al de especies de otras regiones de Norte América. Aquí, nosotros examinamos esta hipótesis de "carencia de datos" mediante una revisión de literatura que compara la frecuencia de publicaciones a través de varios taxa de mamíferos fuera del Archipiélago Madrense con publicaciones de datos sobre otras especies dentro de la región. Los resultados de nuestro análisis apoyan la hipótesis de la "carencia de datos" y sugiere donde podría ser mas informativa una investigación adicional.

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Management and conservation of tree squirrels: the importance of endemism, species richness, and forest condition. Tree squirrels are dependent upon mature forests for food, cover, and nest sites. As a result of this dependence, tree squirrels have been suggested to serve much as the 'miner's canary' to indicate changes in forest condition. The majority of tree squirrels of the world are of precarious conservation status particularly in the more northerly latitudes. The diversity of tree squirrels in the Madrean Archipelago is among the greatest of any region outside the tropics. My objective was to review the state of knowledge and assess the impact of various forest management strategies on the ecology of the endemic tree squirrels of the Sky Islands. Several major patterns emerge in this review of the conservation status and management of tree squirrels in the borderlands. Few studies have been conducted on the species endemic to the region, in particular the species that inhabit lower elevation pine and oak forests. Additionally, the threats to tree squirrels in the region have been suggested to include the introduction of non-native species, development and fragmentation of forests, and anthropogenic changes to forest structure due to timber harvest and fire suppression. Furthermore, the impacts of forest management strategies on tree squirrels have not been thoroughly reviewed prior to this effort.

Manejo y conservación de ardillas arbóreas: la importancia del endemismo, riqueza de especies y condición del bosque. Las ardillas arbóreas dependen de los bosques maduros para alimentos, cobertura y sitios de anidamiento. Como resultado de esta dependencia las ardillas arbóreas han sido consideradas por servir de la misma forma que "el canario del minero", al indicar cambios en la condición del bosque. La mayoría de las ardillas arbóreas del mundo están en un precario status de conservación, particularmente en las latitudes del más al norte. La diversidad de ardillas arbóreas en el Archipiélago Madrense está entre la mas grande de cualquier región fuera de los trópicos. Mi objetivo fue revisar el estado de conocimiento y evaluar el impacto de varias estrategias de manejo de bosques sobre la ecología de las ardillas arbóreas endémicas de las islas del cielo. Varios patrones mayores surgen en esta revisión sobre el status de conservación y manejo de las ardillas arbóreas en las tierras fronterizas. Pocos estudios han sido conducidos sobre las especies endémicas de la región, en particular las especies que habitan las elevaciones mas bajas de los bosques de pino y encino. Adicionalmente, las amenazas a las ardilla arbóreas en la región, han sugerido incluir la introducción de especies no nativas, el desarrollo y fragmentación de bosques y cambios antropogénicos en la estructura del bosque, debido a la cosecha de madera y a la supresión de incendios. Más aun, los impactos de las estrategias en manejo del bosque sobre las ardillas arbóreas no han sido totalmente revisados previamente a este esfuerzo.

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Projected responses of vegetation pattern and ecotone location to climatic change in an Arizona Sky Island ecosystem. The spatial distribution of Madrean Sky Island plant communities and the ecotones that serve as transitions between them is determined by biotic responses to abiotic conditions and disturbances, especially fire. It has been posited that changes in climate will result in shifts in community pattern and ecotone location as plants respond to newly imposed climatic conditions. This study uses a predictive vegetation model developed for Saguaro National Park East (SNP) to examine projected response of Sky Island communities to climatic change. Current plant community distributions were mapped using a supervised classification of late-1990 Landsat TM and ETM+ imagery. Explanatory environmental variables included in the model were: (1) topographic indices extracted from a DEM, (2) climatic conditions estimated by a spatially explicit version of the MT-CLIM model, and (3) fire history, based on fire perimeter maps of SNP. The model was then used to project potential vegetation types under a range of climate scenarios. The results, visualized as both potential vegetation maps for a given scenario and as probability surfaces based on the full range of climate scenarios, identified areas of greatest predicted sensitivity (i.e., highest probability of community transformation) that may also serve as the best locations to monitor for future vegetation change.

Respuestas proyectadas del patrón de vegetación y localización de ecotono al cambio climático en un ecosistema de isla del cielo en Arizona. La distribución espacial de comunidades vegetales de las islas del cielo Madrenses y los ecotonos que sirven como transiciones entre ellas, es determinada mediante respuestas bióticas a las condiciones abióticas y a las perturbaciones, especialmente el fuego. Se ha afirmado que los cambios en el clima resultaran en desplazamientos en los patrones de las comunidades y en la localización de ecotonos conforme las plantas respondan a condiciones climáticas impuestas nuevamente. Este estudio utiliza un modelo predictivo sobre la vegetación, desarrollado y validado por el Saguaro National Park East (SNP) para examinar la respuesta proyectada de comunidades de islas del cielo a los cambios climáticos. Las distribuciones de comunidades vegetales actuales fueron mapeadas usando una clasificación supervisada de imágenes Landsat TM y ETM+ de fines de 1990. Las variables ambientales explicatorias incluidas en el modelo fueron: 1) índices topográficos extraídos de un DEM, 2) condiciones climáticas estimadas por una versión espacial explicita del modelo MT-CLIM, y 3) historia de fuego, basada en mapas perimetrales de fuego del SNP. El modelo fue entonces usado para proyectar tipos potenciales de vegetación bajo un rango de escenarios climáticos. Los resultados, visualizados como mapas potenciales de vegetación para un escenario dado y como superficies probables basadas en el amplio rango de escenarios climáticos, identificaron áreas con la mas alta predicción de sensibilidad (por ejemplo las mas alta probabilidad de transformación en la comunidad) que pueden servir también como los mejores sitios para monitorear intensivamente cambios futuros en la vegetación.

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The development of landscape-scale ecological units and their application to the greater Huachuca mountains fire planning process. The multi-partner Greater Huachuca Mountains Fire Management Group aims to develop a strategic approach to operational fire management. The planning area extends over a relatively large geographic area and involves a variety of public and private lands. A prerequisite for success is an understanding of broad-scale physical and biotic interrelationships and patterns, and how landscape-scale ecosystems interact with and affect fire. Landscape-scale ecological units are being mapped at a scale of 1:250,000 to help define and illustrate these relationships. Utilizing GIS as a tool, US Forest Service General Ecosystem Survey and Natural Resources Conservation Service STATSGO (State Soil Geographic Database) mapping was refined using digital elevation model-derived data, geology maps, existing vegetation mapping and expert knowledge. These ecological units provide a context for modeling fire regime changes, and their associated vegetative and hydrologic implications, in response to various fire management strategies. These units help define and characterize fire

management units and they will be used as a stratification mechanism for fire condition class inventories. The development of these units will serve as a prototype to assist other similar fire planning efforts.

El desarrollo de unidades ecológicas a escala de paisaje y su aplicación al gran proceso de planificación de fuego en las Montañas Huachuca. El gran esfuerzo multi-participativo para la planificación del fuego en las montañas Huachuca ayuda a desarrollar un estudio estratégico para el manejo operacional del fuego. El área de planificación se extiende sobre un área geográfica relativamente grande e implica a una variedad de terrenos públicos y privados. Un prerrequisito para el éxito es el entendimiento de patrones e interrelaciones físicas bióticas a gran escala y como estos ecosistemas a escala de paisaje interaccionan y afecta al fuego. Las unidades ecológicas a escala de paisaje están siendo mapeadas a una escala de 1:250,000 para proporcionar un marco que ayude a definir e ilustrar esas relaciones. Utilizando un SIG como una herramienta, el mapa del US Forest Service General Ecosystem Survey y el Natural Resources Conservation Service STATSGO (State Soil Geographic Database), fue redefinido usando información derivada de un modelo de elevación digital, mapas geológicos, mapas existentes sobre la vegetación y el conocimiento de expertos. Estas unidades ecológicas proporcionan un contexto para modelar cambios en el régimen de fuegos y sus implicaciones vegetativas e hidrológicas asociadas, en respuesta a varias estrategias de manejo del fuego. Estas unidades ayudan a definir y caracterizar unidades de manejo del fuego y serán utilizadas como un mecanismo de estratificación para inventarios de condición del fuego. El desarrollo de estas unidades servirá como un prototipo para asistir en otros esfuerzos similares de planificación del fuego.

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Biodiversity and importance of ant-phorid interactions in the Madrean Archipelago. Flies in the family Phoridae parasitize adult worker ants. These flies can act as keystone species, impacting local ant assemblages out of proportion to their abundance. Although in North America phorid parasitoids occur as far north as the boreal forests of Canada, these parasites are largely a tropical group. The Madrean Archipelago is one of the most northern locations where phorids become a prominent feature of local ant assemblages. The widespread nature and importance of these parasites is largely unappreciated. At least 31 ant parasitizing phorids occur in the Sky Island mountain ranges. Twenty of these species are currently undescribed. Host species and natural history information are known for 13 of these species, and detailed ecological studies have been conducted on 2. We present experimental evidence from the Chiricahua Mountains demonstrating that phorids can reduce the behavioral dominance of their host ant, dramatically altering its ability to capture food resources. This eliminates the linearity of the ant assemblage dominance hierarchy and alters the assemblage tradeoff between the ability to dominate and to discover food resources. Both of these effects promote co-existence. In addition, we summarize what is known about the identity, distribution, and natural history of the ant-phorid associations in the Madrean Archipelago. Poster.

Importancia y biodiversidad de interacciones hormiga-fórido en Archipiélago Madrense. Algunas moscas de la familia Phoridae parasitan hormigas trabajadoras adultas. Estas moscas pueden actuar como especies clave impactando la porción actual de las hormigas en relación a su abundancia. Aunque los parasitoides fóridos ocurren tan al norte como en los bosques boreales de Canadá, estos parásitos son en su mayoría un grupo tropical. El Archipiélago Madrense es una de las localidades más hacia el norte donde los fóridos aparecen como una característica prominente de ensamble con las hormigas locales. La dispersión natural e importancia de estos parásitos es altamente inapreciada. Al menos ocurren 31 foridos parasitando hormigas en las montañas de las islas del cielo. 20 de estas especies no están actualmente descritas. Solo se conocen las especies huéspedes e información sobre la historia natural para 13 de estas especies y estudios ecológicos detallados han sido realizados solo en dos. Presentamos evidencia experimental de las montañas Chiricahua demostrando que los fóridos pueden reducir la dominancia conductual de su hormiga hospedera, alterando su habilidad para capturar recursos alimenticios. Esto elimina la linearidad de la jerarquía en el ensamble de dominancia de la hormiga y altera la forma de el ensamble entre la habilidad para dominar y para descubrir recursos alimenticios. Ambos efectos promueven la coexistencia. En adición, nosotros resumimos lo que hasta hoy es conocido acerca de la entidad, distribución, e historia natural de las asociaciones hormiga-fórido en el Archipiélago Madrense. Póster.

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Landscape transformations: changes in biodiversity and ecosystem functioning following the Ryan Fire of 2002. The replacement of native flora with non-native species raises several serious threats to native landscapes. Among these threats are possible changes in biodiversity, species composition, and ecosystem functioning. In 1949, two non-native lovegrass species, *Eragrostis lehmanniana* Nees and *Eragrostis curvula* (Schrad.) Nees var. *conferta* Stapf. were introduced to the Audubon Research Ranch of Elgin, Arizona. The subsequent establishment and spread of both species has led to differences between native and non-native grasslands in diversity, composition, and biogeochemical conditions. In addition, both lovegrass species have proven successful in re-establishing in recently burned areas, more so than native grasses of southeast Arizona. In May of 2002, the 38,000 acre Ryan Fire burned through the entire research area. This event provided us with an opportunity to examine the differences between non-native and native dominated grasslands, both before and after the fire. Comparison of pre- and post-fire results suggests that native and non-native grasslands are responding differently over time to the effects of wildfire. Significant transformations are occurring in aboveground biomass, soil structure, species composition, and diversity. These alterations may be leading to changes in native fire regime characteristics such as fire intensity and frequency.

Transformaciones del paisaje: cambios en la biodiversidad y funcionamiento del ecosistema después del incendio Ryan del 2002. El reemplazo de flora nativa con especies no nativas origina varias amenazas serias a los paisajes nativos. Entre estas amenazas están posibles cambios en la biodiversidad, composición de especies y funcionamiento del ecosistema. En 1949, dos especies de pastos no nativos, *Eragrostis lehmanniana* Nees y *Eragrostis curvula* (Schrad.) Nees var. *conferta* Stapf, fueron introducidos al Rancho Experimental Audubon de Elgin, Arizona. El establecimiento y dispersión subsecuentes de ambas especies han llevado a crear diferencias entre pastizales nativos y no nativos en cuanto a diversidad, composición, y condiciones biogeoquímicas. Adicionalmente ambas especies de pastos han sido exitosas en el reestablecimiento de áreas incendiadas recientemente, más que los zacates nativos del sureste de Arizona. En mayo del 2002 el incendio Ryan de 19,000 hectáreas, quemó por entero el área de investigación. Este evento nos proporcionó una oportunidad para examinar las diferencias entre pastizales nativos y no nativos antes y después del fuego. Resultados comparativos tomados antes y después del fuego sugieren que los pastizales nativos y no nativos están respondiendo en forma diferente a lo largo del tiempo, al menos en parte, a los efectos del fuego. Trasformaciones significativas están ocurriendo en biomasa aérea, estructura del suelo, composición de especies y diversidad. Estas alteraciones pueden estar conduciendo a cambios en las características del régimen de fuego nativo tales como intensidad y frecuencia de incendios.

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Long-term ecosystem monitoring and change detection: the Sonora initiative. The Ecoregional Systems Heritage & Encroachment Monitoring (ESHEM) work examines issues of change and land management at an ecosystem level. Recent technological advances have made this feasible using remote sensing. ESHEM is grounded in requirements for managing or tracking an entire ecoregion (or sensible sub elements). ERDC in partnership with Hunter College is developing an ecoregional database and monitoring capability covering the entire Sonora region. The data will become a potential baseline for applications and integrates multi-agency (USGS, NASA, EPA) data and state-of-the-art scientific capabilities. The monitoring time horizon will extend from the 1960s to at least 2020 with a high degree of detail (60 meters over the entire area. The work derives from the fact that military installation mission sustainability and encroachment are big issues in the military. For example threatened and endangered species habitat fragmentation and residential development near installations have the potential to affect their military training and readiness. To deal with these issues, Federal lands management must occur in cooperation with neighbors, political and local interest groups. Past experience has shown us that ignoring realities beyond the “fence-line” is an invitation to land use conflicts.

Monitoreo y detección de cambios en el ecosistema en un largo plazo: la iniciativa Sonora. El trabajo Ecoregional Systems Heritage & Encroachment Monitoring (ESHEM) examina características de cambio y manejo de tierras a nivel de ecosistema. Avances tecnológicos recientes han hecho esto posible utilizando percepción remota. El ESHEM está bien fundamentado en requerimientos para manejar o monitorear una ecoregión entera (o sub elementos sensibles). El ERDC en asociación con el Hunter College esta desarrollando una base de datos ecoregional y esta monitoreando la capacidad de cubrir por entero la región de Sonora. La información será una base potencial para ciertas aplicaciones e integra información multi-agencias (USGS, NASA, EPA) y capacidades científicas avanzadas. El horizonte de monitoreo en el tiempo se extenderá desde los 1960s hasta al menos el 2020 con un alto grado de detalle (60 metros sobre el área total). El trabajo deriva del hecho de que la sustentabilidad y la usurpación en la misión de instalación militar son grandes problemas en la milicia. Por ejemplo la fragmentación del hábitat de especies amenazadas y en peligro y el desarrollo residencial cerca de las instalaciones, tienen el potencial para afectar su entrenamiento militar. Para afrentar estos problemas, el manejo de tierras federales debe darse en cooperación con los vecinos, políticos y grupos de interés local. La experiencia en el pasado nos ha mostrado que ignorando las realidades mas allá de la “linea divisoria”, es una invitación a los conflictos del uso de la tierra.

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Abundance and food habits of cougars and bobcats in the Sierra San Luis, Sonora. Cougars (*Puma concolor*) and bobcats (*Lynx rufus*) are present throughout the Sky Islands. In recent decades their Mexican populations had been affected by livestock ranching where they are hunted and vegetation is overgrazed and landscape is altered, concurrent with no information on abundance or food habits in the region. For those reasons we started a study to determine their abundance and food habits in an area without cattle, namely “Los Ojos” and “El Pinito” ranches. Cougars are feeding on white-tailed deer (36.9%), peccaries (23.7%) skunks (23.7%) and cattle (15.7%), where bobcats are eating lagomorphs (84.2%) and occasionally on skunks (5%) peccaries (5%) and cattle (5%). We found no significant association of cougars with the vegetation, being the species more abundant in “Los Ojos” (3.7 ±5.7 ind/100km^2) than “El Pinito” (1.6 ±3.9 ind/100km^2). We found no significant differences between habitat types utilized by bobcats, and determined a low density for either ranch surveyed (“El Pinito” 0.17 ±0.05 ind/100 km^2 and 0.16 ±0.18 for “Los Ojos”) probably reflecting a time-lag crash on lagomorph populations. Our data provides baseline information for the management and conservation of these ranches as important refuges for these top predators and their prey.

Abundancia y hábitos alimenticios de pumas y gatos monteses en la Sierra San Luis, Sonora. Los pumas (*Puma concolor*) y los gatos monteses (*Lynx rufus*) están presentes a lo largo de las islas del cielo. En décadas recientes, sus poblaciones mexicanas han sido afectadas en los ranchos ganaderos donde ellos son cazados, la vegetación es sobrepastoreada y el paisaje es alterado, lo que es concurrente con la ausencia de información sobre abundancia y hábitos alimenticios en la región. Por estas razones, iniciamos un estudio para determinar su abundancia y hábitos alimenticios en un área sin ganado llamada ranchos "Los Ojos" y "El Pinito". Los pumas se están alimentando con venado cola blanca (36.9%), jabalíes (23.7%) zorrillos (23.7%) y ganado bovino (15.7%), mientras que los gatos monteses están comiendo lagomorfos (84.2%) y ocasionalmente zorrillos (5%), jabalíes (5%) y ganado bovino (5%). No encontramos asociación significativa de los pumas con la vegetación, siendo la especie mas abundante en "Los Ojos" (3.7 ±5.7 ind/100km^2) en relación con "El Pinito" (1.6 ±3.9 ind/100km^2). No encontramos diferencias significativas entre tipos de hábitat utilizados por los gatos monteses y determinamos una baja densidad para cada rancho estudiado ("El Pinito" 0.17 ±0.05 ind/100 km^2 y 0.16 ±0.18 para "Los Ojos") probablemente reflejando un impacto en el tiempo sobre las poblaciones de lagomorfos. Nuestros datos proporcionan información básica para el manejo y conservación de estos ranchos, como refugios importantes para estos gran depredadores y sus presas.

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Flash floods and aquatic insect communities in Madrean Sky Island streams. Extreme flows, such as flash floods and droughts, are characteristic of Madrean Sky Island streams. An intriguing aspect of these streams is that diversity and abundance of aquatic insects is relatively high despite (1) monsoon-season flash floods that can remove >95% of individuals, (2) droughts that can shrink stream habitat to a few small pools, and (3) low recolonization potential because of large distances among streams. A partial explanation for this pattern is that Sky Island aquatic insects possess life histories, behaviors, and morphologies that enhance survival of flash floods. Examples include synchronization of adult emergence to coincide with the average arrival date of monsoon floods, shortening of the larval vs. adult stage to minimize flood risk, and the use of rainfall as a cue to abandon streams prior to floods. While some of these traits have ancient origins, in other cases the traits appear to have evolved in response to local flood cycles that differ among streams. Dams are a conservation concern for this flood-adapted fauna—by reducing floods, dams facilitate the invasion of non-native taxa that are not flood adapted, allowing competition with the native fauna.

Inundaciones intermitentes y comunidades de insectos acuáticos en corrientes de las Islas del Cielo Madrense. Los flujos extremos tales como las inundaciones y sequías intermitentes, son característicos de las corrientes de las Islas del Cielo Madrense. Un aspecto intrigante de estas corrientes es que la diversidad y abundancia de los insectos acuáticos es relativamente alta sin importar 1) las inundaciones intermitentes de la estación monzónica que puede remover mas del 95% de los individuos, 2) sequías que pueden reducir las corrientes hábitat a muy pocos charcos pequeños, y 3) la baja recolonización potencial debido a las grandes distancias entre corrientes. Una explicación parcial a este patrón es que los insectos acuáticos de las islas del cielo poseen historias biológicas, comportamientos y morfologías, que aumentan la sobre vivencia de las inundaciones intermitentes. Algunos ejemplos incluyen la sincronización de la emergencia de adultos para coincidir con la fecha de llegadas promedio de inundaciones monzónicas, acortando el estadio de larva a adulto para minimizar el riesgo de inundación, y el uso de la lluvia como una pista para abandonar las corrientes antes de las inundaciones. Mientras que algunos de estos trucos tienen sus orígenes ancestrales, en otros casos parecen haber evolucionado en respuesta a ciclos locales de inundamiento que difieren entre corrientes. Las presas son un problema de conservación para esa fauna adaptada a las inundaciones ya que al reducir las inundaciones, las presas facilitan la invasión de taxa no nativos que no están adaptados a las inundaciones, permitiendo la competencia con la fauna nativa.

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Defining boundaries across borders: a case study extending a major land resource area into Mexico. The lack of understanding of the ecological systems surrounding the Madrean Archipelago is a major constraint on the management of the "desert seas". There is a clear need to identify those areas that will have similar responses to management on both sides of the border and share all available information. We used geographic information science (GIS) and field work to extend a USDA-NRCS classification scheme, Major Land Resource Areas (MLRAs), from southeastern Arizona and southwestern New Mexico into northeastern Sonora and Chihuahua. The Southeastern Arizona Basin and Range, MLRA 41, is a very diverse ecological area in the transition zone between the Sonora and Chihuahua Deserts. MLRAs have relatively homogeneous patterns of topography, soil, climate, water resources, and land use. The delineation of MLRA 41 into Mexico will allow for a more effective linkage of research and increased availability of information. The result of this analysis is a boundary line extending MLRA 41 into Mexico allowing for the enumeration of ecological sites, potential plant communities, threatened and endangered species habitat, and their implications in rangeland management. Poster.

Definiendo límites a través de bordes: caso de estudio en extensión de un recurso terrestre dentro de México. No conocemos bien los sistemas ecológicos que rodean el Archipiélago Madreano, lo que preocupa mucho al momento de manejar los "mares desérticos". Hay una clara necesidad de identificar las áreas que tendrán respuestas similares al manejo en ambos lados de la frontera, así como de compartir toda la información disponible. Nosotros usamos sistemas de información geográficos (SIG) y trabajo de terreno para extender un proyecto USDA-NRCS, MLRA, del sureste de Arizona y del suroeste de Nuevo México dentro del noreste de Sonora y Chihuahua. MLRA 41 es un área ecológica muy diversa en la zona de transición entre los desiertos de Sonora y Chihuahua. Los MLRAs son relativamente homogéneos en topografía, suelo, clima, recursos acuíferos y uso de la tierra. La delineación de MLRA 41 dentro de México permitirá una conexión más efectiva en investigación y una creciente disponibilidad de información. El resultado de este análisis es una línea divisoria que extiende MLRA 41 dentro de México permitiendo la enumeración de sitios ecológicos, potenciales comunidades de plantas, habitats de especies en peligro y sus implicaciones en manejo de pastizales. Póster.

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The fates of the Sonoran: the human ecosystem model as a tool for regional monitoring. Ecosystem monitoring is an invaluable (and greatly increasing) source of information for science-based resource stewardship. It is also a potential tool for communicating ecological conditions and trends to citizens and decision-makers. Comprehensive ecosystem monitoring includes both biophysical and sociocultural indicators. The Human Ecosystem Model (HEM) provides a foundation for such monitoring, and can help resource managers understand the alternative future trajectories ("fates") of the ecosystems and bioregions within which they operate. The model includes biophysical and sociocultural variables, and is useful for anticipating first-, second- and third-order effects. The HEM has been applied to the Upper Columbia River Basin, parks and greenways in the US and China, and urban ecosystems including Baltimore, Kuala Lumpur and Ho Chih Minh City. The HEM has potential application to the general Madrean region as well as the Sonoran Desert ecosystem.

El destino del Desierto Sonorense: el modelo de ecosistema humano como herramienta para monitoreo regional. El monitoreo de ecosistemas es una fuente de información invaluable (y en aumento) para la administración de recursos basada en la ciencia. Es también un potencial para comunicar condiciones ecológicas y tendencias a ciudadanos o a quienes hacen toma de decisiones. Un completo monitoreo de ecosistemas debe incluir indicadores tanto biofísicos como socioculturales. El Modelo de Ecosistema Humano (MEH) provee la base para semejante monitoreo, siendo capaz de ayudar a comprender a quienes manejan los recursos las futuras trayectorias alternativas ("destinos") de los ecosistemas y bioregiones en los cuales operan. El modelo incluye variables biofísicas y socioculturales, y es útil para anticipar efectos de primer, segundo y tercer orden. El MEH ha sido aplicado en la parte alta de la cuenca del río Columbia, parques y áreas verdes de los Estados Unidos y China, así como también en ecosistemas urbanos incluyendo Baltimore, Kuala Lumpur y la ciudad de Ho Chih Minh. Potencialmente el MEH se puede aplicar en toda la región Madrean en general, así como también en los ecosistemas del desierto sonorense.

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Flora of the San Pedro Riparian National Conservation Area. A flora is defined as an inventory of plants growing within a specific geographic boundary. Botanical inventories advance our understanding of our natural resources and provide a foundation of information for Government agencies, applied fields, and academia. The goals of this study were to document the occurrence and abundance of the vascular flora of the San Pedro Riparian National Conservation Area. The free-flowing hydrology and location among crossroads of landscapes have resulted in an ecosystem of considerable environmental heterogeneity and biological diversity. There are six major vegetation communities in the study site: Chihuahuan Desertscrub, cottonwood riparian corridors, mesquite terraces, sacaton grasslands, rocky outcrops, and cienegas. Six hundred and sixteen taxa from 93 families have been vouchered from this study including a new species of *Eriogonum*, 4 new state records, and numerous rare taxa. Community structure and species composition in riparian systems such as the San Pedro River will change over time. Baseline data is important to monitor change from dynamics such as beaver reintroduction, changing fire regimes, and declining water tables from groundwater pumping.

La flora del Área Nacional de Conservación de la Zona Ribereña del Río San Pedro. Flora se define como un inventario de plantas que crecen en un área geográfica específica. Los inventarios botánicos aportan al entendimiento de nuestros recursos naturales y proveen la base de información para agencias gubernamentales, áreas aplicadas y de educación. La meta de este estudio fue documentar la ocurrencia y abundancia de la flora vascular del Área Nacional de Conservación de la Zona Ribereña del Río San Pedro. Las características hidrológicas y la ubicación entre encrucijadas de paisajes han dado como resultado a un ecosistema de heterogeneidad ambiental considerable y con una gran diversidad biológica. Hay seis comunidades vegetales principales en el área de estudio: Matorrales desérticos Chihuahuenses, corredores ribereños de álamo (cottonwood), terrazas de mesquito, pastizales de zacatón, afloramientos rocosos y ciénegas. Seiscientos dieciséis taxa pertenecientes a 93 familias fueron considerados en este estudio, incluyendo una nueva especie de *Eriogonum*, cuatro nuevos records estatales y numerosos taxas raros. La estructura de las comunidades y la composición de especies en sistemas ribereños como el del río San Pedro irán cambiando con el tiempo. Datos iniciales son importantes para monitorear cambios en las dinámicas como la introducción del castor, cambios en regimenes de fuego y disminución de napas freáticas por causa de bombeo de aguas subterráneas.

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Vegetation classification in southwestern Arizona for the endangered Sonora pronghorn. The extraordinary home range of the Sonoran pronghorn – up to 4000 square kilometers – is likely a response to vegetation, which provides nutrition, moisture, shade and cover from predators. The goal of this study was to gather enough data in the field to allow detailed aerial photo interpretation of vegetation, to produce a map of Sonoran Pronghorn habitat in the Cabeza Prieta National Wildlife Refuge, and the BLM lands near Ajo, Arizona. The method combined taking 413 detailed samples — releves — to assess relative dominance, percent cover, and the height of all perennial plants, and "quick samples" that recorded the prominence and cover of the most common species. The resulting map(s) show 21 vegetation associations/sub-associations that are based on earlier classifications and the emerging National Vegetation Classification System (NVCS). Poster.

Clasificación vegetacional en el suroeste de Arizona para el berrendo Sonorense, especie en peligro de extincción. La extraordinaria extención del territorio del berrendo Sonorense, que incluye más de 4000 kilómetros cuadrados seguramente está relacionado con la vegetación, la cual provee nutrición, humedad, sombra y protección de los depredadores. La meta de este estudio fue recopilar suficiente información en el campo para facilitar la interpretación de fotografías aéreas de la vegetación y producir un mapa del hábitat del berrendo Sonorense en el Refugio Nacional de Vida Silvestre Cabeza Prieta y los terrenos del BLM cerca de Ajo, Arizona. En este método se combinaron 413 muestras detalladas para determinar el dominio relativo, porcentaje de cubierto de las especies más comunes. Los mapas que resultaran muestran 21 asociacones y sub-asocaciones que se basan en clasificaciones anteriores y en el nuevo Sistema Nacional de Clasificación de la Vegetación (SNCV). Póster.

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"Sky Islands" or "Desert Seas" – which deserves our immediate attention in the Apache Highlands Ecoregion? The Apache Highlands ecoregion is best known among the scientific community for the "Sky Island" mountain ranges that rise above intervening basins. While the Sky Island moniker has helped focus research and conservation attention on the region's mountains, it may have inadvertently relegated the "desert seas" to second-class biological status. The ecoregion's basins harbor their own unique suite of species and habitats that cannot be protected elsewhere. All of the major mountain ranges in the U.S. portion are managed by the Forest Service or Bureau of Land Management, and thus are largely protected from permanent development. This contrasts with our grassland basins, which are comprised mainly of private and state trust lands. Basin grasslands are now subject to economic and demographic forces causing a wave of land conversion as traditional land uses, such as ranching and agriculture, give way to growing communities. Without conservation focused on basins we are unlikely to maintain or recover populations of grassland endemics (e.g., grassland birds, black-tailed prairie dog) or maintain wide-ranging species such as the pronghorn. Moreover, land conversion in some basins may permanently sever dispersal routes used by Sky Island organisms that periodically move to adjacent ranges.

"Islas del Cielo" o "Mares Desérticos" – Cúal merece nuestra atención inmediata en la Ecorregión de Tierras Elevadas Apache? La ecoregión de tierras elevadas Apache es muy conocida entre la comunidad científica por sus mas de 40 "islas de altura" que se elevan sobre cuencas intervenidas. Mientras que el moniker de las islas en altura ha ayudado a enfocar la atención de la investigación y la conservación en las montanas de la región, también ha relegado inadvertidamente a los "mares desérticos" a status biológicos de segunda clase. Aunque hay diferencias en riqueza de especies entre cuencas desérticas o de pastizales y nuestros bosques Madrenses, la riqueza de especies es solo un atributo de la biodiversidad biológica que es importante proteger. Las cuencas de la ecoregión poseen especies únicas que no pueden ser protegidas en ninguna otra parte. Nosotros analizamos datos regionales en especies y hábitats que están restringidos a las cuencas de la ecoregión, contrastándolos con datos de tenencia de la tierra, desarrollo de la tierra, y otras amenazas potenciales. El manejo de la tierra influencia fuertemente el actual y futuro estado de la biodiversidad. Las más altas cordilleras de la porción estadounidense de la ecoregión son manejadas por el Servicio Forestal y la Oficina de Manejo de la Tierra (BLM), y están en su mayoría protegidas contra el desarrollo permanente. Esto contrasta con nuestras cuencas de pastizales, las cuales están comprendidas en su mayoría por tierras privadas y estatales. Las cuencas de pastizales están ahora susceptibles a fuerzas económicas y demográficas, causando una ola de conversión de la tierra, como ranchos y agricultura, dando lugar a nuevas subdivisiones para comunidades crecientes. Sin conservación basada en cuencas no podremos mantener o recuperar poblaciones endémicas en pastizales (e. g. aves de pastizales, perro de pradera de cola negra) o mantener un amplio rango de especies como el berrendo. Además, las tasas de conservación de uso de la tierra en algunas cuencas podrían romper permanentemente las rutas de dispersión usadas por los organismos de las Islas del Cielo que periódicamente se mueven a zonas adyacentes.

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Climate mitigation potential of the San Pedro River riparian zone. Due to the semi-arid climate, few researchers have speculated on the role of the Madrean Archipelago for forcing or mitigating climate change. Studies were initiated in 2001 in the riparian zone with three vegetation communities, an open brush site, a sacaton (*Sporobolus wrightii*) grass community, and an extensive mesquite (*Prosopis velutina*) community. Litter fall collected for 2001 – 2002 and 2002 – 2003 found that mesquite litter fall for both years was remarkably similar and averaged 4.0 g N m-2 and 65 g C m-2 despite extended dry periods in 2001. Soil carbon (C) and nitrogen (N) contents were elevated in the mesquite community with an extensive litter layer compared to the other sites. Trace gas analysis conducted June 2002 – September 2003 found that CO_2 and N_2O fluxes from the sites were similar in magnitude and closely tied to moisture pulses and not closely related to organic C or N content. All soils showed a strong CH_4 sink suggesting that the overall C flux was into the riparian zone. Water is essential for the productivity of the riparian zone, so loss of water from the San Pedro River will severely impact the continued function of the C sink in the riparian area.

Potencial de mitigación climática de la zona ribereña del Río San Pedro. Debido al clima semiárido, pocos investigadores han especulado en el rol del Archipiélago Madreano en forzar o mitigar cambios climáticos. Se iniciaron estudios en 2001 en la zona ribereña con tres comunidades vegetales, un sitio de arbusto abierto, una comunidad de pasto (*Sporobolus wrightii*) y una extensa comunidad de mesquite (*Prosopis velutina*). La hojarasca caída recolectada del 2001 – 2002 y del 2002 – 2003 indicó que la hojarasca de mesquite en ambos años fueron similares y promediaron 4.0 g N m-2 y 65 g C m-2, a pesar de extendidos períodos de sequía en 2001. Los contenidos de carbón (C) y nitrógeno (N) en el suelo fueron elevados en la comunidad de mesquite con una extensa capa de hojarasca comparada con los demás sitios. Un análisis de gases conducidos en junio del 2002 y septiembre del 2003 revelaron que los flujos de CO2 y NO2 fueron similares en magnitud y cercanamente relacionados con los contenidos de humedad y no cercanamente relacionados con contenidos orgánicos de C y N, en todos los sitios. Todos los suelos mostraron un fuerte contenido de CH4, sugiriendo que el flujo general de C existía en la zona ribereña. El agua es esencial para la productividad de la zona ribereña, por lo que una pérdida de agua por parte del Río San Pedro impactará severamente el funcionamiento continuo del C en la zona ribereña.

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Sky Islands and near time: revisions for the future. Southwestern “Sky Islands” are isolated mountains of forest or woodland rising in elevation 800 meters or more above inter-montane basins of grassland or desert shrubs. Roughly two-dozen scatter between the southern end of the Rocky Mountains and the northern end of Mexico’s Sierra Madre Occidental. The larger “islands” harbor over 1000 species of vascular plants.

In near time or radiocarbon time the region supported an extinct megafauna of Columbian mammoths, occasional mastodonts, native species of equids, camelids, bison, dwarf pronghorn, dire wolves, the American lion, the Shasta ground sloth, and vampire bats. When determined by radiocarbon dating these animals vanished with the arrival of prehistoric people 13,000 years ago. Along the San Pedro River in Cochise County are rich archaeological sites linking Columbian mammoths, bison, and other extinct animals with the first robust evidence of the Clovis Culture.

Land planners are encouraged to consider the fossil record of near time before deciding on management. What Coronado, James Ohio Pattie, and the Mormon Battalion saw here was not what Clovis hunters found. What belongs on the range is much debated, and should be. Options include nothing not “native,” traditional livestock, and experimental proxies. The worst threat is new home construction.

Islas del Cielo y el tiempo reciente: revisiones para el futuro. Las “Islas del Cielo” del suroeste de E.E.U.U. son montañas aisladas con bosques o montes que se erigen a elevaciones de 800 metros o más por encima de cuencas intermontañosas de pastizal o arbustos desérticos. Alrededor de dos docenas se esparcen entre el sur de las Rocallosas y el norte de la sierra Madre Occidental de México. Las “islas” mas grandes albergan mas de 1000 especies de plantas vasculares.

El en tiempo reciente o tiempo de radiocarbono, la región tuvo una megafauna extinta de mamúts Colombianos, ocasionalmente mastodontes, especies nativas de equinos, camélidos, bisontes, berrendos enanos, lobos salvajes, liones americano, el diente de sable Shasta y murciélagos vampiros. Cuando se datan mediante radiocarbono, se determina que esos animales se extinguieron con la llegada de los habitantes prehistóricos, hace 13,000 años. A lo largo del Río San Pedro en el condado de Cochise, existen sitios arqueológicos muy ricos que ligan a los mamúts Colombianos, bisontes y otros animales extintos con las primeras evidencias robustas de la cultura Clovis.

Se hace una propuesta para que los manejadores del terreno consideren el registro fósil del tiempo reciente antes de tomar desiciones sobre el manejo de los recursos. Lo que vieron Coronado, James Ohio Pattie y el Batallón Mormón no fue lo que hayaron los cazadores Clovis. Qué es lo que pertenece a la región es y deberá ser materia de debate. Las opciones no incluyen nada que no sea “nativo”, ganado tradicional y similares experimentales. La peor amenaza es la nueva construcción de casas.

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Temporal succession and spatial distribution of anurans in the Sonoran/Chihuahuan desert grassland community of Arizona. Anurans that are dependent on water for survival must adapt to xeric conditions in order to inhabit desert communities and survive. Many of these adaptations for individual species have been documented. However, little is known about the population biology and community interaction of desert anurans. A few studies have investigated competition related to predation and the age-structure of the anuran desert community, but temporal succession and spatial partitioning have been overlooked. Adaptations such as temporal succession and spatial partitioning could compensate for a shorter breeding period and smaller breeding area associated with a xeric habitat. Anuran succession has been discovered in other ecological communities and could explain the survival of anuran community inhabiting the Sonoran/Chihuahuan desert grassland. By determining patterns of temporal and spatial structure of this anuran desert community, we can develop hypotheses regarding the mechanisms of the assemblages and gain insight into conserving and protecting these fragile communities.

Sucesión temporal y distribución espacial de anuranos en la comunidad de pastizales de Arizona en el desierto Sonorense y Chihuahuense. Los anuranos que dependen del agua para su sobreviviencia deben adaptarse a condiciones xéricas para así habitar comunidades desérticas y sobrevivir. Ya han sido documentadas muchas de estas adaptaciones para especies individuales. Como sea, poco se sabe acerca de biología de poblaciones e interacciones de comunidades de anuranos desérticos. Unos pocos estudios han investigado la competición relacionada con la depredación y la estructura de edades de la comunidad desértica de anuranos, pero la sucesión temporal y la partición espacial han sido pasados por alto. Las adaptaciones como sucesión temporal y partición espacial pueden compensar un período de crianza más corto y un área de crianza más pequeña asociada con habitats xéricos. La sucesión anurana ha sido descubierta en otras comunidades ecológicas y podría explicar la sobrevivencia de la comunidad de anuranos en los pastizales de los desiertos de Sonora y Chihuahua. Al determinar modelos de estructura espacial y temporal de esta comunidad desértica de anuranos, nosotros podemos desarrollar hipótesis acerca de los mecanismos de reuniones y ganar perspicacia en la conservarción y protección de estas frágiles comunidades.

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Monitoring non-native plants using hand-held GIS technology. Non-native plants can have very detrimental impacts on native ecosystems, impacting nutrient cycling, disturbance regimes, local hydrology, and energy budgets. In addition to a strong commitment of resources and widespread support, successful control of invaders requires a clear picture of the spatial extent of infestations. Accurate inventories of invaded areas are critical to control efforts. The latest mapping technology involves coupling global position systems (GPS) and handheld computers running geographic information systems (mapping) software in the field, eliminating the need for data sheets and office data entry. This system was implemented in two of Arizona's national parks in the summer of 2003, resulting in high-resolution, accurate maps of non-native plant extent. These maps will greatly enhance management decisions at the parks and in adjacent areas. In addition, weed management areas across the state of Arizona are showing interest in adopting the technology. Widespread adoption of common data collection methods, mapping standards, and record keeping will enhance data sharing and facilitate eradication efforts across regions of infestation. This presentation will highlight one approach for weeds mapping which is currently receiving a good deal of attention. The GPS and handheld computer system will be briefly demonstrated as well.

Monitoreo de plantas no nativas usando tecnología SIG manual. Las plantas no nativas pueden tener impactos perjudiciales en los ecosistemas nativos, impactando el ciclo de nutrientes, los disturbios en regimenes, la hidrología local y los balances energéticos. Además de un fuerte compromiso de recursos y un muy difundido soporte, el exitoso control de invasores requiere una imagen clara del la extensión espacial de las infestaciones. Inventarios precisos de áreas invadidas son críticos para controlar esfuerzos. La última tecnología en mapas involucra en conjunto sistemas de geoposicionamiento global (SGG) y un sistema computarizado que presentan software de sistemas de información geográfica (generación de mapas) en terreno, eliminando la necesidad de hojas de datos e ingreso de datos en la oficina. Este sistema fue implementado en dos de los parques nacionales de Arizona en el verano del año 2003 y como resultado se han generaron mapas de alta resolución y precisos de la extensión de plantas no nativas. Estos mapas van a ser muy útiles para la toma de decisiones en los parques y las áreas adyacentes. Además, áreas para el manejo de malezas a lo largo del estado de Arizona están mostrando interés en adoptar la misma tecnología. La adopción difundida de métodos comunes de colección de datos, estándares de mapas y almacenamiento de records realzará la compartición de información y facilitara los esfuerzos de erradicación a lo largo de regiones infestadas. Esta presentación recalcará un enfoque de mapeo de malezas, el cual está recibiendo mucha atención. Además, se hará una breve demostración de la tecnología de GPS y del sistema computacional manual.

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Developing effective ecosystem monitoring strategies for military activities in deserts: results from the US Army Yuma Proving Ground. Biodiversity in arid lands is associated with vegetation along bajada tributary channels which, in addition to precipitation, receive ephemeral runoff generated from surrounding soils. Any change in runoff will therefore directly impact critical parts of the ecosystem, and the recognition of signals indicating change in this water availability will benefit rehabilitation and management of desert lands.

Soil, geomorphic, hydrologic, and biologic characterization data were used to determine if key shrub and tree species distributed along first-order channels draining desert piedmonts in the Yuma Proving Ground can provide cost-effective and reliable signals of ecosystem condition. Results indicate that trends in vegetation health will be sensitive to changes related to either military activities or natural changes in rainfall, and that a long-term (>50-year) trend in a contraction of vegetation is occurring. Low order drainages in this region of the Sonoran Desert appear to be more sensitive to localized patterns of run-on augmentation, for example from infrequent large storms (>2-10 years), than to larger-scale drainage dynamics.

Desarollando estrategias útiles para el monitoreo de ecosistemas desiérticos que tienen actividades militares: resultados desde el U.S. Army Yuma Proving Ground. La biodiversidad en tierras áridas está asociada a la presencia de vegetación enlos canales tributarios de bajadas, lo cuales, que junto con la precipitación, recibe el derrame efímero de nutrientes que generan los suelos circundantes. Cualquier cambio en el derrame de nutientes tendrá un impacto directo en las partes más críticas del ecosistema por lo que el reconocimiento de las señales que indican un cambio en la disponabilidad de agua será beneficioso la recuperación y el manejo de las tierras desiérticas.

Se usaron datos de caracterización geomórfica, hidrológica, biológica y de suelos para determinar si las especies claves de arbustos y árboles que se distribuyen por los canales de primer-orden que reciben derrame de *piedmont* desiértica en el Yuma Proving Ground puede proveer señales de la condición ecosistémica que sean eficientes en términos de costo y confiables. Los resultados indican que los tendencias en el salud de la vegetación será sensible a los cambios relacionados a las actividades militares o a cambios naturales de precipitación, y que esta ocurriendo una contracción de la vegetación desde hace tiempo (>50 años). Los drenajes de bajo orden en esta región del Desierto Sonorense parecen más sensibles al aumento de occurencias localizadas de *run-on*, por ejemplo tormentas grandes (>2-10 años), que a las dinámicas de derrame de nutrientes a escalas más grandes.

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Pollination of Pima pineapple cactus (*Coryphantha scheeri* var. *robustispina*); does pollen flow limit abundance of this endangered species? Rarity among plants generally occurs across a gradient along which individuals at one extreme are relatively abundant in a limited but specific area and on the other extreme they are located in a geographically widespread manner, but occur in low densities throughout their range. Each rare species faces unique challenges associated with its position along that gradient. Pima pineapple cactus (PPC) (*Coryphantha scheeri* var. *robustispina*), a federally Endangered species, occurs throughout southeastern Arizona, but has relatively low population densities. PPC is an obligate outcrosser that is pollinated by a cactus specialist bee (*Diadasia rinconis*), which suggests that sexual reproduction constrains its abundance. We used florescent dye to quantify pollen flow between individuals in a PPC population to determine limitation of PPC reproduction. Preliminary results suggest *Diadasia* bees are capable of transferring pollen analogs greater than 1 km, but most transfer occurs over a few hundred meters. Previous studies have shown that PPC tends to abort 40% of their fruits, however we have found that PPC is not pollen limited, at least when very few competing cactus species are in bloom. Ongoing work will detail the level of limitation when competition between more common cacti and PPC is greater. Poster.

Polinización del cactus de la piña de Pima (*Coryphantha scheeri* var. *robustispina*); la abundancia de esta especie en peligro está limitada por el flujo de polen? La rareza entre plantas generalmente ocurre a lo largo de un gradiente en el que individuos en un extremo son relativamente abundantes en un área limitada pero específica y en el otro extremo están dispersos geográficamente, pero ocurren en bajas densidades a lo largo de su distribución. Cada especie rara enfrenta desafíos únicos asociados con su posición a lo largo de ese gradiente. El cactus de la piña de Pima (PPC), una especie en peligro de extinción federal, habita en el sureste de Arizona, pero en relativamente bajas densidades. PPC es polinizado por una abeja especializada a cactus (*Diadasia rinconis*), lo que sugiere que la reproducción sexual restringe su abundancia. Nosotros usamos tinta fluorescente para cuantificar el flujo de polen entre individuos en una población de PPC para determinar limitantes en la reproducción de PPC. Los resultados preliminares sugieren que dichas abejas son capaces de transferir polen a mas de un kilómetro, pero que la mayoría de las transferencias ocurre a unos cuantos cientos de metros. Estudios anteriores han demostrado que PPC tiende a abortar el 40% de sus frutos, sin embargo, nosotros encontramos que el polen no es un factor limitante en PPC, por lo menos cuando muy pocas especies de cactus competivivos están floreciendo. Los actuales estudios darán en detalle del nivel de limitación cuando la competencia entre los cactus más comunes y PPC es mayor. Póster.

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Studies of trace gas fluxes reveal that desert soils can mitigate global change. Moisture limitations have led researchers to believe that semi-arid soils are not significant consumers or producers of trace gases and as a result, semi-arid soils are often largely overlooked in greenhouse gas inventories. We are studying environmental influences on soil fluxes of greenhouse gases (CO_2, N_2O and CH_4) in vegetation communities throughout southeastern Arizona. In the spring of 2002 and 2003, extremely dry soils during the pre-monsoon period (June through early July) resulted in negligible gas fluxes, but the first pulses of monsoon moisture stimulated soil N_2O and CO_2 production. The largest emissions occurred during the monsoon period (mid-July through September), but small amounts of CO_2 and N_2O production were also found following rainfall events throughout the fall and winter. The CH_4 sink was less responsive to surface soil moisture, with significant CH_4 consumption found through the summer and winter months. The soils averaged 525 μg CH_4 oxidized m^{-2} d^{-1} throughout the year, well within the range reported for temperate forest soils. This work confirms the presence a large, previously unreported, CH_4 sink in Arizona soils, and strongly suggests that the soils of semi-arid ecosystems cannot be discounted in potential mitigation of climate change.

Estudios de flujos de seguimiento de gas que los suelos deserticos pueden mitigar el cambio global. Las limitaciones de humedad han llevado a los investigadores a creer que los suelos semiáridos no son grandes consumidores o productores de gas y como resultado, los suelos semiáridos son pasados por alto en los inventarios de gases de invernadero. Nosotros estamos estudiando influencias ambientales en los flujos de suelo de gases de invernadero (CO_2, N_2O and CH_4) en comunidades vegetacionales en el sureste de Arizona. En la primavera de los años 2002 y 2003, los suelos extremadamente secos durante el periodo de pre-monsón (de junio a principios de julio) resultaron en un flujo de gases insignificante, pero los primeros pulsos de humedad monsónica estimularon la producción de N_2O y CO_2 en el suelo. Las emisiones más grandes ocurrieron durante el periodo del monsón (desde la mitad de julio hasta septiembre), pero pequeños montos de producción de CO_2 y N_2O fueron también encontrados después de lluvias caídas en otoño e invierno. Los niveles de CH_4 no respondieron bien a los niveles de humedad del suelo, con un consumo de CH_4 considerable en los meses de verano e invierno. Los suelos promediaron 525 μg CH_4 oxidado m^{-2} d^{-1} a través del año, concordando con los datos reportados en suelos forestales de zonas templadas. Este trabajo confirma la presencia de un gran e indocumentado flujo de CH_4 en suelos de Arizona, y sugiere fuertemente que los suelos de ecosistemas semiáridos no pueden estar descontados en la mitigación potencial de un cambio climático.

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Variation in populations of Yarrow's spiny lizard, *Sceloporus jarrovi*, in the northern Madrean Archipelago region. Yarrow's spiny lizard, *Sceloporus jarrovi* (Sauria: Phrynosomatidae), a montane, Sky Island lizard, occupies rocky outcrops and canyons at elevations from 1500 - 3000 meters in the Madrean ranges. Enzymatic variation of over 300 individuals from 37 locations in mountain ranges in Arizona and New Mexico revealed variation both within and between ranges. Differences within the Chiricahua Mountains suggest barriers to dispersal, while greater differences between ranges suggests even more reduced gene flow and possible multiple colonization events. Frame-by-frame analysis of display patterns of free-ranging resident males from five mountain ranges in Arizona revealed visually different, mountain-specific patterns and distinguished displays from the Chiricahuas, Pinaleños and Dragoons from the Huachucas and Santa Ritas. Together the genetic and behavioral data provide insight into the evolutionary relationships between populations, the historic origins, and past geographic connections between mountains. The observed variation suggests two ancestral sources and a metapopulational distribution pattern resulting from subsequent constraints on dispersal. We hypothesize that gene flow is constrained by suitable habitat, the availability of crevices suitable for over-wintering, and by high site fidelity. Due to intolerance of higher temperatures typical of lower elevations, dispersal between ranges has probably been severely restricted since the last Pleistocene glaciation event.

Variación en poblaciones de la lagartija espinuda Yarrow, *Sceloporus jarrovi*, en el norte de la región del Archipiélago Madrense. La Lagartija Espinuda Yarrow, *Sceloporus jarrovi* (Phrynosomatidae), una especie de montaña de las islas del cielo , habita en zonas pedregosas y cañones a elevaciones desde 1500 a 3000 metros en las zonas madrenses. La variación enzimática en más de 300 individuos de 37 lugares en zonas montañosas de Arizona y New Mexico reveló variaciones en y entre áreas de dispersión. Las diferencias entre las Montañas Chiricahua sugieren barreras de dispersión, mientras que mayores diferencias entre sitios sugieren incluso un menor flujo genético y posibles eventos de colonización múltiple. Análisis de dispersión cuadro-por-cuadro de libre alcance en machos residentes en cinco sitios montañosos en Arizona revelaron diferencias visuales, tendencias específicas del tipo de montaña, y muestras distinguidas de las Chiricahuas, Pinaleños y Dragoons de las Huachucas y las Santa Ritas. Juntos los datos genéticos y de comportamiento proveen una idea de las relaciones de evolución entre poblaciones, los orígenes históricos y las conexiones geográficas pasadas entre las montañas. La variación observada sugiere dos fuentes ancestrales y una distribución multipoblacional que surgió como resultado de las restricciones sobre la dispersión. Hemos llegado a la hipotesis que el flujo genético esta limitado por hábitats adecuados, la disponibilidad de grietas adecuadas para pasar el invierno y por alta fidelidad a sitios. Debido a la intolerancia de altas temperaturas típicas de bajas elevaciones, la dispersión entre sitios ha sido probablemente severamente restringida desde la última glaciación en el Pleistoceno.

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Stand dynamics of a Madrean evergreen woodland, Big Bend National Park, Texas. The Sky Island archipelagos of the Sierra Madre Oriental and Occidental contain a unique array of flora and fauna found nowhere else in the world. Yet, the stand dynamics of Madrean evergreen woodlands are little studied and poorly understood. The stand structure and species composition of these restricted forests are thought to vary in response to disturbance regime and historical land use, however only a few studies have investigated the role of these factors in maintaining ecosystem health and species diversity. This study uses stand structure analysis, cluster analysis, and detrended correspondence analysis to quantify recent trends in plant population abundance and spatial distribution in pine-oak woodlands of Big Bend National Park, Texas. Results from this study indicate that vegetation abundance and distribution patterns are correlated with environmental gradients of potential soil moisture and elevation. Current stand structure reflects recent human-caused changes in fire frequency as a result of over a century of fire suppression in the southwestern United States. Findings from this study reflect the desperate need for the restoration of Madrean pine-oak woodlands through the reintroduction of fire. Poster.

Dinámicas de rodal en un bosque madrense en el Parque Nacional Big Bend, Texas. El Archipiélago de las Islas del Cielo de la Sierra Madre Oriental y Occidental contienen una gama única de flora y fauna que no se encuentra en ninguna otra parte del planeta. Sin embargo, la dinámica de rodales de los bosques siempreverdes madrenses no ha sido muy estudiada ni tampoco bien entendida. La estructura de rodales y composición de especies de estos bosques restringidos varían en respuesta a disturbios y diferentes usos de la tierra en el pasado. Sin embargo, solo unos pocos estudios han investigado el rol de estos factores en la manutención de la salud del ecosistema y la diversidad de especies. Este estudio usa un análisis de estructura de rodal y análisis grupal, entre otros, para cuantificar recientes tendencias en abundancia de poblaciones de plantas y distribuciones espaciales en los bosques de pino-encino del Parque Nacional Big Bend, en Texas. Los resultados indican que la abundancia y distribución de la vegetación están correlacionadas con factores ambientales de humedad potencial del suelo y elevación. La actual estructura de rodal indica un reciente cambio por causa del hombre en la frecuencia del fuego, como resultado de más de un siglo de supresión de fuego en el suroeste de Estados Unidos. Considerando los resultados de este estudio se necesita rectorar los bosques de pino-encino reintroduciendo el fuego. Póster.

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The evolution of heterostylous reproductive systems in populations of *Oxalis alpina*. Populations of *Oxalis alpina* (section *Ionoxalis*, Oxalidaceae) with variable reproductive systems are found at high elevations throughout the Madrean Archipelago. Tristylous populations with three self-incompatible floral morphs are found in southeastern Arizona, adjacent New Mexico, and in all of the mountain ranges in Sonora that we have investigated. The frequency of the mid morph is highest in populations from Mexico. At the northwestern edge of the Madrean Archipelago in Arizona populations are distylous, with two self-incompatible floral morphs. The distribution of tristylous and distylous populations in Arizona and Mexico suggests that distyly has evolved at the northern edge of the distribution, probably after a tristylous race migrated into this region. Presumably *Oxalis alpina* spread north throughout this region during the Pleistocene, when cooler, wetter conditions prevailed, and this species had a more continuous distribution. Drying following the Pleistocene is likely to have resulted in restriction of this species to higher elevations. Studies of the incompatibility system of tristylous *Oxalis alpina* populations have shown considerable variability, and modifications of typical tristylous incompatibility relationships that suggest a mechanism resulting in selection against the mid morph and the evolution of distyly. Evolution of distyly has probably occurred independently in the northern populations of the Madrean Archipelago.

La evolución de sistemas reproductivos variables en poblaciones de *Oxalis alpina*. Las poblaciones de *Oxalis alpina* (sección *Ionoxalis*, Oxalidaceae) del sistema de montañas del Archipiélago Madrense muestran un sistema heterostílico variable. Las poblaciones tristílicas con tres morfos florales auto-incompatibles se distribuyen en el sureste de Arizona, en áreas adyacentes de Nuevo México y en todas las montañas del Archipiélago Madrense que hemos investigado en Sonora, México. La frecuencia del morfo intermedio es mayor en las poblaciones de México. Las poblaciones distílicas con dos morfos (corto y largo) auto-incompatibles se localizan en el extremo noroeste del sistema de montañas del Archipiélago Madrense de Arizona. La distribución actual de las poblaciones tristílicas y distílicas en Arizona y Sonora sugiere que la distilia ha evolucionado en el extremo norte de su distribución, probablemente después de que las poblaciones tristílicas migraron hacia esta región. Se presume que *O. alpina* migró hacia esta región durante el Pleistoceno cuando existían condiciones más mésicas y esta especie tenía una distribución más continua. Es probable que el incremento de la aridez posterior al Pleistoceno haya afectado su distribución y restringido esta especie a la parte más alta del sistema de montañas del Archipiélago Madrense. Los estudios del sistema de incompatibilidad de las poblaciones tristílicas muestran una variación considerable y las modificaciones de las reacciones de incompatibilidad sugieren un mecanismo que opera en contra del morfo intermedio y que da como resultado la evolución de la distilia. Es probable que la evolución de la distilia haya ocurrido de manera independiente en las poblaciones del norte del Archipiélago Madrense.

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The Cascadia Scorecard, Northwest Environment Watch's project to measure what matters. Every three minutes in 2003, the Pacific Northwest added another person to its population; every 35 minutes, the region's cities sprawled across another acre of open space; every day, the life expectancy of a northwesterner born that day increased by three hours. These are examples of trends that change slowly, but over decades transform a region more dramatically than the short-lived events of headline news. The Cascadia Scorecard is Seattle-based Northwest Environment Watch's new regional index of progress that tracks such seven slow-changing but critical trends: health, economy, population, energy, sprawl, forests, and pollution. Elisa Murray, communications director, will explain the Scorecard project, the tools that it provides to media and community leaders, and how Northwest Environment Watch hopes to use it to not just monitor but to effect change.

El proyecto Cascadia Scorecard del Northwest Environment Watch para medir lo que es de interés. En el 2003, cada tres minutos el Noroeste del Pacífico agregó una persona mas a su población; cada 35 minutos, las ciudades de la región se extendieron sobre un acre de espacio abierto; cada día, la esperanza de vida de un recién nacido en el noroeste se incrementó en uno por cada tres horas. Estos son ejemplos de tendencias que cambian lentamente, pero sobre décadas transforman una región más dramáticamente que los eventos de corta duración de las noticias principales. El Cascadia Scorecard es un nuevo índice regional de progreso del Northwest Environment Watch establecido en Seattle, que sigue de cerca siete tendencias críticas y de lento cambio: salud, economía, población, energía, urbanización, bosques y contaminación. La directora de comunicaciones Elisa Murray explicará el proyecto Scorecard, las herramientas que el proporciona a los lideres de la comunidad y de los medios y como el Northwest Environment Watch espera usarlo no solo para monitorear sino para efectuar el cambio.

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Post-fire saguaro community: impacts on associated vegetation still apparent 10 years later. In recent decades thousands of hectares of saguaro habitat burned by wildfire have converted to grasslands. Historically, this was desirable and saguaro-shrub was burned to improve rangeland for livestock. New priorities now support conservation of healthy saguaro communities and restoration of burned or degraded habitat. Understanding regeneration and developing restoration techniques for fire-scarred saguaro-shrub habitat requires understanding post-fire community response. Regeneration of vegetation associated with saguaro is crucial for saguaro regeneration. However, little information exists on post-fire dynamics of this desert community. In previous papers we reported that saguaro mortality increased from 19 to 30 percent over 10 years. Additionally, fire stalled the growth of burned compared to unburned saguaro. Furthermore, many associated species regenerated shortly after fire either from seed or by sprouting. This paper describes the natural progression of post-fire changes in the plants associated with saguaro 10 years after the 1993 Vista View fire. Interestingly, successive post-fire years of observations show that some saguaro associated plant species responded similarly to the saguaro—after sprouting, growth rates stalled for some while others eventually died. The long-term survival of all plant species in the saguaro-shrub need to be studied so future conservation or restoration resources may be effectively applied.

Comunidad de sahuaros en post-incendio: impacto sobre la vegetación asociada todavía aparente 10 años después. En décadas recientes miles de hectáreas de hábitat de sahuaro quemadas por un incendio natural se han convertido en pastizales. Históricamente, esto fue deseable y los matorrales con sahuaro fueron quemados para mejorar los ranchos ganaderos. Nuevas prioridades ahora apoyan la conservación de comunidades saludables de sahuaro y la restauración de hábitats quemados o degradados. El entendimiento de la regeneración y el desarrollo de técnicas de restauración para el matorral de sahuaro dañado por el fuego, requiere del entendimiento de la respuesta post-incendio de la comunidad. La regeneración de la vegetación asociada con sahuaro es crucial para la regeneración del sahuaro. Sin embargo existe poca información sobre la dinámica post-incendio en esta comunidad del desierto. En artículos previos, nosotros reportamos que la mortalidad de sahuaros se incrementó de 19 a 30% en 10 años. Adicionalmente el fuego paró el crecimiento de sahuaros quemados en comparación a no quemados. Además, muchas de las especies asociadas se regeneraron rápidamente después del fuego ya sea por semilla o por rebrote. Esta presentación describe el progreso natural de cambios post-incendio en las plantas asociadas con el sahuaro 10 años después del incendio Vista View de 1993. Interesantemente los años sucesivos de observaciones posteriores al fuego muestran que algunas especies vegetales asociadas al sahuaro respondieron similarmente a las tasas de crecimiento del rebrote del sahuaro mientras que otras eventualmente murieron. La sobrevivencia a largo plazo de todas las especies vegetales en el matorral de sahuaro necesita ser estudiada de tal forma que los recursos para la conservación y restauración futuras puedan ser aplicados efectivamente.

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Hydrology, ecology, and management of riparian areas in the Madrean Archipelago. Riparian corridors in the Madrean Archipelago have historically provided water necessary for people, livestock, and agricultural crops. Anglo settlers during the 1800s were attracted to riparian areas in this arid and semi-arid region where they enjoyed the forage and shade for themselves and their livestock and existed on the readily available wildlife and fish. Trees growing along stream banks were harvested for fuel, poles, and building materials. Demands for water dominated the management of the riparian ecosystems as human populations increased, particularly after World War II. Many uniquely structured ecosystems were altered by attempts to salvage water as a result. Only within the last 25 to 30 years have people once again begun to recognize the value of the diverse benefits associated with riparian areas. The changing management emphasis from the evolving human attitudes about the holistic importance of riparian areas in the Madrean Archipelago is the focus of this paper. As they have in the past, riparian research, planning, and management issues continue to concern the flows of water and sediments, impacts of livestock and other human activities on these fragile systems, sustaining key wildlife and fish habitats, and vegetative structure, classification, and patterns of plant succession.

Hidrología, ecología, y manejo de áreas ribereñas en el Archipiélago Madrense. Las áreas ribereñas en el Archipiélago Madrense históricamente han proporcionado el agua necesaria para los habitantes, el ganado y los cultivos agrícolas. Durante los años de 1800, los colonizadores anglos fueron atraídos por las áreas con corredores ribereños de esta región, donde disfrutaron la sombra y productos alimenticios, así como el forraje para su ganado y aprovecharon, además, los fácilmente disponibles peces y otras especies de fauna silvestre; los árboles que crecían a lo largo de las riveras fueron cosechados para leña, postes, y materiales para construcción de viviendas. Las demandas de agua determinaron el manejo de los ecosistemas ribereños conforme las población humanas se incrementaban después de la segunda guerra mundial. Muchos ecosistemas de estructura única fueron alterados en intentos de salvar el agua. Solo dentro de los últimos 25 a 30 años la gente de nuevo ha empezado a reconocer el valor de los diversos beneficios asociados con las áreas ribereñas. El enfoque de esta ponencia es el énfasis en el cambio de manejo considerndo la importancia holística de las áreas ribereñas en el Archipiélago Madrense. Disputas en Investigación, planificación y manejo continúan en relación a los flujos de agua y sedimentos, impactos del ganado y otras actividades humanas sobre estos frágiles sistemas, el sostenimiento de hábitats clave para la fauna silvestre y peces, y la estructura vegetativa, clasificación, y patrones de la sucesión vegetal.

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Monitoring post-fire vegetation regeneration in a Madrean ecosystem. Fire suppression in the semi-arid ecosystems of southeast Arizona and southwest New Mexico has contributed to the conversion of grasslands to shrublands in Sky Island communities. Prescribed fire is being experimented with as a method to restore grasslands to their historical range and to sustain that range in the future. Two prescribed fires were ignited in the Peloncillo Mountains on the Arizona-New Mexico border: Baker Canyon in 1995 and Maverick Spring in 1997. This research utilized remote sensing data to examine the effectiveness of prescribed fire in reducing shrub cover in the study areas. Spectral mixture analysis was applied to Landsat TM/ETM+ data to monitor post-fire regeneration and recovery patterns in the study areas. Images acquired in February and August of each year from 1994-2002 were used to map changes and rate of change in the percent grass, shrub, and bare soil cover. The landcover maps identify an initial decrease in shrub cover due to foliage loss and top-killing. However, shrub cover increases gradually in the following growing seasons since many areas were not burned severely enough to kill the shrubs completely. Results indicate the need for a regular schedule of prescribed fire to achieve permanent reduction of shrub cover. Poster.

Monitoreando la regeneración de la vegetación post'incendio en un ecosistema madrense. La supresión del fuego en los ecosistemas semiáridos del sureste de Arizona y suroeste de New Mexico ha contribuido a la conversión de pastizales a matorrales en las comunidades de las Islas del Cielo. El fuego preescrito esta siendo experimentado como un método para restaurar los pastizales en su estado histórico y sostener esa situación en el futuro. Dos fuegos preescritos fueron aplicados en las Montañas Peloncillo en la frontera Arizona- New Mexico: Baker Canyon en 1995 y Maverick Spring en 1997. Esta investigación utilizó información de percepción remota para examinar la efectividad del fuego preescrito en la reducción de la cobertura de arbustos en las áreas de estudio. Un análisis de mezcla espectral fue aplicada a imágenes Landsat TM/ETM+ para monitorear regeneración en post-fuego y recobrar patrones en las áreas de estudio. Imágenes adquiridas en Febrero y Agosto de cada año desde 1994 a 2002 fueron usadas para mapear cambios y tasas de cambio en el por ciento de cobertura de pastos, arbustos y suelo desnudo. Los mapas de cobertura vegetal identifican un decremento inicial en la cobertura de arbustos debido a la pérdida de follaje. Sin embargo la cobertura de arbustos se incrementa gradualmente en las siguientes estaciones de crecimiento ya que muchas áreas no fueron quemadas en forma severa tal como para matar a los arbustos completamente. Los resultados indican la necesidad de un calendario regular de fuegos preescritos para lograr la reducción permanente en la cobertura de arbustos. Póster.

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Phenology and trend indictors derived from spatially dynamic bi-weekly satellite imagery to support ecosystem monitoring. Ground-based monitoring presents some practical challenges to natural resource managers and ecologists tasked with assessing vegetation dynamics across large areas through time. Information obtained from ground-based techniques can be enhanced through frequent, synoptic satellite observations. Since 1989, the USGS/EROS Data Center has been deriving an index of vegetation greenness from 1-km satellite imagery commonly used in phenology studies, the normalized difference vegetation index (NDVI). Through NASA/Raytheon sponsorship, the University of Arizona partnered with natural resource managers to make these data accessible online. The resulting "RangeView" website (http://rangeview.arizona.edu) empowers a user to zoom in anywhere in the conterminous U.S., northern Mexico and southern Canada, and run a time series animation of NDVI for any sequence from 1989 to the current period. It also permits side-by-side comparisons of different periods and relative greenness products (e.g. difference from average). Natural resource managers have now requested analytical functionality to complement the visualization power of the time series imagery. This study endeavors to identify meaningful phenology (onset and duration of greenness) and trend (magnitude, direction and variability in change in NDVI) measures that can ultimately be used operationally in concert with the visualization tools currently available on RangeView.

Indicadores de tecnología y tendencia derivados de imágenes satelitales bi-semanales espacialmente dinámicas para apoyar el monitoreo de ecosistemas. El monitoreo de ecosistemas basado en técnicas terrestres presenta algunos desafíos prácticos para los manejadores de recursos naturales y ecologistas dedicados a evaluar dinámicas de vegetación de grandes áreas a través del tiempo. La información obtenida con técnicas de campo puede ser mejorada mediante observaciones sinópticas frecuentes hechas con sensores satelitales. Desde 1989, el USGS/EROS Data Center ha estado derivando un índice de coloración de la vegetación de imágenes satelitales de un kilómetro usado en estudios de fenología, el índice de vegetación de diferencia normalizada (NDVI, por sus siglas en ingles). A través del patrocinio de NASA/Raytheon, la Universidad de

Arizona se asoció con manejadores de recursos naturales para hacer esta información operacionalmente accesible en la web. El sitio resultante en la web llamado "Range View" (http://rangeview.arizona.edu) da poder al usuario para ver en aumento cualquier sitio de los Estados Unidos continentales, Norte de México y Sur de Canadá, y correr una animación en serie de tiempo del NDVI para cualquier secuencia desde 1989 al período actual. El también permite comparaciones de lado a lado de diferentes períodos y productos de relativo verdor (ejemplo diferencias del promedio). Los manejadores de recursos naturales han pedido ahora una funcionalidad analítica para complementar el poder de visualización de las imágenes en las series de tiempo. Este estudio procura identificar mediciones de una fenología con sentido (comienzo y duración del verdor en la vegetación) y tendencia (magnitud, dirección y variabilidad en el cambio del NDVI) que puede al final ser usado operacionalmente en concierto con las herramientas de visualización actualmente disponibles en el Range View.

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An on-line interface for integrated modeling of wildfire, climate and society for strategic planning for the Sky Islands. Managers increasingly use digital databases to support wildfire management. Models to simulate how fuels, weather, and topography affect fire behavior at specific sites have evolved into spatial process simulations across landscapes. These advances represent powerful tools for site/time-specific *tactical* management of wildfire as well as insight into the ramifications of prescribed burns under specific conditions. While acknowledging the power of these tools for tactical management, researchers and managers have expressed a need for comparable tools that would integrate the climate and human dimensions of wildfire behavior for *strategic* planning. In response, researchers from five disciplines at the University of Arizona collaborated through an EPA Star Grant called Wildfire Alternatives (WALTER) (http://walter.arizona.edu/) to integrate modeling of fire, climate and society (FCS-1). A sixth team blended geospatial technology, database development, web programming, and web design to create an FCS-1 fire risk scenario generator for three Sky Islands in southeastern Arizona (Catalina/Rincons, Huachucas, Chiricahuas) and the Jemez Mountains, New Mexico. This paper documents the information architecture behind the website and the on-line FCS-1 interface after setting the context by reviewing model elements and their integration through expert knowledge via an Analytical Hierarchy Process.

Una interfase electrónica para la simulación integrada de fuegos naturales, clima y sociedad para la planificación estratégica en las Islas del Cielo. Los manejadores están utilizando cada vez mas bases de datos digitales para apoyar el manejo de los fuegos naturales. Los modelos que simulan como los combustibles, el clima y la topografía afectan el comportamiento del fuego en un área especifica han evolucionado en procesos espaciales de simulación a través de paisajes. Estos avances representan herramientas poderosas para el manejo *táctico* de fuegos naturales específicos en sitio/tiempo así como una penetración en las ramificaciones de fuegos preescritos bajo condiciones específicas. En su proceso de conocimiento del poder de estas herramientas para manejo táctico, los investigadores y manejadores han expresado una necesidad de herramientas comparables que integrarían el clima y las dimensiones humanas del comportamiento del fuego natural para una planificación *estratégica*. En respuesta, investigadores de 5 disciplinas en la Universidad de Arizona colaboraron a través de un Star Grant de la EPA llamado Wildfire Alternatives (WALTER) (http://walter.arizona.edu/) para integrar la simulación del fuego, clima y sociedad (FCS-1). Un sexto equipo convino tecnología geoespacial, desarrollo de base de datos, programación en la web y diseño de web para crear un generador de escenarios de riesgo al fuego tipo FCS-1 para las tres Islas del Cielo en el Sureste de Arizona (Catalina/Rincons, Huachucas, Chiricahuas) y las Montañas Jemez, en New Mexico. Esta presentación documenta la arquitectura de información detrás del sitio web y la interfase En–Línea FCS-1 después de establecer el contexto revisando los elementos del modelo y su integración a través de un conocimiento experto vía un Proceso de Jerarquía Analítica.

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Evaluation of post-wildfire runoff and erosion on semi -arid ecological sites. Fire is a natural and important part of the regime of many ecosystems, including semi-arid southwestern grasslands. Natural fire regimes have changed and the frequency of natural wildfires to maintain the grasslands is not expected to return. However, wildfires still occur on southwestern grasslands and as the wildland urban interface expands and more rangelands are being settled the need to evaluate the short and long term risks and impacts associated with wildfires is becoming more important. Land managers and BAER teams need to assess the effects of wildfires on semi-arid grasslands in order to calculate the on and offsite risks due to potential increases in runoff and erosion. Rainfall simulator experiments are being conducted on ecological sites in southern Arizona immediately following wildfires to quantify post wildfire runoff and erosion rates. Experiments have been conducted on three ecological sites using a range of intensities between 50 and 180 mm/h. Runoff and erosion rates were measured for each intensity. The plot characteristics including cover, basal gap intercept and microtopography were measured. The post wildfire hydrologic and erosion responses for the three ecological sites are presented and the results discussed in terms of their implications for BAER team land use managers. Poster.

Evaluación del escurrimiento y erosión en post-fuego en sitios ecológicos semiáridos. El fuego es una parte natural e importante del régimen de muchos ecosistemas, incluyendo los pastizales semiáridos del suroeste. Los regimenes naturales de fuego han cambiado y no se espera que regrese la frecuencia de los fuegos naturales para mantener los pastizales. Sin embargo, los incendios naturales todavía ocurren en los pastizales del suroeste y conforme se expande la interfase de tierras naturales y urbana y más ranchos están siendo poblados, la necesidad de evaluar los riesgos e impactos en el corto y largo plazo asociados con los fuegos naturales se está haciendo mas importante. Los manejadores de tierras y los equipos BAER necesitan valorar los efectos de los incendios naturales en los pastizales semiáridos para calcular los riesgos dentro y fuera del lugar debido a los incrementos potenciales en escurrimiento y erosión. Experimentos con simuladores de lluvia están siendo conducidos en sitios ecológicos del sur de Arizona inmediatamente despeués de incendios naturales para cuantificar las tasas de escurrimiento y erosión posteriores a un fuego natural. Los experimentos han sido conducidos en tres sitios ecológicos usando un rango de intensidades entre 50 y 180 mm/h. Las tasas de escurrimiento y erosión fueron medidas para cada intensidad. Se midieron las características de las parcelas incluyendo la cobertura de intersección basal de las brechas y la microtopografía. Las respuestas hidrológicas y de erosión en post-fuego para los tres sitios ecológicos son presentadas, y los resultados son discutidos en términos de sus implicaciones por los equipos de manejadores en uso de la tierra BAER. Póster.

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Ecology and conservation of Chiricahua fox squirrels (*Sciurus nayaritensis chiricahuae),* a Sky Island endemic. Chiricahua fox squirrels (*Sciurus nayaritensis chiricahuae)* are a subspecies of Mexican fox squirrels relegated to the Chiricahua Mountains of southeastern Arizona. A complete lack of ecological data resulted in Category 2 designation of the species, a listing category subsequently abandoned by the USFWS in the mid-90's. Biogeographical isolation, paucity of natural history information, and uncertain conservation status of Chiricahua fox squirrels served as the impetus for us to initiate basic descriptive ecological studies of the species. Herein we review spatial, reproductive, and population ecology of Chiricahua fox squirrels to highlight patterns that exemplify the unique nature of this sky- island endemic. Chiricahua fox squirrels appear to possess 10 of 13 life history characteristics associated with vulnerability to extinction, including large home range size and reduced reproductive capacity. We underscore potential negative impacts of fire suppression on the species and provide direction for future research and management programs.

Ecología y conservación de las ardillas zorra de Chiricahua (*Sciurus nayaritensis chiricahuae),* una especie endémica de las Islas del Cielo. Las ardillas zorra de las Chiricahua (*Sciurus nayaritensis chiricahuae)* son una subespecie de ardillas zorra mexicanas relegadas a las Montañas Chiricahua del sureste de Arizona. Una completa carencia de información ecológica resultó en la designación de la especie en Categoría 2, una categoría de enlistado subsecuentemente abandonada por la USFWS a mediados de los 90s. El aislamiento biogeográfico, la escasez de información de su historia natural y el status incierto de conservación de las ardillas zorra de las Chiricahua ha servido como un ímpetu para que nosotros iniciáramos estudios ecológicos básicos y descriptivos de la especie. Aquí revisamos la ecología espacial, reproductiva y poblacional de las ardillas zorra de las Chiricahuas para resaltar los patrones que ejemplifican la naturaleza única de esta especies endémica de las Islas del Cielo. Las ardillas zorra de las Chiricahua parecen poseer 10 de l13 características de la historia de vida asociadas con la vulnerabilidad a la extinción, incluyendo un gran tamaño de hábitat hogareño y una reducida capacidad reproductiva. Nosotros subrayamos los impactos negativos potenciales de la supresión del fuego sobre la especie y proporcionamos una dirección para programas futuros de investigación y manejo.

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***Ursus* in a Sky Island range: a historical and contemporary analysis of bears in the Huachuca Mountains and Canelo Hills.** From prehistoric short-faced bears, to grizzlies, to black bears, the Huachuca Mountains and the adjacent Canelo Hills in southeastern Arizona has long been home to the family *ursidae.* The purpose of this paper is to document through the archaeological, historical, and contemporary records the presence of bears in this region for the purpose of determining their role in this special ecosystem, and to ascertain – in regard to the black bear – the prospects of their continued survival. Among the important questions to be addressed: What is the estimated population of bears that are present? Do they migrate to and from other nearby mountain ranges? What impact does hunting have on this population? What impact does ranching have on this population? And lastly, what conservation issues are at play for a species whose habitat overlaps different management jurisdictions – Federal (Fort Huachuca) and State? The data compiled for this presentation will be gathered from a number of sources including published reports, personal interviews, and information collected through the author's own research projects.

***Ursus* en una extensión de las Islas del Cielo: un análisis histórico y contemporáneo de osos en las Montañas Huachuca y Cerros Canelo.** Desde los prehistóricos osos de cara corta hasta los osos grizzlies, y los osos negros, las Montañas Huachuca y los adyacentes Cerros Canelo en el sureste de Arizona han sido casa para la familia *ursidae* por mucho tiempo. El propósito de esta presentación es, a través de datos arqueológicos, históricos y contemporáneos, documentar la presencia de osos en esta región con el propósito de determinar su papel en este ecosistema especial y averiguar - en relación al oso negro - las perspectivas de la continuación de su supervivencia. Entre las preguntas importantes a contestar están: cuál es la población estimada de osos en el presente? Migran ellos a y desde otros macizos montañosos? Qué impacto tiene la casería en esta población? Qué impacto tiene la ganadería en esta población? y, finalmente, qué formas de conservación están en juego para una especie cuyo hábitat se sobrepone a diferentes jurisdicciones de manejo, Federal (Fort Huachuca) y estatal? Los datos recompilados para esta presentación serán obtenidos de varias fuentes incluyendo reportes publicados, entrevistas personales e información colectada a través de proyectos de investigación propios del autor.

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Habitat and conservation status of the beaver (*Castor canadensis*) in the Sierra San Luis Sonora, México. The actual status of beaver in northeastern Sonora is uncertain. Therefore we surveyed the river Cajon Bonito to assess the conservation status and habitat characteristics of the species. We found that beavers used to inhabit the entire river, but now there are just five colonies in five kilometers of the river. The limiting factors are water pollution by animal waste, riparian vegetation deforestation, and hunting. Beavers do not depend on habitat diversity as long as the plants they feed on remain predictably present, but they do need dense sites. Beavers also need water with low levels of organic material as well as aquatic and riparian vegetation in good condition.

Habitat y estado de conservacion del castor (*Castor canadensis*) en la Sierra San Luis Sonora, Mexico. El estado actual de los castores en el noreste de Sonora es incierto. Muestreamos el río Cajón Bonito con el fin de conocer el estado de conservación y las características del hábitat del castor en Sonora. Anteriormente, los castores solían habitar en todo el río, pero ahora, sólo hay cinco colonias en cinco kilómetros del río. Los factores limitantes para estos mamíferos son la contaminación del agua por desperdicios animales, deforestación de la vegetación riparia y la cacería. Los castores no dependen de la diversidad del hábitat mientras las plantas de las que se alimentan se mantengan. Sin embargo, sí necesitan lugares con vegetación densa y con vegetación acuática en buenas condiciones.

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The Western Apache home: landscape management and failing ecosystems. Western Apaches have lived within the ecosystems of the Madrean Archipelago for at least several hundred years. Integral elements of Western Apache culture go back to the earliest human inhabitants of the region. The natural resources of the region make up the basis of the Apache home and culture. Profound landscape changes in the region have occurred over the past 150 years. A survey of traditional Western Apache place names documents many of these changes. An analysis of one of these places illustrates the loss of Apache natural resources. Many Apache elders attribute the loss of these resources to disrespectful land management practices and disrespectful attitudes towards the natural world.

La casa Apache de Occidente: manejo de paisaje y ecosistemas desfallecientes. Los Apaches de Occidente han vivido dentro de los ecosistemas del Archipiélago Madrense por al menos varios cientos de años. Elementos integrales de la cultura Occidental Apache datan desde los primeros habitantes humanos de la región. Los recursos naturales de la región confeccionan la base de la cultura y vivienda Apache. Los profundos cambios en el paisaje de la región han ocurrido en los últimos 150 años. Un estudio de nombres de lugares tradicionales de los Apaches occidentales documenta muchos de estos cambios. Un análisis de uno de estos lugares ilustra la pérdida de los recursos naturales Apaches. Muchos ancianos Apache atribuyen la pérdida de estos recursos a prácticas de manejo sin respeto a la tierra y actitudes irrespetuosas al mundo natural.

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Coyote abundance in relation to the habitat characteristics in Sierra San Luis, Sonora, México. Historically the coyote *(Canis latrans)* has occupied diverse habitats that it originally did not use. This change can be attributed to human activities like the extirpation of other carnivores. Our objective was to understand the relationship between vegetation structure and coyote abundance, under the hypothesis that dense vegetation provides a safe place for coyote prey, principally lagomorphs and rodents, and therefore supports low numbers of coyotes. We found shrub layers are better correlated with coyote abundance. We conclude that the vegetation structure represents an important factor in the distribution and conservation of the big carnivores.

Abundancia del coyote en relación a las características del habitat en la Sierra San Luis, Sonora, México. Históricamente el coyote (*Canis latrans*) ha ocupado diversos habitats que originalmente no ocupaba, atribuyendo lo anterior a actividades humanas tales como el exterminio de los grandes carnívoros. El objetivo fue determinar la relación entre la estructura vegetal y la abundancia del coyote, bajo la hipótesis de que los lugares con una vegetación densa, proporcionan un lugar mas seguro para las presas potenciales del coyote, principalmente lagomorfos y roedores, y por lo tanto presentan una menor abundancia de coyotes. Determinamos que el estrato arbustivo es el factor más relacionado con la presencia del coyote. Concluyendo que la estructura vegetal representa un factor importante en la distribución y conservación de los grandes carnívoros.

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Choosing appropriate parameters for monitoring vertebrates in the Sonoran Desert. Vertebrates are inherently difficult to monitor as their mobility makes them elusive, their cognition makes their potential responses to environmental change complex, their populations vary spatially and temporally, and surveys that precisely estimate population parameters are costly. Though humans place high value on maintaining vertebrate populations, there is little consensus among ecologists regarding what constitutes "appropriate" parameters. We maintain that these parameters must be relevant to management goals, sensitive to change, have low natural and sampling variability, and be cost effective. We developed a series of criteria on these principles to evaluate 180 candidate parameters and to select a subset for use in the Sonoran Desert Monitoring Plan, a regional ecosystem monitoring effort. We identified parameters by (1) identifying characteristics of populations (e.g., density) or communities (e.g., species richness); (2) grouping species within each taxonomic Class based on common life-history traits and survey methods. We used cost efficiency as an initial filter and researched or derived estimates of variation for final selection of parameters that would have sufficient statistical power to detect meaningful changes in vertebrate communities of the Sonoran Desert ecoregion.

Seleccionando parámetros apropiados para monitorear vertebrados en el Desierto Sonorense. Los vertebrados son inherentemente difíciles de monitorear ya que su movilidad los hace evasivos, su consciencia hace que sus respuestas potenciales a los cambios ambientales sean complejas, sus poblaciones varían espacial y temporalmente y los estudios que estiman en forma precisa los parámetros de población son costosos. Aunque los humanos ponen un alto valor al mantenimiento de las poblaciones de vertebrados, existe un poco consenso entre los ecologistas en relación a lo que constituyen los parámetros "apropiados". Nosotros sostenemos que estos parámetros deben ser relevantes para las metas de manejo, sensibles al cambio, tener baja variabilidad natural y de muestreo y ser efectivos en costo. Nosotros desarrollamos una serie de criterios basados en estos principios para evaluar 180 parámetros candidatos y seleccionar un subgrupo para usarlo en el Plan de Monitoreo del Desierto Sonorense, un esfuerzo regional de monitoreo de ecosistemas. Nosotros identificamos los parámetros 1) identificando características de las poblaciones (densidad) o comunidades (riqueza de especies); 2) agrupando especies dentro de cada clase taxonómica, basados en rasgos comunes de su historia de vida y métodos de estudio. Nosotros usamos la eficiencia en costos como un filtro inicial y estimaciones estudiadas y derivadas de la variación para la selección final de parámetros que tuvieran suficiente poder estadístico para detectar cambios importantes en las comunidades vegetales de la ecoregión del Desierto Sonorense.

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Citizen science and ecological monitoring: experience from the foothills and Rockies of Alberta. The pursuit of sustainability and concomitant concerns over anthropogenic influences on environmental deterioration, have resulted in calls for high-quality methods and long-term datasets for detecting and understanding environmental change. To state it simply: sustainable community development requires information that is socially meaningful and scientifically defensible. Community Based Monitoring (CBM) is a process whereby stakeholders in a community develop mechanisms to respond to environmental and health concerns through monitoring of ecological indicators. Besides expanding the knowledge base on the regions ecological health, the process activates volunteers, strengthens links between decision makers and the community and develops local leadership, leading to a more collaborative decision making process. Typically, citizen science projects are developed in conjunction with government or university research programs but volunteers within the local community collect the data. This paper will highlight key lessons learned from Canadian CBM projects and highlight the next steps for two emerging CBM projects in southwestern Alberta. The goals of the two projects are to engage the local community in citizen science projects, provide useful information to decision makers, highlight the value of citizen science to decision makers, and develop a constituency for conservation-based science.

Ciencia ciudadana y monitoreo ecológico: experiencia de las foothills y Rockies de Alberta. La búsqueda de sustentabilidad e inquietudes afines acerca de las influencias antropogénicas sobre el deterioro ambiental, han resultado en requerimientos de métodos de alta calidad y bases de datos a largo plazo para detectar y entender el cambio ambiental. Para establecerlo simplemente: el desarrollo de una comunidad sostenible requiere información que es socialmente justificable y científicamente defendible. El Monitoreo Basado en la Comunidad (CBM, por sus siglas en inglés) es un proceso por el cual los propietarios en una comunidad desarrollan organismos para responder a preocupaciones ambientales y de salud a través del monitoreo de indicadores ecológicos. Además de expandir el conocimiento básico sobre la salud ecológica de las regiones, el proceso activa voluntarios, refuerza enlaces entre tomadores de decisiones y la comunidad y desarrolla un liderazgo local, conduciendo a un proceso más colaborativo en la toma de decisiones. Típicamente los proyectos de ciencia ciudadana son desarrollados en conjunto con programas de investigación gubernamentales o universitarios, pero los voluntarios de la

comunidad local colectan la información. Esta presentación resaltará las lecciones claves aprendidas en los proyectos canadienses CBM y resaltará las etapas próximas para dos proyectos CBM que están iniciando en el suroeste de Alberta. Las metas de los dos proyectos consisten en involucrar a la comunidad local en proyectos científicos ciudadanos, proporcionar información útil a los tomadores de decisiones, resaltar el valor de la ciencia ciudadana para los tomadores de decisiones y desarrollar la constitución para una ciencia basada en la conservación.

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Changes in forest species composition and structure after wildfire. A stand replacement wildfire in the Chiricahua Mountains of southeastern Arizona has altered the species composition and spatial pattern of the post-fire forest. Prior to the 1996 fire the century-old closed canopy conifer forest was almost exactly divided between evenly mixed Arizona pine (*Pinus ponderosa* var. *arizonica*) and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). Quaking aspen (*Populus tremuloides*) is the most abundant post-fire tree. Seedlings of Douglas-fir and Arizona pine have become established, but in lesser densities than prior to the fire. All 3 tree species are now distributed unevenly across the site, and there are gaps with no tree seedlings. Aspens are strongly clumped, Douglas-firs tend to germinate around the edges of taller vegetation, and scattered Arizona pines have established in open areas. The pattern of reestablishment of trees suggests that the new forest will be markedly different from the old. The observed shift in forest structure and species composition could have important management implications. Other sites may respond in similar ways to the intense, stand replacing wildfires that are becoming increasingly common in the Mountain West.

Cambios en la composición y estructura de especies de bosque después de un fuego natural. El reemplazo de un rodal afectado por un fuego natural en las Montañas Chiricahua del sureste de Arizona ha alterado la composición y el patrón espacial de especies del bosque posterior al incendio. Antes del fuego de 1996 el bosque de coníferas de cerrada cobertura y de mas de cien años de edad, fue casi exactamente dividido entre un bosque de pino de Arizona (*Pinus ponderosa* var. *arizonica*) y Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). El Alamo (*Populus tremuloides*) es el árbol post-fuego mas abundante. Plántulas de Douglas-fir y pino de Arizona se han establecido pero en mas bajas densidades que las existentes antes del fuego. Las tres especies están ahora distribuidas irregularmente a lo largo del sitio y existen brechas sin plántulas de dichos árboles. Los álamos están fuertemente agrupados, los Douglas-fir tienden a germinar en los bordes de la vegetación mas alta y algunos pinos de Arizona se han establecido en forma dispersa en áreas abiertas. El patrón de restablecimiento de árboles sugiere que el nuevo bosque será marcadamente diferente al antiguo. El desplazamiento observado en la estructura del bosque y en la composición de especies podría tener importantes implicaciones de manejo. Otros sitios podían responder en formas similares a los intensos fuegos reemplazadores de rodales, que se están haciendo comunes y crecientes en las Montañas del Oeste.

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Population ecology of the green rat snake at Leslie Canyon National Wildlife Refuge, Cochise County, Arizona. While the green ratsnake (*Senticolis triaspis*) has a geographic distribution ranging north from Costa Rica through Central America and Mexico, it barely enters the United States in and among several Madrean mountain foothills in southeast Arizona and southwest New Mexico. The perception that the green rat snake is perhaps an uncommon, arboreal species results from its restricted geographic range in the U.S., its secretive habits, and its cryptic coloration. Little is known regarding the general population ecology and behavior of this species. Since 2000, seven green ratsnakes have been opportunistically captured at Leslie Canyon National Wildlife Refuge, and four adult green rat snakes have been implanted with telemetry transmitters to allow researchers to track their movements on the refuge and help determine some basic population ecology information. We report on several natural history and ecological aspects of the species, including home range, habitat associations, thermal regime, and food items. We relate this information to management and protection measures which may be applicable to the species' U.S. range, and perhaps its range throughout the Sierra Madrean province.

Ecología de poblaciones de la víbora rata verde en el Leslie Canyon National Wildlife Refuge, Condado Cochise, Arizona. Mientras que la víbora rata verde (*Senticolis triaspis*) tiene una distribución geográfica que se extiende hacia el norte desde Costa Rica, pasando por Centro América y México, rara vez entra a los Estados Unidos entre varios pie de montes de las montañas Madrenses en el sureste de Arizona y el suroeste de New Mexico. Su restringida extensión geográfica en los Estados Unidos, sus hábitos silenciosos y su coloración confundible han llevado a la percepción de que es quizás una especie arborícola poco común. Poco se conoce en relación a la ecología general de sus poblaciones y al comportamiento de esta especie. Desde el 2000, siete víboras ratas verdes han sido oportunísticamente capturadas en el Leslie Canyon National Wildlife Refuge, y cuatro víboras ratas verdes adultas han sido implantadas con transmisores de telemetría para permitir a los investigadores seguir sus movimientos en el refugio y ayudar a determinar algo de información básica sobre la ecología de sus poblaciones. Nosotros reportamos varios aspectos ecológicos y de historia natural de la especie, incluyendo la extensión de su hogar, asociaciones de hábitat, régimen de temperaturas y objetos alimenticios. Nosotros relacionamos esta información a mediciones de manejo y protección los cuales pueden ser aplicables a todas las especies de Estados Unidos y quizá a su distribución a lo largo de la provincia de la Sierra Madrense.

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Floristic comparison of an Arizona "Sky Island" and the Sierra Madre Occidental in eastern Sonora: the Huachuca Mountains and the Yécora Area. The floras of the Huachuca Mountains (994 taxa; 316 km²; 1524-2885 m elevation, 1361 m range; 31°30'N) and the Municipio de Yécora (1691 taxa; 3300 km²; 480-2140 m; 28°24'N) were compared to assess the strength of the floristic affinities between a Madrean 'Sky Island' in Arizona and the 'mainland' Sierra Madre Occidental in eastern, Sonora. For Yécora, taxa in gossan (hydrothermal acid soils) woodland, oak woodland, pine-oak forest, and grassland (1284 taxa; ca. 2080 km²; 820-2140 m, 1320 m range) were compared. In both areas, the Compositae, Gramineae, and Leguminosae were the largest families (39.3% and 40.2% of the taxa). Non-native species accounted for 6.5% and 5.1% of the floras. Of the native Huachuca taxa, 38.8% had Apachian (= core Madrean) affinities, very close to the 39.9% actually shared with Yécora. The Huachucas have additional desert grassland, Chihuahuan Desert, and high elevation temperate forest plants while Yécora has more lowland tropical plants. Tree diversity in the Huachucas is less than in Yécora: e.g., *Pinus* (6 versus 11), *Quercus* (8 versus 14), and *Juniperus* (2 versus 3). Only 62.5% of these Huachuca trees also occur in Yécora. Thus, the Madrean floristic relationships of the 'Sky Island' were less than expected.

Comparación florística entre una "Isla del Cielo" en Arizona y la Sierra Madre Occidental al este de Sonora: las Montañas Huachucas y el área de Yécora. Se comparó la flora de la Sierra Huachuca (994 taxa; 316 km5; 1524-2885 m de elevación, rango de 1361 m; 31°30'N) con la flora del Municipio de Yécora (1691 taxa; 3300 km5, 480-2140 m de elevación; 28°24'N) con el fin de evaluar la intensidad de las afinidades florísticas entre una 'isla del cielo' con vegetación Madrense en Arizona y el 'territorio continental' de la Sierra Madre Occidental al este de Sonora. Con respecto al área de Yécora, se comparó la taxa presente en bosques en *gossans* (suelos ácidos hidrotermales), bosques de encino, bosques de pino-encino y pastizal (1280 taxa; ca. 2081 km5; 820-2140 m de elevación, rango de 1320 m). Los resultados muestran que la composición florística es similar en ambas áreas, siendo las familias botánicas Compositae, Gramineae y Leguminosae las más numerosas (39.3% vs. 40.2% de la taxa). Las especies exóticas representan el 6.5% y 5.1% de las floras respectivamente. De la taxa nativa de las Huachucas, 38.8% estaban consideradas con afinidades Apachenses (= Madrense nuclear), muy cercano al 39.9% que se comparten con Yécora. La flora de las Huachucas presenta más elementos de pastizal del desierto, Desierto Chihuahuense y bosques templados de elevaciones altas, mientras que la flora de Yécora tiene más plantas tropicales. La diversidad de árboles es menor en las Huachucas que en Yécora: e.g., *Pinus* (6 vs.11), *Quercus* (8 vs.14) y *Juniperus* (2 vs. 3). De los árboles presentes en las Huachucas, solamente el 62.5% ocurren en Yécora. En síntesis, las relaciones florísticas madrenses de la "Isla del Cielo" son menores de lo que se esperaba.

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Linking science and policy: the Upper San Pedro Partnership. Approximately 68,000 people share the Sierra Vista Subwatershed with the San Pedro Riparian National Conservation Area, established by Congress in 1988 to protect what is considered one of the most extensive riparian forests along a major free-flowing river remaining in the Southwestern United States. However, without sustainable long-term groundwater supplies neither the people of the area nor the riparian area will thrive. The Upper San Pedro Partnership was formed in 1998 as part of the Arizona Department of Water Resources's Rural Watershed Initiative, to help meet the long-term groundwater needs of both current and future residents and the San Pedro River. The Partnership conducts essential hydrologic research and monitoring studies, and assists its member agencies with implementation of a wide array of water conservation projects. This broad coalition of 20 government organizations and private agencies employs state-of-the-art technical tools including predictive models and decision support systems to address these challenges. Each year the Partnership produces annual "working conservation plans" within an adaptive management framework to apply the best science available to decision-making. Their five-year financial plan includes a $33.9 million budget that pools the resources of its member agencies.

Ligando ciencia y política: la asociación del alto San Pedro. Aproximadamente 68,000 personas comparten la subcuenca Sierra Vista con la San Pedro Riparian National Conservation Area, establecida por el congreso en 1988 para proteger lo que es considerado uno de los bosques ribereños mas extensivos a lo largo de un río que permanece fluyendo libremente en el suroeste de los Estados Unidos. Sin embargo sin provisiones sostenibles de agua subterránea en el largo plazo, ni la gente del área ni el área ribereña prosperarán. La Asociación del Alto San Pedro fue formada en 1998 como parte de la Arizona Department of Water Resources's Rural Watershed Initiative, para ayudar a encontrar las necesidades de agua subterránea a largo plazo de los residentes actuales y futuros y el río San Pedro. La Asociación lleva acabo investigaciones hidrológicas y estudios de monitoreo esenciales y asiste a sus agencias y miembros con la implementación de un amplio arreglo de proyectos de conservación de agua. Esta amplia coalición de 20 organizaciones gubernamentales y agencias privadas, emplea herramientas técnicas modernas como modelos de predicción y sistemas de soporte en la toma de decisiones para enfrentar esos desafíos. Cada año la asociación produce "planes de trabajo de conservación" anuales dentro de un marco de trabajo y manejo adaptativo para aplicar la mejor ciencia disponible a la toma de decisiones. Su plan financiero de cinco años incluye un fondo de 33.9 millones de dolares que junta los recursos de sus agencias asociadas.

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Prospects for Mexican gray wolf recovery in the Sky Islands. On April 1, 2003, the U.S. Fish and Wildlife Service (FWS) created the Southwestern Gray Wolf Distinct Population Segment (DPS), extending from (and including) Mexico to northern Utah and Colorado. A DPS is a unit of listing under the Endangered Species Act, and FWS has begun the process of developing recovery or delisting criteria for this DPS. Its boundaries encompass the historic range of several gray wolf subspecies, the only surviving of which is the Mexican gray wolf (*Canis lupus baileyi*), whose northernmost historical range extended to the Gila River of southeastern Arizona and southwestern New Mexico. The configuration of this DPS undervalues the genetic uniqueness and the specialized evolutionary course of *baileyi*; as a result, upcoming recovery criteria will likely not serve to conserve the Sky Islands ecosystems which helped shape the "lobo." Furthermore, current federal rules require FWS to remove members of the only known wild population of *baileyi*, reintroduced to the White and Mogollon Mountains as an experimental, nonessential population, should they disperse to the Sky Islands. Profound changes in federal policies will be necessary to recover the Mexican gray wolf in the Sky Islands, and efforts to enact those changes are underway.

Perspectivas para la recuperación del lobo gris Mexicano en las Islas del Cielo. En abril 1, 2003, el U.S. Fish and Wildlife Service (FWS) creó el Southwestern Gray Wolf Distinct Population Segment (DPS), extendiéndose desde (e incluyendo) México hasta el Norte de Utah y Colorado. Un DPS es una unidad de listado bajo el acta de especies en peligro y el FWS a iniciado el proceso de desarrollar la recuperación o el criterio de deslistado para este DPS. Sus límites abarcan la extensión histórica de varias subespecies del lobo gris, de las cuales la única sobreviviente es el lobo gris mexicano (*Canis lupus baileyi)* cuya extensión histórica más hacia el norte se extendía hasta el río Gila del sureste de Arizona y suroeste de nuevo México. La configuración de este DPS menosprecia la singularidad genética y el curso evolutivo especializado de *baileyi;* como resultado, el criterio de recuperación venidero probablemente no servirá para conservar los ecosistemas de las Islas del Cielo que ayudaron a conformar al "lobo". Además, las leyes federales actuales requieren que el FWS remueva miembros de la única población silvestre conocida de *baileyi,* reintroducida a las Montañas White y Mogollon como una población experimental no esencial, que deberían dispersarse a las islas del cielo. Profundos cambios en las políticas federales serán necesarios para recuperar el lobo gris mexicano en las Islas del Cielo y esfuerzos para decretar esos cambios están en proceso.

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Grassland monitoring using satellite images in Zapata site, Mexico. The San Pedro is a bi-national basin located in southwestern USA and northwestern Mexico. Mining and livestock are the most important economic activities there. They have produced erosion and spatial heterogeneity in grasses for a long time and modified the landscape. Remote sensing has been used to estimate biomass in different ecosystems. The estimates are based on Vegetation Index (VI) and showed good agreement with harvest grass. The grassland ecosystem shows an apparent homogeneity in species composition. The grassland has suffered important effects from grazing, and these areas that were more or less homogenous with annual and perennial grass currently exhibit shrubs, low production, and very important heterogeneity. To analyze this situation and measure the biomass production by this type of vegetation an experiment was carried out on Zapata site, near Cananea. In the field, climate and vegetation were sampled during growing season of 2003 each hour and once a week, respectively. Additional measurements of reflectance were recorded every week and satellite images from MODIS and VEGETATION were analyzed. The results show that field data agree with MODIS images and represent very well the heterogeneity in the spatial grass distribution by topography. The VEGETATION data also permit monitoring of grass phenology. Poster.

Monitoreo de pastizal usando imágenes de satélite en el sitio Zapata México. El San Pedro es una cuenca binacional localizada en el suroeste de Estados Unidos de América y el Noroeste de México. Las principales actividades económicas realizadas en la cuenca son la ganadería y minería, y estas han producido erosión y heterogeneidad espacial en los pastizales por largo tiempo y modificado el paisaje. Para el monitoreo de los ecosistemas han sido utilizados los sensores remotos a través de los índices de vegetación (IV´s) y estos muestran buenas relaciones con la cosecha de biomasa. Los pastizales de la región muestran una aparente heterogeneidad en su composición y han sufrido importantes efectos por el pastoreo y aquellas áreas que fueron más o menos homogéneas con pastos anuales y perennes, actualmente exhiben arbustos, baja producción y una importante heterogeneidad. Para analizar esta situación y medir la producción de biomasa por este tipo de vegetación se realizo un experimento en el Ejido Zapata, cerca de Cananea. En el sitio fueron medidas variables climáticas y de la vegetación durante la estación de crecimiento en el 2003, de manera horaria y semanal respectivamente. Mediciones adicionales de reflectancia se realizaron simultáneamente al muestreo de vegetación e imágenes de satélites MODIS y VEGETATION fueron analizadas también para el mismo periodo. Los resultados muestran un adecuado ajuste entre las imágenes MODIS y los datos de campo, y éstas representan bien la heterogeneidad en la distribución espacial de los pastos por la topografía. De manera similar las imágenes de VEGETATION también permitieron monitorear la fenología del pastizal. Póster.

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Analysis of twenty years of landscape fragmentation in the Peloncillo Mountains in relation to wildfire, prescribed burning, and cattle grazing. The relations between disturbance regime and landscape patterns in Madrean forests, woodlands and grasslands have been developed from a theoretical perspective. Few studies have tested these relations when forces promoting opposing heterogeneity patterns are simultaneously operating on a landscape. This work provides quantitative evidence of these relations in areas dominated historically by human activity in the Peloncillo Mountains of Arizona and New Mexico, showing that fire suppression and grazing have affected landscape heterogeneity. Land cover changes, wildfire occurrence, and general grazing activities were examined in the study area between 1984 and 2004. Changes in landscape pattern in relation to disturbance regime were analyzed using patch density, mean patch size, mean distance to the nearest neighbor of the same category, edge density, and Shannon diversity index. Results indicate a trend to increasing landscape homogenization due to the expansion of shrublands linked to a decrease in wildfires and continued cattle grazing over the time period. However, recent prescribed burns in the Maverick Spring and Baker Canyon areas have been successful in re-establishing a trend towards increased shrubland and grassland heterogeneity, as the natural disturbance regime is returned to the region.

Análisis de veinte años de fragmentación del paisaje en las Montañas Peloncillo en relación al fuego natural, incendios prescritos y pastoreo de ganado. Las relaciones entre el régimen de perturbación y los patrones del paisaje en los bosques y pastizales Madrenses han sido desarrolladas desde una perspectiva teórica. Sin embargo pocos estudios han probado estas relaciones cuando las fuerzas que promueven los patrones de oposición en heterogeneidad están operando simultáneamente sobre un paisaje. Este trabajo proporciona evidencia cuantitativa de estas relaciones en áreas dominadas históricamente por las actividades humanas en las Montañas Peloncillo de Arizona y New Mexico mostrando que la supresión del fuego y el pastoreo han tenido efectos pronunciados en la heterogeneidad del paisaje. Los cambios en la cobertura vegetal, ocurrencia de incendios naturales y actividades generales de pastoreo, fueron examinados en el área de estudio entre 1984 y 2004. Cambios en el patrón del paisaje en relación al régimen de perturbación fueron analizados utilizando densidad de manchas, tamaño promedio de las manchas, distancia media al vecino más cercano con la misma categoría, densidad de borde e índice de diversidad de Shannon. Los resultados indican una tendencia a incrementar la homogenización del paisaje debido a la expansión de matorrales ligados a un descenso en los incendios naturales y al pastoreo continuo de ganado a través del tiempo. Sin embargo, fuegos prescritos recientes en las áreas Maverick Spring y Baker Canyon han tenido éxito en el restablecimiento de una tendencia hacia una heterogeneidad más grande en el matorral y el pastizal, conforme el régimen de perturbación natural es regresado a la región.

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Measuring and monitoring responses of Madrean ecosystems to management variability: translating fire research into local expertise for ecosystem sustainability. The future status of the Madrean ecosystem and the trajectories of many important ecological processes will be determined largely by one major set of factors—the extent, intensity and landscape pattern of ongoing human influences on these ecosystems. Limited data on land use decrease the quality of spatial information on landscape sustainability. Superimposed upon this shortfall is the heavily dissected political topography of the arid Southwest: land ownership patterns are complex, defined by a matrix of large vs. small parcels of private ownership mixed with large and small protected areas co-mingled with governmental holdings. Regional analyses of the pattern and rate of ecosystem change are critical in defining the fate of such arid ecosystems from disturbances. Chief among such disturbances, and the focus of this research, is wildland fire. We use remote sensing technology to characterize the resiliency of differently managed fire-prone Madrean regions within the most recent megadrought era, beginning in the early 1990s.The Peloncillos, administered by the Forest Service, and Fort Huachuca, run by the Army, represent distinctive land use management regimes. Results indicate that management regimes in Madrean ecosystems could affect vegetation cover type, composition and relative abundance significantly as a direct result of varying approaches to fire suppression and prescribed burning practices.

Respuestas de medición y monitoreo de ecosistemas madrenses a la variabilidad de manejo: traduciendo investigación en fuegos a experiencia local para la sostenibilidad de ecosistemas. El estatus futuro del ecosistema Madrense y las trayectorias de muchos procesos ecológicos será determinado en gran forma por un gran grupo de factores – la extensión, intensidad y patrón de paisaje de influencias humanas activas sobre estos ecosistemas. La información limitada en el uso de las tierras disminuye la calidad de la información espacial en la sostenibilidad del paisaje. Sobrepuesto a este déficit está la altamente dividida topografía política del suroeste árido: los patrones de tenencia de la tierra son diversos y complejos, definidos por una matriz de parcelas de propiedad privada, grandes y pequeñas, mezcladas con áreas protegidas grandes y pequeñas que se mezclan con posesiones gubernamentales. Los análisis regionales del patrón y tasas de cambio en el ecosistema, son críticos al definir el destino de tales ecosistemas áridos de perturbaciones naturales e impuestas por el hombre. La principal de tales perturbaciones y el enfoque de este trabajo es el fuego natural. Nosotros usamos tecnología de percepción remota para caracterizar la resistencia de regiones Madrenses predispuestas al fuego y que son manejadas distintamente, dentro de la más reciente era de mega sequías, que inició a principios de los 90s. Las Montañas Peloncillo, administradas por el Forest Service, y Fort Huachuca, y manejadas por la armada, representan regimenes distintos de manejo en el uso de la tierra. Los

resultados indican que los regimenes de manejo en los ecosistemas Madrenses podrían afectar el tipo de cobertura vegetal y la composición y abundancia relativa en una forma significativa, como un resultado directo de estudios variantes para la supresión del fuego y prácticas de fuegos prescritos.

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Return of the Tarahumara frog to Arizona. The last wild Tarahumara frog (*Rana tarahumarae*) in Arizona was found dead in Big Casa Blanca Canyon, Santa Rita Mountains, in May 1983. The species disappeared from its limited range in the Santa Rita and Pajarito-Atascosa-Tumacacori mountains possibly due to chytridiomycosis, a fungal disease; airborne pollutants from copper smelters; flooding; non-native predators; and/or habitat loss. The range of the Tarahumara frog is centered in the northern Sierra Madre Occidental and adjacent Sky Islands of Sonora and Chihuahua, where the species still persists in numerous canyons. Plans to re-establish the Tarahumara frog in Arizona were initiated in 1991 and have been coordinated by the Tarahumara Frog Conservation Team, composed of agency, university, and other experts on the frog. Steps leading to re-establishment included development of a re-establishment proposal, completion of Arizona Game and Fish Department's 12-step Procedures for Nongame Wildlife and Endangered Species Re-establishment Projects, National Environmental Policy Act and Endangered Species Act compliance, status surveys in Sonora and collection of frogs for re-establishment, and captive maintenance and propagation. Initial releases of frogs are scheduled for March 2004 in Big Casa Blanca Canyon. If successful there, Tarahumara frogs would also be released in Sycamore Canyon in the Pajarito Mountains.

Regreso de la rana Tarahumara a Arizona. La última rana Tarahumara silvestre (*Rana tarahumarae*) en Arizona fue encontrada muerta en Big Casa Blanca Canyon, Santa Rita Mountains, en mayo de 1983. La especie desapareció de su limitada extensión en las Montañas Santa Rita y Pajarito-Atascosa-Tumacacori, posiblemente debido a quitridiomicosis, una enfermedad fungosa; los contaminantes aéreos de las fundadoras de cobre; inundaciones; depredadores no nativos; y/o perdida del hábitat. La extensión de la rana Tarahumara está centrada en el norte de la Sierra Madre Occidental e Islas del Cielo de Sonora adyacentes y en Chihuahua donde la especie persiste todavía en numerosos cañones. Se iniciaron planes en 1991 para restablecer la rana Tarahumara en Arizona y han sido coordinados por el Tarahumara Frog Conservation Team, constituido por expertos en la rana de agencias y universidades. Las etapas para guiar al restablecimiento incluyeron el desarrollo de una propuesta de restablecimiento, el cumplimiento de 12 etapas de los Procedures for Nongame Wildlife and Endangered Species Re-establishment Projects, del Arizona Game and Fish Department, una condescendencia con las National Environmental Policy Act y Endangered Species Act, status de inspecciones en Sonora y colección de ranas para el restablecimiento, mantenimiento y propagación en cautiverio. Liberaciones iniciales de ranas están programadas para marzo de 2004 en el Big Casa Blanca Canyon. Si se tiene éxito allí, las ranas Tarahumaras deberían también liberarse en el Sycamore Canyon en las Montañas Pajarito.

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Lowland Riparian Herpetofaunas: The San Pedro River in Southeastern Arizona. Previous work has shown that south-eastern Arizona has a characteristic, high diversity lowland riparian herpetofauna with 62-68 or more species along major stream corridors, and 46-54 species in shorter reaches within single biomes, based on intensive fieldwork and museum record surveys. The San Pedro River supports this characteristic herpetofauna, at least some of which still occurs in the lower basin within the Sonoran Desert. It has about 64 species (55 vouchered to date), with 48-53 species within each of three somewhat ecologically homogeneous portions of the basin. This assemblage is more similar to other lowland herpetofaunas than to an example of a canyon riparian herpetofauna. Most of the characteristic riparian species are not known to be abundant along the San Pedro, and some expected species are apparently absent, suggesting that the herpetofauna may have not yet recovered from the history of grassland, cienega, and bottomland degradation.

Herpetofauna de Cuencas Ribereñas: el Rio San Pedro en el Sureste de Arizona. Trabajos anteriores han demostrado que la parte sureste de Arizona poseé una característica herpetofauna de cuencas ribereñas que muestra una alta diversidad con la presencia 62-68 o más especies a lo largo de los principales caudales del río y entre 46 a 54 especies que se encuentran en biomas localizados. Esta información está basada en estudios de campo intensivos y en el análisis de colecciones de museo. El Río San Pedro ampara esta herpetofauna característica, por lo menos a aquella que todavía existe en la parte baja de la cuenca en el Desierto Sonorense. Esta región presenta 64 especies (55 de las cuales han sido observadas actualmente), junto con 48-53 especies dentro de cada una de las porciones ecológicamente homogéneas de la cuenca. Esta ensambladura es más similar a otras herpetofaunas de cuenca que a un ejemplo de herpetofauna de barranca ribereña. La mayoría de estas especies ribereñas no son abundantes a lo largo del Río San Pedro, y algunas especies esperadas parecen estar absentes, lo cual sugiere que la herpetofauna puede no haberse recuperado de la prolongada degradación de los pastizales y la ciénega.

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Leopard frog population trends associated with chytrid fungus disease (chytridiomycosis) in southern and central Arizona. During the past two decades, we have observed cool-season mortality events among ranid frogs in Arizona. We present case studies of population trends for the Lowland Leopard Frog (*Rana yavapaiensis*) and Chiricahua Leopard Frog (*R. chiricahuensis*), and contrast these to observations of the non-native American Bullfrog (*R. catesbeiana*). We used methods including wintertime mortality surveys, visual encounter surveys, and mark-recapture to obtain presence-absence and population trend data. At many sites, dead leopard frogs or large-scale and repeated mortality episodes were observed. Histological analyses indicated an emerging disease caused by a chytrid fungus (*Batrachochytrium dendrobatidis*) was the proximate cause of mortality. Bullfrog mortality events were infrequently observed. Although the disease was confirmed in bullfrogs, the species has not declined. In *R. chiricahuensis*, some populations were apparently extirpated soon after we detected chytridiomycosis, but at least two – in relatively natural, unmodified ecosystems – have persisted for years after known arrival of the disease. Among many *R. yavapaiensis* populations studied, some have disappeared, but in no case can extirpation be convincingly tied to disease alone. Natural population variability precludes a firm conclusion of disease-related decline in *R. yavapaiensis*, but we suspect this may be the case for some populations. Among many sites where chytridiomycosis was confirmed, this frog remains highly abundant at two warm environments that may be inhospitable to the disease pathogen.

Tendencias de la población de ranas leopardo asociadas con la enfermedad del hongo Chytrid (Chytridiomicosis) en el centro y sur de Arizona. Durante las últimas dos décadas, hemos observado los eventos de mortalidad en la época fría entre las ranas de Arizona. Presentamos casos de estudio de las tendencias de la población para la rana de Yavapai (*Rana yavapaiensis*) y la rana de Chiricahua (*R. chiricahuensis*) y los comparamos con las observaciones de la rana toro no nativa (*R. catesbeiana*). Usamos métodos que incluyen estudios de mortalidad durante el invierno, estudios de encuentros visuales y marca-recaptura para obtener la presencia y ausencia y los datos de la tendencia de la población. En muchos sitios, se observaron ranas toro muertas o episodios de mortalidad a gran escala y repetitivos. Los análisis histológicos indicaron una enfermedad ocasionada por el hongo chytridiomycete (*Batrachochytrium dendrobatidis*) era la causa más cercana a la mortalidad. Los eventos de mortalidad de la rana toro se observaron raramente. Aunque esta enfermedad se confirmó en las ranas toro, la especie no ha disminuido. En *R. chiricahuensis*, algunas poblaciones fueron aparentemente extirpadas poco tiempo después de que detectamos el chytridiomycete, pero al menos dos – en ecosistemas relativamente naturales sin modificarse – han persistido durante años después de la llegada de esta enfermedad. Entre las muchas poblaciones de *R. yavapaiensis* estudiadas, algunas han desaparecido, pero en ningún caso puede asociarse de manera convincente la extirpación a la enfermedad únicamente. La variabilidad natural de la población descarta una conclusión firme de la disminución relacionada con la enfermedad en *R. yavapaiensis*, pero sospechamos que este puede ser el caso para algunas poblaciones. Entre muchos de los sitios donde se confirmó chytridiomicosis, esta rana permanece abundante en dos ambientes cálidos que pueden ser inhóspitos para el patógeno de esta enfermedad.

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Herpetofauna of lowland bottomlands of southeastern Arizona: a comparison of sites. We report species composition and relative abundances of amphibians and reptiles at two intensively studied, extant bottomland bosque-wetland complexes, San Bernardino National Wildlife Refuge, Cochise County, and Las Cienegas (Empire Ranch), Pima County, and contrast these to Leslie Canyon, a mid-elevation canyon stream in Cochise County that we have also sampled intensively. We also show similarities of existing lowland riparian herpetofaunas to a literature-based reconstruction of the early-20th century herpetofauna of the Santa Cruz River at Tucson and San Xavier. We demonstrate that, with notable exceptions, the three lowland sites have remarkably similar herpetofaunas, which we characterize as the semi-arid lowlands riparian assemblage. It differs from canyon assemblages, even those at relatively low elevations, as here represented by Leslie Canyon. We will explore biogeographic relationships of these distinctive assemblages, illustrate conservation issues and significance of the lowland systems, and discuss their potential roles as connecting corridors for Madrean montane and subtropical lowland species.

Herpetofauna de las tierras bajas del sur de Arizona: una comparación de lugares. Reportamos la composición de las especies y las abundancias relativas para los anfibios y los reptiles en dos complejos existentes de bosque-humedal, estudiados con intensidad, el Refugio Nacional de Vida Silvestre San Bernardino, Condado de Cochise, y Las Ciénegas (Empire Ranch), Condado de Pima, y los comparamos al cañón Leslie, un cañón de mediana elevación en el municipio de Cochise, lugar en donde también hemos realizado muestreos intensamente. También mostramos las similitudes de las herpetofaunas ribereñas de las tierras bajas a la reconstrucción de la herpetofauna del Río Santa Cruz basada en la literatura de principios del siglo XX, en Tucson y San Xavier. Demostramos que, sin excepciones notables, los tres lugares en las tierras bajas cuentan con herpetofauna sorprendentemente similar, lo cual caracterizamos como la colección ribereña de las tierras bajas

semiáridas. Es diferente a las colecciones de cañones, aún a aquellos a elevaciones relativamente bajas, como lo representa aquí el cañón Leslie. Exploraremos las relaciones biogeográficas de estas colecciones características, ilustraremos las cuestiones de conservación y la importancia de los sistemas de las tierras bajas. También discutiremos sus papeles potenciales como corredores que conectan a las especies Madrenses y de las tierras bajas subtropicales.

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Environmental education for the conservation of floristic resources in the communities adjacent to the Sierra de Mazatán, Sonora, Mexcio. The intent of this project is to organize the citizens of communities near the Sierra de Mazatán into local groups of professors, students, and ranchers for the collection of flora samples. The collected samples will be placesd in the USON herbarium and in a mini-herbarium. They will be established in the prepatory school CBTA 53 of Mazatán where the people will have immediate access to the native flora information of the region. An educational CD about the flora and vegatation of the Sierra de Mazatán will be developed in order to support the identification of local plants, including those species considered rare or with ecological status within NOM-059. The USON herbarium will provide follow-up in conservation and improvement of the mini-herbarium. In the future, more mini-herbarium projects will be established in other rural locations of Sonoran state.

Educación ambiental para la conservación de los recursos florísticos en las comunidades adyacentes a la Sierra de Mazatán, Sonora, México. Con este proyecto se pretende involucrar a los pobladores de las comunidades de la región de la Sierra de Mazatán en la recolección de ejemplares de herbario, organizando grupos de colecta locales entre profesores, alumnos y rancheros. Los ejemplares colectados se depositarán en el herbario USON, y en un mini-herbario que será establecido en la escuela preparatoria CBTA 53 de la población de Mazatán donde la gente tendrá acceso inmediato a información de la flora nativa de la región. Un disco compacto educativo sobre la flora y vegetación de la Sierra de Mazatán será desarrollado para apoyar la identificación de las plantas locales, incluyendo aquellas especies consideradas como raras ó con status ecológico dentro de la NOM-059. El herbario USON dará seguimiento a la conservación y crecimiento del mini-herbario. En el futuro, se planea establecer más mini-herbarios en otras localidades rurales del Estado de Sonora.

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Advances in the floristic inventory of the Sierra de Mazatán, Ures Municipality, and Mazatán, Sonora, Mexico. The Sierra de Mazatán is located 70 Km. to the east of Hermosillo, Sonora and reaches elevations of 1,545 meters above sea level. The Sierra is located in the municipalities of Mazatán and Ures. CONABIO considers the region a priority for conservation due to the "island" of temperate biodiversity in an arid environment. The type of vegetation is subtropical scrubland between 600 and 1,200 meters, and oak forest at elevations above 1,200 meters.

With financing from the National Forest Commission, a flora inventory of 600 species can be accomplished in the area. The project contributes to the knowledge of floristic resources of the municipalities of Ures and Mazatán, Sonora and to increase the herbarium collection at the USON. Three hundred samples have been collected with important duplicates deposited at the ARIZ. Currently, there are 269 listed species of plants distributed through 62 families. The most numerous families are the Leguminosae with 39, Gramineae with 38, Compositae with 24, Euphorbiaceae with 12, and Solanaceae with 11.

Avances en el inventario florístico de la Sierra de Mazatán, Municipios de Ures y Mazatán, Sonora, México. La Sierra de Mazatán se localiza a 70 Km. al Este de Hermosillo, Sonora, y alcanza elevaciones de hasta 1545 metros sobre el nivel del mar. Se comparte entre los municipios de Mazatán y Ures. La CONABIO la considera una región prioritaria para la conservación por constituir una "isla" de biodiversidad templada en un entorno árido. El tipo de vegetación es matorral subtropical entre los 600 y 1,200 metros, y bosque de encino a elevaciones por arriba de los 1,200 metros,.

Con financiamiento de la Comisión Nacional Forestal, se está realizando un inventario florístico que puede alcanzar unas 600 especies en el área. El proyecto contribuye al conocimiento de los recursos florísticos de los municipios de Ures y Mazatán, Sonora, y a incrementar la colección del herbario USON. Se han colectado 300 ejemplares depositando duplicados importantes en ARIZ. Actualmente se cuenta con un listado de 269 especies de plantas distribuidas en 62 familias. Las familias más numerosas en especies son Leguminosae con 39, Gramineae con 38, Compositae con 24, Euphorbiaceae con 12, y Solanaceae con 11.

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Rangeland degradation and restoration in "the desert seas": social and economic drivers of ecological change between the Sky Islands. The relative importance of different factors in driving ecological change in the valleys of southeastern Arizona and southwestern New Mexico has been hotly debated for decades. Most have attributed degradation to anthropogenic factors such as livestock grazing, agricultural clearing and irrigation, or fire suppression; others have countered these arguments with evidence of the primacy of climatic patterns and events such as severe droughts, floods or frosts. Clearly, both categories of drivers have played roles: the focus should turn to how they have interacted over time and what can be done to re-mediate rangelands now. I utilize historical and contemporary case studies to examine the social and economic processes driving degradation and restoration at different times and places. I suggest that debt and government policies interacted with drought to cause degradation related to livestock in the period 1870-1960, but that since that time the social and economic processes influencing rangelands have changed. Climate now dominates over livestock because stocking rates have been reduced to relatively insignificant levels, while the distribution of homes and conservation resources determines where fire and other tools are employed for rangeland restoration.

Degradación y restauración de las praderas en los "mares de desierto": conductores sociales y económicos del cambio ecológico entre las Islas del Cielo. La importancia relativa de los diferentes factores que conducen al cambio ecológico en los valles del sureste de Arizona y el suroeste de New Mexico se ha debatido arduamente durante décadas. La mayoría atribuye la degradación de los factores antropogénicos como el pastoreo del ganado, los claros agrícolas y la irrigación o la supresión de los incendios; otros refutan estos argumentos con las pruebas de los patrones climáticos y los eventos como las sequías severas, las inundaciones o las heladas. Claramente, ambas categorías de conductores han jugado papeles: la concentración debe centrarse en cómo han interactuado con el tiempo y lo que puede hacerse para remediar las praderas ahora. Usé casos de estudio históricos y contemporáneos para estudiar los procesos sociales y económicos que conducen a la degradación y restauración en diferentes tiempos y lugares. Sugiero que la deuda y las políticas del gobierno interactuaron con la sequía para ocasionar la degradación relacionada con el ganado en el período de 1870 a 1960, pero que desde ese momento los procesos económicos y sociales con influencia en las praderas han cambiado. Ahora el clima domina sobre el ganado porque los índices se han reducido a niveles relativamente insignificantes, mientras que la distribución de las casas y los recursos de conservación determinan dónde se emplean incendios y otras herramientas para la restauración de las praderas.

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Refugia, biodiversity, and pollination roles of bumble bees in the Madrean Archipelago. Bumble bees in the genera *Bombus* and *Psithyrus* are widespread native pollinators that constitute the most important pollinators in temperate North America. Native plants are generally better pollinated by these generalist pollinators than by honey bees, an exotic tramp species introduced by Europeans in the middle of the last millennium. Although they are most abundant in cooler regions of North America, they retain important and viable populations in alpine refugia near the tops of many Sky Islands. For all except one species, desert valleys between the ranges are major barriers to dispersal and gene flow. The species diversity and ranges of bumble bees in the Sky Islands and in the Mogollon mountain area will be discussed with reference to their possible extinction as a result of fires and other natural and anthropogenically caused disasters.

Refugios, biodiversidad y los papeles en la polinización de los abejorros en el Archipiélago Madrense. Los abejorros del género *Bombus* y *Psithyrus* son una especie general de polinizadores que constituyen a los polinizadores más importantes en Norteamérica. Las plantas nativas generalmente se polinizan mejor por estos polinizadores generalistas que por las abejas de miel, una especie exótica introducida por los europeos a mediados del milenio pasado. Aunque son más abundantes en las regiones más frías de Norteamérica, conservan poblaciones importantes y viables en refugios alpinos cercanos a los picos de muchas islas del cielo. Para todas las especies, a excepción de una, los valles del desierto entre las cordilleras son barreras importantes para la dispersión y flujo genético. La diversidad y distribución de estas especies de abejorros en las islas del cielo y en el área de la montaña Mogollón se discuten en relación con la posible extinción como resultado de los incendios y otros desastres naturales y antropogénicos.

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Successful biological inventories in Sonoran Desert National Parks. Most land management units in the Sonoran Desert lack detailed lists of vascular plants and vertebrates, yet inventories are important for natural resource management and interpretation, and can be a foundation for long-term monitoring programs. We inventoried plants and vertebrates in nine national parks in southern Arizona and western New Mexico from 2000 through 2003. Parks range in size from 17 to 41,300 hectares, from 425 to 2625 meters in elevation, and represent a diversity of ecological communities. In four parks these were the first biological inventories, while in other parks our work focused on taxonomic groups not previously surveyed. In all parks we recorded previously undocumented species and in most parks found new species in each taxonomic Class (e.g., Aves). We collected data using repeatable designs, commonly accepted methods and standardized protocols, and we documented species abundance, distribution (presence/absence across survey sites) and status (e.g. breeding). Once the inventories are complete, parks will receive annotated species lists, voucher photographs, and distribution maps of study sites and species of interest. These data will also be used in developing monitoring plans both for national parks in the Madrean Archipelago and for the Sonoran Desert ecoregional monitoring effort. Poster.

Inventarios biológicos con éxito en los parques nacionales del Desierto Sonorense. La mayor parte de las unidades de manejo de tierras en el Desierto Sonorense carecen de listas detalladas de plantas vasculares y vertebrados, sin embargo los inventarios son importantes para el manejo de los recursos naturales y la interpretación, y pueden ser la base de los programas de monitoreo a largo plazo. Elaboramos inventarios de plantas y vertebrados en nueve parques nacionales del sur de Arizona y el oeste de New Mexico desde 2000 hasta 2003. Los parques tienen entre 17 y 41,300 hectáreas, de 425 a 2625 metros en elevación y representan una diversidad de comunidades ecológicas. Estos fueron los inventarios biológicos en cuatro parques, mientras que en otros nuestro trabajo se centró en los grupos taxonómicos que no se habían evaluado con anterioridad. En todos los parques se registraron especies no documentadas previamente y en la mayor parte de los parques se encontraron especies nuevas en cada clase taxonómica (por ejemplo, Aves). Recolectamos datos usando diseños repetibles, métodos aceptados comúnmente y protocolos estandarizados, y documentamos la abundancia de las especies, la distribución (presencia y ausencia en los sitios de monitoreo) y estatus (por ejemplo, reproductivo). Al terminar los inventarios, los parques recibirán listas de especies, fotografías y mapas de distribución de los sitios de estudio y las especies de interés. Esta información también se usará para desarrollar los planes de monitoreo de los parques nacionales en el Archipiélago Madrense y para el esfuerzo de monitoreo ecoregional del Desierto Sonorense. Póster.

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Testing causal models for the evolution of dioecy in *Echinocereus coccineus* (cactaceae) using GIS and SEM: The birds and the bees of plant sex. *Echinocereus coccineus* is a hummingbird-pollinated cactus of the Madrean Archipelago with a unique mating system. It is hermaphroditic in Sky Islands within the hummingbird migration corridor, but is dioecious (separate sexes) in drier areas to the east and west where it is pollinated by Halictid bees. I tested four causal models to examine the evolution of dioecy in *E. coccineus*: (1) Dioecy is selected in areas of low precipitation in order to more efficiently partition resources to male and female reproduction. (2) Dioecy could be selected in these areas to reduce inbreeding caused by the absence of hummingbird pollination. (3) Dioecy could be selected directly by both rainfall and inbreeding. (4) Dioecy could be selected indirectly by rainfall through its effects on pollinator distribution. To test these causal models, a GIS map was compiled using data on the distribution of dioecious *E. coccineus* populations from over 300 herbarium specimens, USGS data on average annual rainfall, and Audubon Society BBS maps of hummingbird abundance. The data were analyzed using Structural Equation Modeling (SEM) to assess the relative direct and indirect associations among the variables and to determine which causal model best explains the patterns of the data.

Pruebas de los modelos causales para la evolución de dioecia en *Echinocereus coccineus* (cactaceae) usando SIG y SEM: Las aves y las abejas del sexo en plantas. *Echinocereus coccineus* es un cactus del Archipiélago Madrean polinizado por los colibríes con un sistema de apareamiento singular. Este cactus es hermafrodita en las islas del cielo dentro del corredor de migración de los colibríes, pero es dioecia (sexos separados) en áreas más áridas al este y oeste donde lo polinizan la abejas Halictid. Probé cuatro métodos causales para examinar la evolución de dioecia en *E. coccineus*: (1) Dioecia se selecciona en áreas con poca precipitación a fin de repartir los recursos de manera más eficaz a la reproducción masculina y femenina. (2) Dioecia puede seleccionarse en estas áreas para reducir la endogamia ocasionada por la ausencia de la polinización por colibríes. (3) Dioecia puede seleccionarse directamente por la lluvia y la endogamia. (4) Dioecia puede seleccionarse indirectamente por la lluvia a través de sus efectos en la distribución de los polinizadores. Para probar estos modelos causales, se compiló un mapa SIG usando datos en la distribución de las poblaciones dioecias E. coccineus de 300 especimenes de herbarios, datos del USGS sobre la precipitación promedio anual, y los mapas BBS de abundancia del colibrí de la Audubon Society. Los datos se analizaron usando el Modelaje de Ecuación Estructural (SEM por sus siglas en inglés) para evaluar las asociaciones relativas directas e indirectas entre las variables y determinar qué modelo causal explica mejor los patrones de la información.

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Comparing ecosystem water and carbon exchanges across a riparian mesquite invasion gradient. Woody plants are expanding their range in many semiarid landscapes of the Southwest. In many of the “grassland seas” of southern Arizona, native mesquite (Prosopis velutina) has dramatically increased in abundance across the desert floor uplands and in riparian bottomlands. We are monitoring water and carbon exchanges using the eddy covariance method over a riparian grassland, invaded grassland, and mesquite bosque in order to understand the consequences of woody plant encroachment on ecosystem carbon and water balances. Initial results suggest that the deep roots of mesquite lead to a decoupling of ecosystem water sources as the invading mesquites mature in former grasslands. This ability of the mesquite to rely on stable groundwater sources rather than precipitation then creates an unusual decoupling between ecosystem carbon acquisition (photosynthesis) and loss (respiration). Furthermore, the strength of this decoupling between water and carbon exchanges changes during the growing season as a result of the mid-summer arrival of monsoon moisture. These results highlight the important role that water sources and ecosystem morphology play on controlling water and carbon balances in semiarid areas.

Comparación del agua del ecosistema y los intercambios de carbono a lo largo de un gradiente de invasión de mesquite ribereño. Las plantas leñosas están extendiendo su distribución en muchos paisajes semiáridos del suroeste. En muchos de los “mares de pastizales” del sur de Arizona, el mesquite nativo (Prosopis velutina) aumentó de manera dramática en abundancia a lo largo del suelo desértico y los fondos ribereños. Monitoreamos el agua y los intercambios de carbono usando el método de covarianza hedí en un pastizal ribereño, pastizal invasor y un bosque de mesquite para comprender las consecuencias de la invasión de las plantas leñosas en los equilibrios de carbono y agua del ecosistema. Los resultados iniciales sugieren que las raíces más profundas del mesquite provocan un desapareamiento de los recursos de agua del ecosistema conforme los mesquites invasores maduran en los pastizales. Esta habilidad del mesquite de depender de las fuentes de agua subterránea en lugar de la precipitación crea un desapareamiento poco común entre la adquisición de carbono del ecosistema (fotosíntesis) y a pérdida (respiración). Además, la fortaleza de este desapareamiento entre el agua y los intercambios de carbono, cambia durante la época de crecimiento como resultado de la humedad proveniente de monsones en el verano. Estos resultados destacan el papel importante que las fuentes de agua y la morfología del ecosistema juegan en para controlar el equilibrio del agua y carbono en las áreas semiáridas.

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Visitor monitoring and simulation at Saguaro National Park. Saguaro National Park is a superb example of the Sonoran Desert ecosystem, featuring exceptional stands of saguaro cacti, important wildlife habitat, associated mountains and significant cultural resources. The park has become a top destination for local, national and international visitors who come to see and experience its natural beauty. Along with this popularity has come the increased demand for new types of recreation use, such as mountain bicycles, pack goats, llamas, and baby strollers on trails and increased variety of access for the disabled are having significant impacts on the park. Proliferation of trails in sensitive areas, traffic congestion, and conflicts among recreation activities are posing huge challenges to the park's management. While these problems are not insurmountable there is a need to develop a more systematic way to understand the dynamics of visitor use patterns throughout the park in relation to the increasing demand for new access and opportunities. This paper discusses a study currently underway to evaluate the spatiotemporal distribution of visitor use in Saguaro National Park. The study uses state of the art inventory and monitoring techniques to document baseline visitor use distribution, patterns of use, and visitor opportunities in the park. In addition, travel simulation modeling is used to replicate baseline visitor use behavior and subsequently to test the feasibility and effectiveness of GMP alternatives.

Monitoreo y simulación de visitantes en el Parque Nacional Saguaro. El Parque Nacional Saguaro es un ejemplo magnífico del ecosistema del Desierto Sonorense, caracterizado por cactus excepcionales, hábitat importante para la vida silvestre, montañas aledañas y recursos culturales importantes. El parque se ha convertido en el destino principal de los visitantes locales, nacionales e internacionales que vienen a ver y experimentar su belleza natural. Junto con la popularidad viene la demanda para nuevos tipos de uso recreativo, como las bicicletas de montaña, cabras de carga, llamas y carreolas para bebés en los senderos y el aumento en la variedad de accesos para los discapacitados está teniendo impactos importantes en el parque. La proliferación de los senderos en áreas sensibles, la congestión del tráfico, y los conflictos entre las actividades recreativas, representan retos a la administración del parque. Mientras que estos problemas no sean superables existe la necesidad de desarrollar una forma más sistemática para comprender las dinámicas de los patrones de uso de los visitantes en el parque en relación con el aumento en el uso y la demanda de nuevos accesos y oportunidades. Este trabajo presenta un estudio actual para evaluar la distribución espaciotemporal del uso del Parque Nacional Saguaro por parte de los visitantes para resolver el uso por visitantes y las cuestiones de manejo de recursos en el parque. Este estudio usa técnicas de inventarios y monitoreo de punta para documentar la distribución del uso por visitantes, los patrones de uso y las oportunidades para los visitantes en el parque. Además, el modelaje de simulación de viaje se usa para replicar el comportamiento de los visitantes y posteriormente examinar la viabilidad y eficacia de las alternativas GMP.

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Optimizing Emory oak woodlands for multiple resource benefits. The Emory oak woodlands in the southwestern United States present a diverse range of resources. People utilize these woodlands for wood products, cattle grazing, and recreational purposes. The woodlands provide a diversity of wildlife habitats for resident and migratory species. Occupying predominantly upland regions, the oak woodlands protect watersheds from excessive soil erosion. Managing entities are increasingly moving towards an ecosystem approach to holistically manage the oak woodlands as a sustainable resource. However, to move towards an effective ecosystem based management system requires an understanding of the ecological and hydrological processes in these oak woodlands. This paper draws on the results of prior studies that focused on four resource components found in the Emory oak woodlands. This information, collectively, was used to develop a decision support system to provide a basis for managing entities to optimize wood, water, forage, and wildlife objectives. Poster.

Optimizando el manejo de bosques de beyota para el beneficio de recursos multiples. Los bosques de beyota en el suroeste de los Estados Unidos presentan una diversa gama de recursos. La gente utiliza estos bosques para obtener leña, ganadería y actividades recreasionales. Estos bosques proveen una diversidad de hábitats para especies residentes y migratorias. Al estar presentes en las altiplanicies, los bosques de beyota protejen las cuencas de la erosión excesiva. Los manejadores se están enfocando hacia un manejo de ecosistemas para lograr la sustentabilidad de este recurso. Sin embargo, el cambio hacia un sistema de manajo efectivo de ecosistemas requiere un entendimiento de los procesos ecológicos e hidrológicos de estos bosques. A menudo, es de particular interés manejar el monte bajo desde que evoluciona a partir de las tempranas actividades de cosecha de leña. La beyota es una especie de rebrotación prolífica y, como consecuencia, los rodales en post-cosecha pueden producir un gran número de brotes en los tocones cortados. Una buena opción de manejo consiste en aclarear el monte bajo para obtener una densidad deseada con múltiples beneficios. Se ha desarrollado una matriz de decisión basada en recursos derivados de estudios preliminares para asistir a los manejadores en la prescripción de tratamientos de aclareos para optimizar uno o más recursos benéficos. Información tal como la presentada en esta matriz de decisión, es un pre requisito para planificar más holísticamente el manejo ecosistémico de estas comunidades de bosques. Póster.

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Bats of Saguaro National Park revisited. In 1986, Hoffmeister documented 26 species of bats from southern Arizona. Various subsets of 24 of these species are recorded from the different mountain islands in southeastern Arizona. As is true for terrestrial mammals, bat biodiversity on mountain islands is due to island size, number of biotic communities, and latitude. Isolation also affects diversity on islands, but is less influential on bats which, like birds, are less constrained by distances. Sampling effort is obviously important in determining species richness in any area. Upon first visit, every species is new in a geographical place. However, as numbers of species accumulate, typically more effort is continuously required to record additional species. At some point sampling costs outweigh the returns: a financial dilemma for government agencies. Determining biodiversity of bats in Saguaro National Park in the Rincon Mountains exemplifies diminishing returns with increased effort. In the mid-1980's, only seven bat species were known. By 1992, our surveys added nine. By 2002, we added just two, to total 18 species of bats. While there are six additional species likely or possible to occur, it may require an inordinate amount of survey effort to add any of these to the known diversity of this mountain island.

Los murciélagos del Parque Nacional Saguaro. En 1986, Hoffmeister documentó 26 especies de murciélagos del sur de Arizona. Varios subconjuntos de 24 de estas especies están registrados en diferentes islas montañosas en el sur de Arizona. Como lo es para los mamíferos terrestres, la biodiversidad de los murciélagos en las islas montañosas se debe al tamaño de la isla, el número de comunidades bióticas y la latitud. El aislamiento también afecta a la diversidad en las islas, pero con menos influencia en los murciélagos, lo que, al igual que con las aves, tiene menor limitación por las distancias. El esfuerzo de muestreo es totalmente importante para determinar la riqueza de las especies en el área. A primera visita, cada especie es nueva en un lugar geográfico. Sin embargo, conforme los números de las especies se acumulan, típicamente se necesita se requiere un mayor esfuerzo continuo para documentar especies adicionales. De igual manera los costos del muestreo son mayores que las utilidades: un dilema financiero para los organismos gubernamentales. Determinar la biodiversidad de los murciélagos en el Parque Nacional Saguaro en las montañas Rincón ejemplifica la reducción en las utilidades de nuestro creciente esfuerzo. A mediados de los 80, sólo se conocían 18 especies de murciélagos. Para 1992, nuestros muestreos añadieron nueve. Para 2002, añadimos sólo dos, para un total de 18 especies de murciélagos. Mientras que existen seis especies adicionales, puede necesitarse una cantidad exorbitante de esfuerzo para sumarlas a la diversidad conocida de esta isla montañosa.

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First records of three species of mammals in the Huachuca Mountains: results of ecological stewardship at Fort Huachuca. We report the first occurrences of two species of bats and one species of chipmunk in the Huachuca Mountains that were not recorded there in historical and modern references of the region. We present capture/voucher data for the silver haired bat (*Lasionycteris noctivagans*), Brazilian free-tailed bat (*Tadarida brasiliensis*), and cliff chipmunk (*Tamias dorsalis)* from Fort Huachuca. These species were observed during inventory and monitoring projects initiated by biologists working for the Department of Defense at Fort Huachuca.

Primeros registros de tres especies de mamíferos en las Montañas Huachuca: resultados del patrimonio ecológico en el Fuerte Huachuca. Documentamos las primeras incidencias de dos especies de murciélagos y una especie de ardilla en las Montañas Huachuca que no se habían registrado en informes históricos y modernos de la región. Presentamos los datos de captura/voucher para el murciélago plateado (*Lasionycteris noctivagans*), el murciélago brasileño (*Tadarida brasiliensis*) y la ardilla de precipicio *(Tamias dorsalis)* del Fort Huachuca. Estas especies se observaron durante los proyectos de inventario y monitoreo iniciados por los biólogos trabajando para el Departamento de Defensa en el Fort Huachuca.

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Black bear abundance, habitat use, and food habits in the Sierra San Luis, Sonora. Black bears are an endangered species in Mexico, resulting from overharvest and lack of biological knowledge. The Mexican Sky Islands provide a unique opportunity to study black bear ecology due to their remoteness and low human population. During 2002 and 2003, we determined density, habitat use, and food habits in two privately owned ranches (El Pinito and Los Ojos). Black bear density was significantly different between ranches. At El Pinito density was 5.9 (± 8.5) bears/100 km^2 and at Los Ojos, 0.0 bears. At El Pinito the density varied throughout the seasons, showing a reduction (0.0 bears /100 km^2) when stock tanks dried and an increase (2.9 bears/100 km^2) during the short rainy season. Bears at El Pinito showed temporal variation in habitat use, selecting open woodlands and chaparral during different seasons. Black bear diet consisted of manzanita (99%) during 2002, and juniper (85%) for 2003. Environmental conditions regulating the distribution and density of black bears were affected by El Niño (2003), causing animals to move from 2002 refuge areas. Consequently black bears should be managed at a landscape level by adding other protected areas that would allow bear movements in response to these cycles of nature.

Abundancia del oso negro, uso del hábitat y hábitos alimenticios en la Sierra San Luis, Sonora. Los osos negros son una especie en peligro de extinción en México, como resultado de la sobreexplotación y la falta de conocimiento biológico. Las Islas del Cielo mexicanas brindan una oportunidad singular para determinar los aspectos ecológicos de los osos negros gracias a su lejanía y baja población humana. Durante 2002 y 2003, determinamos la densidad, uso del hábitat y hábitos alimenticios en dos ranchos privados (“El Pinito” y “Los Ojos”). La densidad del oso negro fue muy diferente entre los ranchos, en “El Pinito” la densidad fue 5.9 (± 8.5) osos/100 km^2 y en “Los Ojos” fue 0.0 osos. En “El Pinito” la densidad varió a lo largo de las estaciones mostrando una reducción (0.0 osos /100 km^2) cuando los tanques de almacenamiento se secaron y un aumento (2.9 osos/100 km^2) durante la corta temporada de lluvia. Los osos en “El Pinito” mostraron uso temporal del hábitat, seleccionando bosques y chaparrales abiertos en las diferentes estaciones. La dieta del oso negro consistió de manzanita (99%) durante 2002 y enero (85%) para 2003. Las condiciones ambientales que regulan la distribución y densidad de los osos negros están afectadas por El Niño (2003), excluyendo las áreas de refugio 2002, y como consecuencia los osos negros deben manejarse a un nivel de paisaje añadiendo áreas protegidas que incluyan los movimientos de los osos a través de estos ciclos naturales.

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Linking science, policy, and management: an example of how ecosystem management may work for the Sky Island region. Repeated failures to effectively manage individual species for a wide range of conservation goals combined with greater understanding of the complexities of ecosystem function have led the scientific community to emphasize the importance of ecological process, structure, and scale in the maintenance of biological diversity. Humans have affected natural landscapes in ways ranging from complete alteration in the form of agriculture to the cumulative suppression of fire resulting in different forest structure. Many naturally occurring processes, structures, and species may not return to naturally sustaining function without intervention. Management at some level is often necessary to maintain natural processes. Ecosystem management is a continually expanding and evolving approach that relies on the foundation of science and its transcendence into public policy to effectively manage ecosystems so as to assure their long-term sustainability. Given the above, ecosystem management is defined, implemented, and understood in vastly different ways. This paper intends to (1) summarize ecosystem management origination and intent within the scientific community and public policy, (2) assess the different interpretations of ecosystem management, and (3) offer insight into its use and effectiveness in maintaining sustainable ecosystems in the Sky Island region. Ecosystem management, depending upon definition and use, can be an effective way of linking science, policy, and management because of its foundation in scientific principles and acknowledgement of political, economic, and social variables.

Uniendo la ciencia, la política y el manejo: un ejemplo de cómo el manejo de los ecosistemas puede funcionar para la región de las Islas del Cielo. En respuesta a los fracasos repetidos para el eficiente manejo de especies específicas para una amplia gama de metas de conservación, combinado con la mejoría del conocimiento en relación a las complejidades e interrelaciones de las funciones de los ecosistemas, la comunidad científica recientemente se enfocó en la importancia de los procesos ecológicos, la estructura y la escala en el mantenimiento de la diversidad biológica. Los seres humanos hemos afectado a casi todos los paisajes naturales en varias formas: desde la alteración completa en la forma de agricultura hasta la supresión acumulativa de los incendios que da como resultado diferentes estructuras de bosques. Muchos procesos naturales, estructuras y especies pueden no recuperarse sin intervención. El manejo hasta cierto nivel es con frecuencia necesario para mantener los procesos naturales. El manejo de los ecosistemas es un método de evolución continua que depende de las bases de la ciencia y su trascendencia a la política pública para manejar los ecosistemas con eficacia para garantizar su sustentabilidad a largo plazo. Dado lo anterior, el manejo de los ecosistemas se define, implementa y comprende en diferentes formas. Este trabajo tiene el objetivo de resumir el origen del manejo de los ecosistemas y su intención en la comunidad científica y de política pública, evaluar las diferentes interpretaciones del manejo de los ecosistemas y ofrecer la oportunidad de comprender su uso y eficacia para mantener los ecosistemas de la región de las Islas del Cielo sustentables. El manejo de los ecosistemas, dependiendo de su definición y uso, puede ser una manera eficaz para unir la ciencia, la política y el manejo porque se basa en los principios científicos y reconoce las variables políticas, económicas y sociales.

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A cooperative approach to road closures and landscape restoration. The Sky Island Alliance (SIA), a regional non-profit organization, and the Coronado National Forest (CNF), in southeast Arizona, have been collaborating to inventory roads on the forest and subsequently close wildcat roads. Wildcat roads are non-system, user-created roads not needed to meet forest resource management objectives. Since 1998 over 500 volunteers have logged over 20,000 hours surveying roads. Results show that 20% of all roads surveyed were wildcat roads. The 1000 miles of undocumented roads works out to an average of over 2.5 mi/mi^2 on roaded portions of the CNF. In response to this burgeoning "illegal" transportation system and its effects on biological and geomorphological integrity, SIA, in cooperation with the CNF, has focused volunteers, using techniques from restoration ecology, to close, obliterate, revegetate, and decompact wildcat roads. Priority closures were wildcat roads with significant soil erosion and those creating habitat fragmentation. SIA volunteers get the satisfaction of restoring landscapes and educating the public, while the Forest Service gets an updated inventory of roads and assistance restoring degraded sites. The result is a cooperative, volunteer based process using grassroots organizing to restore the unique biological processes in the Sky Island region.

Un método de cooperación para el cierre de caminos y la restauración de paisajes. Sky Island Alliance, una organización sin fines de lucro, y el Coronado National Forest, en el sur de Arizona, han estado trabajando para hacer inventarios de los caminos en el bosque y caminos cercanos de gato montés. Los caminos de gato montés son caminos creados por usuarios sin la intención de cumplir con los objetivos de manejo de los recursos del bosque. Desde 1998 más de 500 voluntarios han empleado 20,000 horas estudiando caminos. Los resultados muestran que 20% de todos los caminos estudiados eran caminos de gato montés. Esto se correlaciona con más de 1000 millas de caminos no documentados, o un promedio de más de 2.5 mi/mi^2 en porciones del bosque con caminos. En respuesta a este creciente sistema "ilegal" de transporte y sus efectos en la integridad biológica y geomorfológica, Sky Island Alliance, en cooperación con el Coronado National Forest, centró a los voluntarios, usando técnicas de restauración ecológica, para cerrar, borrar, plantar vegetación y decompresionar los caminos de gato montés. Los cierres prioritarios fueron caminos con erosión del suelo importante y aquellos que creaban fragmentación del hábitat. Los voluntarios de Sky Island Alliance obtienen la satisfacción de restaurar el paisaje y educar al público, mientras que el Servicio Forestal obtiene un inventario actualizado de los caminos y ayuda para restaurar los sitios degradados. El resultado es un proceso de cooperación, fundado en voluntarios usando organización de base para restaurar los procesos biológicos singulares de la región de las Islas del Cielo.

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Historical biogeography of the longhorn cactus beetles: the impact of Pleistocene climate changes on American desert communities. Three species of the flightless cactus beetles *Moneilema* occur in the Cochise filter region of southeastern Arizona and southwestern New Mexico. *M. appressum* occurs in semidesert grasslands and oak woodlands in the Sky Islands of the Madrean Archipelago; *M. gigas* and *M. armatum* occur in desert scrub communities throughout the Sonoran and Chihuahuan deserts, respectively. Mitochondrial and nuclear DNA sequence data from each of these species were analyzed to reveal biogeographic and population genetic patterns and to test the hypothesis that expansion of desert communities promoted vicariance in Sky Island populations. Parsimony- and Maximum Likelihood-based phylogenetic analyses and Bayesian analysis of molecular evolution suggest high degrees of geographic structure in all three species. These analyses and a Nested Clade Analysis also indicate that both desert species have undergone successive northward population expansions, whereas the Sky Island species has experienced historic range fragmentation. Coalescent analyses indicate that these demographic events were coincident with major global climate changes throughout the Pleistocene.

Biogeografía histórica de los escarabajos de cactus: el impacto de los cambios climáticos del Pleistoceno en las comunidades desérticas de América. Tres especies de escarabajo de cactus *Moneilema* ocurren en la región Cochise del sur de Arizona y suroeste de New Mexico. *M. appressum* ocurre en los pastizales semidesérticos y en bosques de roble en las islas del cielo del Archipiélago Madrense; *M. gigas* and *M. armatum* ocurren en las comunidades desérticas a lo largo de los desiertos Sonorense y Chihuahuense, respectivamente. Los datos de las secuencias mitocondriales y de ADN nuclear para cada una de estas especies se analizaron para conocer los patrones biogeográficos y genéticos de la población y para probar la hipótesis de que la expansión de las comunidades del desierto promueve la vicarianca en las poblaciones de las islas del cielo. Los análisis filogenéticos de mezquindad y probabilidad máxima y los análisis Bayesianos de evolución molecular sugieren altos grados de estructura geográfica en las tres especies. Estos análisis y los análisis Nested Clade también indican que ambas especies de desierto han pasado por expansiones de población sucesivas hacia el norte, mientras que las especies de las islas del cielo han experimentado una fragmentación en su zona histórica de distribución. Los análisis de fusión indican que estos eventos demográficos coinciden con los cambios climáticos globales de mayor importancia a lo largo del Pleistoceno.

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Drought survival behavior in a large flightless aquatic insect, *Abedus herberti* in interrupted Sky Island streams (Heteroptera: Belostomatidae). Madrean Sky Island streams are characterized by flow extremes that range from flash floods during the summer monsoon season, to absence of surface flow during the Sonoran dry season. Typically, insects abandon shrinking aquatic habitat by flight during the dry season and recolonize these drainages when flow is seasonally restored. *Abedus herberti* is a large predatory giant water bug found in most Sonoran mountain streams. This species is flightless and thus unable to abandon shrinking habitat or recolonize streams by flight. The species survives the annual dry season and protracted droughts by forming dense aggregations in plunge basin rock pool. These aggregations rapidly exhaust heterospecific prey and ultimately consist of adult bugs that sustain themselves by cannibalism of their immatures. Paternal brooding promotes reproduction under these extreme conditions. When no surface water is accessible, *A. herberti* bugs burrow under the leaf pack to moist soil where they remain inactive for weeks or months until flow is restored. Bugs experimentally deprived of leaf pack overlying moist soil became moribund or died within hours.

Comportamiento de supervivencia ante la sequía de un insecto acuático no volador, *Abedus herberti* en los arroyos no interrumpidos de las Islas del Cielo (Heteroptera: Belostomatidae). Los arroyos de las Islas del Cielo Madrense se caracterizan por flujos extremos que varían de inundaciones en el verano durante la época de monsones, a la ausencia de flujo superficial durante la época de sequía Sonorense. Típicamente, los insectos abandonan el reducido hábitat acuático volando durante la época de sequía y recolonizar estas vías cuando el flujo estacional se restaura. *Abedus herberti* es un bicho de agua gigante que se encuentra en la mayoría de los arroyos montañosos Sonorenses. Esta especie no vuela y no puede abandonar el reducido hábitat o recolonizar otros. Esta especie sobrevive la época anual de sequía y las sequías prolongadas formando agregaciones densas en las pozas de rocas. Estas agregaciones agotan las presas heteroespecíficas rápidamente y consisten de bichos adultos que se sostienen por canibalismo de sus juveniles. La camada de padres promueve la reproducción bajo estas condiciones extremas. Cuando no hay agua superficial accesible, los *A. herberti* se entierran bajo el suelo húmedo donde permanecen inactivos por semanas o meses hasta que se restaura el flujo. Los bichos privados de la humedad del suelo se vuelven moribundos o mueren en horas.

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Water quality monitoring for high-priority water bodies in the Sonoran Desert Network. This paper describes a network monitoring program for "high priority" water bodies in the Sonoran Desert Network of the National Park Service. In particular, we provide protocols for monitoring selected waters of Montezuma Well within Montezuma Castle National Monument, Tuzigoot National Monument, Tumacácori National Historical Monument, Organ Pipe Cactus National Monument, and Saguaro National Park. Park and network staff assisted in identifying potential locations of testing sites, local priorities, and how water quality sampling might be integrated into overall vital signs monitoring and park operations. Several criteria were used to determine the priority of these water bodies. These include ecological and perceptual threats to public and wildlife health, as well as adequacy of monitoring efforts. In conjunction with selecting water bodies and sample sites, we also identified water quality monitoring parameters. These include five "core" parameters that will be sampled as part of the NPS Vital Signs monitoring program: temperature, dissolved oxygen, conductivity, pH, and flow or water levels. Additional parameters were selected based on park-specific stressors or threats gathered from discussions with park and network staff, literature research, and ADEQ 303(d) mandated reports on water quality.

Monitoreo de la calidad del agua para cuerpos de agua importantes en la Red del Desierto Sonorense. Este trabajo describe un programa de monitoreo para cuerpos de agua "importantes" en la Red del Desierto Sonorense del Servicio de Parques Nacionales. En particular, brindamos protocolos para monitorear aguas selectas en el pozo Montezuma en el Monumento Nacional Montezuma Castle, Monumento Nacional Tuzigoot, Monumento Histórico Nacional Tumacácori, Monumento Nacional Organ Pipe Cactus y el Parque Nacional Saguaro. El personal del parque y la red ayudó a identificar las ubicaciones potenciales para analizar los sitios, las prioridades locales y la forma de integrar el muestreo de la calidad del agua a todos los signos vitales del monitoreo y las operaciones del parque. Se usaron varios criterios para determinar la prioridad de estos cuerpos de agua. Estos incluyen las amenazas ecológicas y preceptúales a la salud del público y la vida silvestre, así como lo aceptable de los esfuerzos de monitoreo. Además de seleccionar los cuerpos de agua y los sitios de muestreo, también identificamos los parámetros de monitoreo de la calidad del agua. Estos incluyen cinco parámetros "núcleo" que se muestrearán como parte del programa de monitoreo de Signos Vitales del SPN: temperatura, oxígeno disuelto, conductividad, pH y flujo o niveles de agua. Se seleccionaron parámetros adicionales según amenazas específicas al parque reunidos a partir de las discusiones con el personal del parque y de la red, la investigación de la literatura y los informes obligatorios sobre la calidad del agua ADEQ 303 (d).

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Coping with fragmented habitats on mountain islands: dispersal and metapopulation structure in the Mexican spotted owl. The Mexican spotted owl (*Strix occidentalis lucida*) typically occurs in canyon riparian and adjacent woodland areas in the mountains of the American Southwest and the Sierra Madre of Mexico. Suitable habitat for this species is therefore often highly fragmented and separated by areas of grassland or desert. Rainfall patterns also are extremely variable, and reproduction and survivorship are subject to highly stochastic processes. The owls show a number of behavioral characteristics that may allow them to cope with both fragmented habitats and stochastic environments. Unlike many resident bird species in the region, all young disperse in their first fall. Juveniles wander over large areas, and rarely return to breed in the same mountain range in which they were born. Owl populations are thus connected together into a metapopulation. One consequence is that recruitment into a local population is independent of local reproductive success; this in turn allows for the rapid reestablishment of populations that may have gone extinct due to local stochastic events. However, many owl populations studied in the last fifteen years have exhibited an overall decrease in numbers; whether this is a result of normal climatic variation or a decline in overall habitat quality remains to be determined.

Haciendo frente a los hábitats fragmentados en las islas montañosas: dispersión y estructura de la metapoblación del tecolote moteado mexicano. El tecolote moteado mexicano (*Strix occidentalis lucida*) existe típicamente en los cañones ribereños y las áreas boscosas adyacentes en las montañas del Suroeste Norteamericano y la Sierra Madre en México. De modo que el hábitat adecuado para esta especie se encuentra altamente fragmentado y separado por áreas de pastizales o desierto. Los patrones de precipitación también son extremadamente variables, y la reproducción y supervivencia están sujetas a procesos muy variados. Los tecolotes muestran un número de características de comportamiento que pueden permitirles hacer frente a la fragmentación del hábitat y variabilidad del medio ambiente. A diferencia de las especies de aves residentes en la región, todos los juveniles se dispersan en su primer otoño. Los juveniles deambulan sobre áreas grandes y raramente regresan a reproducirse a la misma cordillera en donde nacieron. De modo que las poblaciones de tecolote se encuentran conectadas por una metapoblación. Una consecuencia es que el reclutamiento a la población local es independiente del éxito reproductivo local; eso permite un restablecimiento rápido de las poblaciones que pueden haberse extinguido por los eventos variables. Sin embargo, las poblaciones de tecolote estudiadas en los últimos quince años han mostrado una disminución general en sus números; ya sea por resultado de la variación normal del clima o una disminución general en la calidad del hábitat, aún está por determinarse.

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Systematic investigations of the fish assemblage of San Pedro River, Arizona 1990-2003. Fourteen years of monitoring disclosed no changes in species diversity, and few in relative abundance of the fish assemblage in San Pedro Riparian National Conservation Area, Arizona. Congress established the area in 1988 to "…conserve, protect, and enhance the desert riparian ecosystem along 61 kilometers of the upper San Pedro River". After establishment, the Bureau of Land Management closed the area to livestock grazing, and substantially reduced vehicular access and other uses. We sampled the fish assemblage at four sites annually in the spring during 1990-2003. We detected no change in species diversity. Native fauna was represented by longfin dace and desert sucker, which comprised 52% and 25% of the total catch (n = 5,347), respectively. Non-native species were western mosquitofish (9%), fathead minnow (6%), green sunfish and black bullhead (4% each), and largemouth bass and common carp (<1% each). Desert sucker exhibited a long-term downward trend in abundance; long-term trends of other species were static. During the sampling period, drought flows were the lowest on record, which significantly affected abundance of fish the following year. Aquatic habitats did not change qualitatively or quantitatively.

Investigaciones sistemáticas de la colección de peces del Río San Pedro, Arizona 1990-2003. Catorce años de monitoreo no indicaron cambios en la diversidad de especies y sólo algunos en la abundancia relativa de la colección de peces del Área Nacional de Conservación Ribereña San Pedro, Arizona. El congreso estableció el área en 1988 para "...conservar, proteger y mejorar los ecosistemas ribereños del desierto a lo largo de 61 kilómetros del alto Río San Pedro". Después de su establecimiento, la Oficina de Manejo de Tierras cerró el área a la pastura de ganado, y redujo de manera sustancial el acceso a vehículos y otros usos. Muestreamos la colección de peces en cuatro sitios anualmente en la primavera durante 1990-2003. No detectamos cambio en la diversidad de especies. La fauna nativa se representó por el pupo y el matalote del desierto, que componen 52% y 25% de la captura total (n=5,347), respectivamente. Las especies no nativas fueron el guayacón mosquito (9%), carpita cabezona (6%), mojarra verde y el bagre cabeza de toro negro (4% cada uno), lobina negra y carpa común (<1% cada una). El matalote del desierto exhibió una disminución en la tendencia a largo plazo en abundancia; las tendencias a largo plazo para otras especies fueron estáticas. Durante el período de muestreo, los flujos de sequía fueron los más bajos en los registros, lo que afecta de manera significativa a la abundancia de los peces en el año siguiente. Los hábitats acuáticos no cambiaron de manera cualitativa ni cuantitativa.

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The science and practice of ecosystem monitoring. Reliable information and an objective framework for inference will provide the foundation for effective monitoring programs. Quantitative information is sought increasingly for assessing changes in and making decisions about natural resources across all scales. The effectiveness of this information will depend on the approaches used to collect and analyze these data. Many parallel efforts to design broad-scale monitoring programs have been initiated recently, sharing the goal of providing a scientific foundation for managing natural resources. Although their objectives differ, they share challenges inherent in quantifying changes in resources through time. Designing monitoring programs requires balancing the need for high quality information with the constraints imposed by high natural variation and fiscal realities. Consequently, design requires choosing among an array of interrelated options for sampling that will dictate the quality and reliability of the information generated, the scope of inference to which they apply, and decisions based on these data. The only feasible alternative for design that will ultimately prove both effective and fiscally tenable is to target efficiency as a fundamental design goal. I will discuss a general framework for designing efficient monitoring programs that, in turn, aims to generate relevant, reliable data to inform conservation and management of natural resources.

La ciencia y práctica del monitoreo de ecosistemas. La información confiable y un marco de trabajo objetivo de inferencia brindan las bases para los programas de monitoreo eficaces. La información cuantitativa se busca cada vez más para evaluar los cambios y tomar decisiones acerca de los recursos naturales en todas las escalas. La eficacia de esta información depende de los métodos usados para reunir y analizar estos datos. Recientemente se iniciaron muchos esfuerzos paralelos para diseñar programas de monitoreo de amplia escala, compartiendo la meta de brindar una base científica para el manejo de los recursos naturales. Aunque sus objetivos son diferentes, comparten los retos inherentes para cuantificar los cambios en los recursos con el tiempo. El diseño de los programas de monitoreo requiere un equilibrio entre la necesidad de la información de alta calidad con las limitantes impuestas por la alta variación natural y las realidades fiscales. Por consiguiente, el diseño requiere elegir entre una gama de opciones interrelacionadas para muestrear lo que dictará la calidad y fiabilidad de la información generada, el campo de conclusión al que aplican y las decisiones basadas en esta información. La única alternativa viable para diseñar lo que ultimadamente probará ser eficaz y sostenible fiscalmente es dirigir la eficacia como meta fundamental del diseño. Discutiré el marco de trabajo general para diseñar programas de monitoreo eficaces que, a su vez, tienen el propósito de generar datos relevantes y confiables para la conservación y manejo de los recursos naturales.

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Biogeography of amphibians and reptiles in Arizona. Arizona is an international destination for herpetologists and is recognized for its high species diversity, which at last count includes one salamander, 25 anurans, 33 lizards, 51 snakes, and six turtles. Interestingly, popular field guides commonly list species distributions in relation to plant communities, elevation range, or geographic area; however, very few state-wide biogeographic analyses specific to these taxa have been conducted. Building on work by Duellman and Sweet, we examine patterns of species richness for amphibians and reptiles in Arizona according to natural regions. In this paper, we summarize community structure according to these regions and examine correlations with elevation, and species range. We determine similarities between regional faunas by calculating Duellman's coefficient of biogeographic resemblance. A major goal of our work is to highlight the significance of the contribution of the Madrean Archipelago region relative to the overall diversity of herpetofauna in Arizona.

Biogeografía de los anfibios y reptiles en Arizona. Arizona es un destino internacional para los herpetólogos y se reconoce por su alta diversidad de especies, que en su última cuenta incluye una salamandra, 25 anuros, 33 lagartijas, 51 víboras y seis tortugas. Curiosamente, las guías de campo populares enumeran la distribución de las especies en relación con las comunidades de plantas, el rango de elevación o el área geográfica; sin embargo, se han realizado muy pocos análisis biogeográficos estatales específicos a este taxa. A partir del trabajo de Duellman y Sweet, examinamos los patrones de la riqueza de las especies de anfibios y reptiles en Arizona según las regiones naturales. En este trabajo, resumimos la estructura de la comunidad según estas regiones y examinamos las correlaciones con la elevación, y distribución de especies. Determinamos las semejanzas entre las faunas regionales calculando el coeficiente de Duellman de parecido biogeográfico. Una meta principal de nuestro trabajo es recalcar la importancia de la contribución de la región del Archipiélago Madrense a la diversidad general de la herpetofauna en Arizona.

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Tamarisk populations along the San Pedro River: trends and environmental influences. Tamarisk (*Tamarix ramosissima*) has been present along the San Pedro River since at least the 1950s. Many environmental processes, including ground water flows, river flooding, and livestock grazing, influence the spatial and temporal patterns of abundance of this shrub species. Spatially, tamarisk has greatest densities in the driest river reaches (those with less frequent stream flow and deeper and more fluctuating groundwater) and is least abundant at wetter sites dominated by Fremont cottonwood and Goodding willow trees. Temporal patterns of abundance vary spatially across the river. Tamarisk appears to be increasing in abundance (relative to cottonwood and willow) in some reaches but declining or remaining constant in others. Tree core data and a recruitment model developed for the river both suggest that winter flood conditions in recent decades have favored cottonwoods and willows. Thus, recent increases in tamarisk at some sites may indicate the influence of other processes, such as progressive site dewatering.

Poblaciones de tamarisco a lo largo del Río San Pedro: tendencias e influencias ambientales. El tamarisco (*Tamarix ramosissima*) has estado presente a lo largo del Río San Pedro desde al menos 1950. Muchos procesos ambientales, incluyendo los flujos de agua subterránea, la inundación del río y el pastoreo del ganado, influyen en los patrones espaciales y temporales de abundancia de esta especie. Espacialmente, el tamarisco tiene grandes densidades en las áreas más secas del río (las que tienen menos flujo frecuente y agua subterránea más profunda y con menor fluctuación) y menor abundancia en los sitios más húmedos dominados por árboles de álamo y sauce. Los patrones temporales de abundancia varían espacialmente a lo largo del río. El tamarisco parece aumentar en abundancia (en relación al álamo y sauce) en algunas áreas pero disminuye o permanece constante en otras. Los datos de núcleo de árboles y el modelo de reclutamiento desarrollado para el río sugieren que las condiciones de inundación en invierno en décadas recientes han favorecido a los álamos y a los sauces. Así, los aumentos recientes en el tamarisco en algunos sitios puede indicar la influencia de otros procesos, tales como la disminución progresiva del agua en el sitio.

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Dispersal and colonization by non-native American bullfrogs in a Sonoran Desert grassland setting. In 1999, we drained ponds and apparently successfully removed bullfrog populations from the core of Buenos Aires National Wildlife Refuge, Pima County, Arizona. Over the subsequent 9 weeks, an apparent wave of migrating bullfrogs was found at these and other ponds and pools at ca. 1 - 11 km from presumed emigration sources near the refuge. In 2000, 2002, and 2003, we cohort-marked bullfrogs at the presumed sources, and kept refuge ponds free of bullfrogs by collecting any that arrived. In dry summers, marked bullfrogs were only recovered at 3.2 and 6.4 km dispersal distances, and bullfrogs were absent further into the refuge. During 2003 (a wet summer), marked frogs were confirmed at 9.6 km and presumed migrants were seen at >11 km from known source populations. Immigrants at two normally dry sites ca. 3 - 4 km from sources were so numerous, and grew so rapidly, that by September 2003, two months after pond filling, the site superficially resembled an established, permanent population. This suggests that studies evaluating bullfrog population dynamics cannot rely on instantaneous measures of abundance, but should include knowledge of population history. The observed dispersal distances present additional difficulties for bullfrog control.

Dispersión y colonización de ranas toro no nativas en pastizales del Desierto Sonorense. En 1990, secamos estanques y aparentemente eliminamos con éxito las poblaciones de ranas toro del núcleo del Refugio Nacional de Vida Silvestre Buenos Aires, Condado de Pima, Arizona. En las siguientes 9 semanas, una aparente ola migratoria de ranas toro se encontró en este y otros estanques y charcas a 1-11km a la redonda de las supuestas áreas de emigración cerca del refugio. En 2000, 2002 y 2003, marcamos a las ranas toro en las supuestas fuentes, y mantuvimos los estanques del refugio sin ranas colectando todas las que llegaran. En los veranos secos, sólo se recuperaron las ranas marcadas a 3.2 y 6.4 km de distancia y estuvieron ausentes en otras partes del refugio. Durante 2003 (un verano húmedo), las ranas marcadas se confirmaron a 9.6 km y los supuestos emigrantes se observaron a >11 km de las poblaciones con fuente conocida. Los inmigrantes en dos sitios normalmente secos a 3-4km de las fuentes eran tan numerosos y crecieron tan rápido que para septiembre 2003, dos meses después de que se llenaron los estanques, el sitio asemejaba superficialmente una población establecida permanente. Esto sugiere que los estudios que evalúan la dinámica de las poblaciones de rana toro no pueden confiar en las medidas instantáneas de abundancia, pero deben incluir conocimiento de la historia de la población. Las distancias de dispersión observadas presentan dificultades adicionales para el control de la rana toro.

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The Arizona striped whiptail: past and present. We surveyed historic and nearby collecting localities for *Cnemidophorus arizonae* (= *Aspidoscelis arizonae*) in Cochise and Graham Counties, Arizona, during spring and summer, 2000-2003. *Cnemidophorus arizonae* was present at or nearby all of the historic sites (eight) that we surveyed located near Willcox (within 10 km), but not the type locality 40 miles to the west at Fairbank nor the Whitlock Valley 40 miles to the northeast in Graham County. The Desert Grassland Whiptail, *C. uniparens,* was present at most sites unoccupied by *C. arizonae*, including the type locality; three sites were occupied by both taxa. Cattle grazing was apparent at virtually all sites occupied by either species; *C. arizonae* was associated with relatively open grasslands whereas *C. uniparens* was often found in habitats with numerous invader (e.g., mesquite) shrubs. Currently, *C. arizonae* is restricted to the northeastern edge of the Willcox Playa in the vicinity of Willcox, although there are at least two disjunct populations roughly 35 km north of Willcox, near Bonita, Graham County. Interestingly, analysis of historic collections indicates that the present distribution of *C. arizonae* may have been largely unchanged over the past 100 years.

El huico liso de Arizona: pasado y presente. Estudiamos sitios históricos y cercanos de recolección para *Cnemidophorus arizonae* (= *Aspidoscelis arizonae*) en los municipios de Cochise y Graham, Arizona, durante la primavera y verano, 2000-

2003. *Cnemidophorus arizonae* estuvo presente en casi todos los sitios históricos (ocho) que estudiamos ubicados cerca de Willcox (a 10km), pero no en el sitio ubicado a 40 millas al oeste en Fairbank ni en el Valle de Whitlock a 40 millas al noreste del municipio de Graham. El huico de la pradera del desierto, *C. uniparens,* estuvo presente en la mayor parte de los sitios que no estaban ocupados por *C. arizonae*, incluyendo el tipo de ubicación; tres sitios estaban ocupados por ambos taxa. El pastoreo de ganado era aparente en virtualmente todos los sitios ocupados por alguna de las especies; *C. arizonae*, estaba asociada con los pastizales relativamente abiertos, mientras que *C. uniparens* con frecuencia se encontraba en hábitats con numerosos invasores (por ejemplo el mesquite). Actualmente, *C. arizonae* está restringida al extremo noreste de Playa Willcox en los alrededores de Willcox, aunque existen al menos dos poblaciones separadas a casi 35 km al norte de Wilcok cerca de Bonita, en el municipio de Graham. Curiosamente, los análisis de las colecciones históricas indican que la distribución actual de *C. arizonae* puede haber permanecido sin cambio en los últimos 100 años.

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In search of the Madrean Line: biogeography of herpetofauna in the Sky Island region. In 1992 the eminent herpetologist Charles H. Lowe proposed what he believed was the major partition in distribution of reptiles and amphibians of southern Arizona and New Mexico and northern Sonora and Chihuahua, Mexico. Specifically, he proposed that herpetofauna were divided between the Madrean Archipelago, to the south, and the Rocky Mountains, to the north, along a lower-elevation barrier that parallels Interstate 10. This biogeographic Madrean Line, Lowe stated, was "as sharp as the world's most famous one, Wallace's Line, which divides the Malay Island Archipelago in two" (Lowe 1992). Using updated species lists and GIS technology not available to Lowe, our goal is to statistically explore the location of the Madrean Line and evaluate the probability that a well-defined line actually exists. We summarize existing data for montane reptiles and amphibians, evaluate the quality of data in the U.S. and Mexico, then define community distribution limits with a range of confidence intervals. We also use climatological and geographic data to develop and evaluate simple explanatory models for the distribution of reptiles and amphibians in the northern Madrean Archipelago.

En busca de la línea madrense: biogeografía de la herpetofauna en la región de las Islas del Cielo. En 1992 el ilustre herpetólogo Charles H. Lowe propuso lo que creemos fue la división más importante en la distribución de reptiles y anfibios en el sur de Arizona y Nuevo México y el norte de Sonora y Chihuahua, México. Concretamente, propuso que la herpetofauna se dividiera entre el Archipiélago Madrense, al sur, y las Montañas Rocallosas, al norte, a lo largo de la barrera de baja elevación que corre paralela a la Interestatal 10. Esta línea madrense biogeográfica, afirmó Lowe, fue "tan marcada como la más famosa del mundo, la línea Wallace, que divide el archipiélago Malayo en dos" (Lowe 1992). Usando listas de especies actualizadas y la tecnología SIG que no estuvo disponible para Lowe, nuestra meta es explorar de manera estadística la ubicación de la línea madrense y evaluar la probabilidad de que verdaderamente existe una línea bien definida. Resumimos los datos existentes para los reptiles y anfibios, evaluamos la calidad de la información en los EE.UU. y México, luego definimos los límites de la distribución de la comunidad con un rango de intervalos de confianza. También usamos datos climáticos y geográficos para desarrollar y evaluar modelos sencillos para explicar la distribución de los reptiles y anfibios en el norte del Archipiélago Madrense.

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Certainties and uncertainties about fire history and climate variability in forests of the Madrean Archipelago. Detailed fire histories spanning more than three centuries have been reconstructed from tree-ring studies in dozens of forest stands within eight mountain ranges of the Madrean Archipelago. By their nature, individual fire scarred trees are typically incomplete point records of past fires that have burned around their bases. Fire scarred trees are also irregularly distributed across the landscape. As a consequence, there are uncertainties in fire frequency estimates, depending upon the extent and scale of sampling, compositing, and extrapolation. Nevertheless, comparisons of fire scar data with independent documentary records of fire occurrence, including mapped fire perimeters, reveals that fire scar records can produce highly accurate reconstructions of past spatial and temporal fire regime patterns. Moreover, broad spatial composites of fire scar records at the scale of landscapes and regions provide valuable time series for studying seasonal, interannual, and decadal variations in fire regime responses to climate variability. This paper will review what we know about fire history and climate variations in montane forests of the Madrean Archipelago, including what is relatively certain and uncertain. Additionally, we will discuss recommended uses of fire and climate history in management of these forest ecosystems.

Certezas e incertidumbres sobre la historia de los incendios y la variabilidad del clima en los bosques del Archipiélago Madrense. Las historias detalladas de incendios que abarcan más de tres siglos han sido reconstruidas a partir de los estudios de los anillos en árboles en decenas de bosques dentro de ocho cordilleras montañosas del Archipiélago Madrense. Por su naturaleza, los árboles individuales con cicatrices de incendios naturales son por lo general registros incompletos de incendios pasados que han ardido alrededor de sus bases. Los árboles con cicatrices de incendios también se encuentran distribuidos de manera irregular a lo largo del paisaje. Como consecuencia, existen incertidumbres en las estimaciones de frecuencia de los incendios, dependiendo de la extensión y escala del muestreo, composición y extrapolación. No obstante, las comparaciones de los datos de cicatrices de incendios con registros independientes de la ocurrencia de los incendios, incluyendo los

perímetros mapeados de los incendios, revelan que los registros de cicatrices de incendios pueden producir reconstrucciones muy precisas de los patrones espaciales y temporales de incendio del pasado. Además, los amplios compuestos espaciales de los registros de cicatrices de incendios a escala de paisajes y regiones brindan series de tiempo valiosas para estudiar las variaciones estacionales, interanuales y por década en los incendios como respuesta a la variabilidad del clima. Este trabajo revisará lo que conocemos acerca de la historia de los incendios y las variaciones del clima en los bosques de montaña del Archipiélago Madrense, incluyendo lo que es relativamente cierto e incierto. Además, discutiremos los usos recomendados de los incendios y la historia del clima en el manejo de los ecosistemas forestales.

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Varmint control in Cochise county, Arizona over the years. With Anglo settlement of Cochise County came an impetus towards trophy hunting as well as killing of animals considered dangerous or pesky, from major predators to skunks and rodents. In the case of the Mexican gray wolf and the grizzly bear, the impact on animal populations was severe. Other species such as coyotes were far more resilient and annual kill numbers remained relatively constant for decades.

This paper traces the history of governmental predator and rodent control programs in southeastern Arizona and introduces anecdotal historical information about other forms of hunting. The various forms of "control" are discussed, including trapping, shooting, and use of poisons. In addition, the paper discusses motivations for control programs, such as rabies control, protection of livestock, protection of crops, and direct threats to human life, and also discusses changing public attitudes. Finally, the paper briefly mentions activities on the Sonoran side of the border where records are fewer and historical official records virtually nonexistent.

Control de animales indeseables en el condado Cochise Arizona a través de los años. Con el establecimiento de los anglos en el condado Cochise vino un ímpetu hacia la casa de trofeos así como el matar animales considerados dañinos o molestos, desde grandes depredadores hasta zorrillos y roedores. En el caso del lobo gris mexicano y del oso grizzly, los impactos sobre las poblaciones animales fueron severas. Otras especies como los coyotes fueron más resistentes y los números de asesinatos anuales permanecieron relativamente constantes por décadas.

Este artículo traza la historia de programas gubernamentales para el control de depredadores y de roedores en el sureste de Arizona e introduce información histórica anecdótica sobre otras formas de cacería. Las diversas formas de "control" son discutidas incluyendo las trampas la cacería y el uso de venenos. Adicionalmente, el artículo discute las motivaciones para los programas de control tales como el control de la rabia, protección del ganado, protección de cultivos y amenazas directas a los seres humanos y discute también los cambios en las actitudes públicas. Finalmente el artículo menciona brevemente las actividades en el lado sonorense de la frontera donde los datos son más reducidos y los registros históricos oficiales virtualmente no existen.

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Southwest regional gap analysis project: keeping common species common in the Madrean Archipelago. The Southwest Regional Gap Analysis Project (SWReGAP) is an update of the Gap Analysis Program's mapping and assessment of biodiversity for the five-state southwest region including the Madrean Archipelago within the US. This gap update is creating detailed, seamless GIS maps of land cover, native terrestrial vertebrate species, and land stewardship. Subsequent analysis of these layers will identify those elements that are underrepresented on conservation managed lands, i.e. the "gaps" in conservation management. While the SWReGAP analysis will not be complete until late spring 2005 the status of the three GIS components of the project for the Madrean Archipelago are presented. Land cover of natural and semi-natural vegetation has been mapped as ecological systems. Ecological systems are biogeographical aggregations of National Classification System associations developed by Nature Serve. Vertebrate species distribution maps are developed by applying habitat relationship models to the land cover map and maps of other environmental factors important in describing the species distribution. Land stewardship maps provide land ownership, managing institutions, and four levels of management status based on the degree of maintenance for biodiversity.

Proyecto regional del suroeste de análisis GAP: conservando comunes a las especies que son comunes en el Archipiélago Madrense. El Proyecto Regional del Suroeste de Análisis GAP (SWReGAP, por sus siglas en inglés) es una actualización del mapeo y evaluación de la biodiversidad del Programa del Análisis GAP para los cinco Estados del suroeste incluyendo el Archipiélago Madrense, dentro de los Estados Unidos. Esta actualización del GAP esta creando mapas detallados en SIG de cobertura terrestre de especies de vertebrados terrestres nativos y tenencia de la tierra. El análisis subsecuente identificará a aquellos elementos que están sub-representados en las tierras de manejo conservacionista, por ejemplo los "gaps" en el manejo conservacionista. Ya que el análisis SWReGAP no estará completo hasta la primavera del 2005, el estatus de los tres componentes SIG del proyecto para el Archipiélago Madrense es presentado aquí. La cobertura terrestre de la vegetación natural y semi natural ha sido mapeada como sistemas ecológicos. Los sistemas ecológicos son agregaciones biogeográficas de asociaciones del sistema nacional de clasificación desarrollado por el Nature Serve. Los mapas sobre la distribución de especies de vertebrados son creados mediante la aplicación de modelos de relación del hábitat desarrollados dentro del proyecto SWReGAP para el mapa de cobertura vegetal y para los mapas de otros factores ambientales identificados como importantes en la descripción de la distribución de especies. Los mapas de tenencia de la tierra proporcionan el tipo de propiedad, las instituciones que la manejan y cuatro niveles de status de manejo basados en el grado de mantenimiento para la biodiversidad.

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Environmental change at Kartchner Caverns: trying to separate natural and anthropogenic changes. Environmental variables such as cave temperature and moisture levels are important factors in the environmental health of Kartchner Caverns. Monitoring of these variables over the past 14 years indicates that cave temperatures have warmed and moisture levels have fallen. Timing of changes and patterns of change within the cave may indicate that the changes are due to development or the cave as a show cave. However, changes in these variables in other (non-developed caves), surface temperature and precipitation changes, and changes in shallow aquifers near the cave all suggest that changes may relate to regional climate patterns. Almost certainly, the changes being recorded at Kartchner Caverns represent a combination of these anthropogenic and regional natural causes. Separating the contributions of these different factors is an important goal in furthering the protection of the cave. Continued and expanded monitoring of Kartchner Caverns and other caves in the region will aid in both cave protection and in understanding how caves in the area respond to changing climates.

Cambio ambiental en las Cavernas Kartchner: tratando de separar los cambios naturales y antropogénicos. Las variables ambientales tales como la temperatura y los niveles de humedad de la cueva son factores importantes en la salud ambiental de las cavernas Kartchner. El monitoreo de estas variables en los últimos 14 años indica que las temperaturas de la cueva se han calentado y los niveles de humedad han caído. El tiempo de los cambios y los patrones de cambio dentro de la cueva pueden indicar que los cambios son debidos al desarrollo. Sin embargo los cambios en estas variables en otras (cuevas no desarrolladas), los cambios en la temperatura superficial y en la precipitación y los cambios en acuíferos someros cerca de la cueva, sugieren que los cambios pueden relacionarse a patrones de clima regional. Casi ciertamente, los cambios que están siendo registrados en las cavernas Kartchner representan una combinación de estas causas antropogénicas y regionales naturales. El separar las contribuciones de estos factores diferentes, es una meta importante para continuar con la protección de la cueva. La continuación y expansión del monitoreo de las cavernas Kartchner y otras cuevas de la región, ayudará en la protección y entendimiento de cómo las cuevas del área responden a los climas cambiantes.

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Kartchner Caverns State Park: approaches to protecting a delicate environment during development and tours. Kartchner Caverns is a humid, highly decorated cave in southeastern Arizona. When it was discovered in 1974, it was identified as being vulnerable to destruction through carelessness. It was kept secret by a small group of people until it was purchased by Arizona State Parks in 1988. Between 1988 when Parks acquired the cave and 1999 when the park opened to the public, State Parks studied the cave, designed plans to develop the cave and park, and constructed both surface and underground facilities at the Park. The over-riding goal in developing the park was to "Develop Kartchner Caverns for public viewing and education while preserving the cave in as pristine a condition as possible." Many of the steps that State Parks undertook in trying to achieve this goal are applicable to other environmental development while some are unique to the cave environment. The importance of comprehensive study of the area and environmental system before developing plans for the area cannot be over-emphasized. Another crucial component of protection is continued monitoring during development and tourism and a willingness to alter operations in response to new information, and monitoring results. Poster.

Parque Estatal Caverna Kartchner: métodos para proteger un ambiente delicado durante el desarrollo y las excursiones. Las cavernas Kartchner constituyen una cueva húmeda altamente decorada, en el Sureste de Arizona. Cuando fue descubierta en 1974, fue identificada como vulnerable a la destrucción a través del descuido. Fue conservada en secreto por un pequeño grupo de gentes hasta que fue comprada por el Arizona State Parks in 1988. Entre 1988, cuando la agencia estatal de parques adquirió la cueva y 1999, cuando el parque se abrió al público, la agencia estatal estudió la cueva, diseñó planes para desarrollar tanto la cueva como el parque y construyó edificios superficiales y subterráneos en el parque. La meta a seguir en el desarrollo del parque fue "desarrollar las cavernas Kartchner para la observación y educación del público y a la vez conservar la cueva en una condición lo más natural como fuera posible". Muchas de las etapas que la agencia estatal de parques sobrellevó al tratar de realizar esta meta, son aplicables a otros desarrollos ambientales mientras que otros son únicos para el ambiente de la cueva. La importancia del estudio comprensivo del área y del sistema ambiental antes de desarrollar planes para el área, no debe ser sobre enfatizada. Otro componente crucial de protección es el monitoreo continuo durante el desarrollo y el turismo y una buena voluntad para alterar las operaciones en respuesta a la nueva información y a los resultados del monitoreo. Póster.

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Proposed wildland fire amendment to the Coronado National Forest Land and Resource Management Plan. The Land and Resource Management Plan (LRMP), approved in 1986, reflects agency fire management policy at that time. Fire management direction was to "develop the most cost efficient operations for fire management activities depending on the resources, property, and lives to be protected." Under the 1986 LRMP, the fire suppression objective is to manage wildland fires at a minimum cost consistent with land and resource management objectives and fire management direction. The Forest Service proposes to amend the Coronado's 1986 Forest Land and Resource Management Plan to align it with the 1995 Federal Wildland Fire Management Policy as revised in 2001. This policy recognized the essential role of fire in maintaining natural systems and allowing managers more options when responding to wildland fires. Currently, suppression is the only fire management option allowed by the LRMP in areas outside of congressionally designated wildernesses, wilderness study areas, and research natural areas. The proposed amendment would allow fire managers discretionary use of a full spectrum of fire management options from aggressive initial attack to managing natural ignitions for resource benefits. Discretionary use of wildland fire is essential to reducing hazardous fuels and sustaining wildland ecosystems.

Enmienda propuesta sobre el fuego en areas naturales al Plan de Manejo de Tierras y Recursos del Bosque Nacional Coronado. El Plan de Manejo de Tierras y Recursos (LRMP, por sus siglas en inglés), aprobado en 1986, refleja la política de la agencia sobre manejo de fuego en esa época. La dirección en el manejo de fuego fue "desarrollar las operaciones mas eficientes en costo para el manejo de actividades de fuego dependiendo en los recursos, propiedad y vidas a ser protegidas". Bajo el LRMP de 1986, el objetivo de supresión del fuego es manejar los fuegos en áreas naturales a un costo mínimo y de acuerdo con los objetivos del manejo de tierras y recursos y la dirección en el manejo del fuego. El servicio forestal propone enmendar el plan de 1986 sobre manejo de tierras y recursos forestales del Bosque Nacional Coronado para alinearlo con la política federal de 1995 sobre manejos de fuegos en áreas naturales, la cual fue revisada en 2001. Esta política federal sobre el fuego reconoció el papel esencial del fuego en mantener los sistemas naturales y permitir a los manejadores un amplio rango de acciones al responder a los incendios en áreas naturales. Actualmente, la supresión es la única opción de manejo del fuego permitida por el LRMP en áreas fuera de las que son designadas congrecionalmente como naturales, áreas naturales bajo estudio y áreas naturales de investigación. La enmienda propuesta permitirá a los manejadores de fuego el uso discreto de un completo espectro de opciones del manejo del fuego desde un ataque inicial agresivo hasta el manejo de igniciones naturales en beneficio de los recursos. El uso indiscreto del fuego en áreas naturales es esencial para reducir combustibles peligrosos y sostener ecosistemas naturales.

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Vegetation in transition: the southwest's dynamic past century. Matched photographs duplicating scenes first recorded on film during the period just before and after 1900 reveal changes that range from dynamic to nonexistent. The photographs sample vegetation at camera stations ranging from extremely arid near the Gulf of California to mesic in the mountains of southern Arizona. The photographic analysis of change is based upon several hundred sets of matched photographs housed at the USGS Desert Laboratory Photograph Archive. Interpretation of the observed changes is strengthened by results from permanent long-term study plots, established from 44 to 97 years ago at sites across the region.

Vegetación en transición: el dinámico siglo pasado del suroeste. Fotografías apareadas que duplican escenas gravadas primeramente en películas durante el periodo antes y después de 1900, revelan cambios que van de lo dinámico a lo inexistente. Las fotografías muestran vegetación en estaciones de cámara que van desde lo extremadamente árido cerca del golfo de California a lo mésico en las montañas del sur de Arizona. El análisis fotográfico de cambio esta basado en varios cientos de grupos de fotografías apareadas depositadas en el USGS Desert Laboratory Photograph Archive. La interpretación de los cambios observados se refuerza con resultados de largo tiempo en parcelas de estudio permanentes, establecidas hace 44 a 97 años en sitios distribuidos a lo largo de la región.

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Conservation priorities in the Apache Highlands ecoregion. The Apache Highlands ecoregion spans 12 million hectares (30 million acres) in the U.S. and Mexico. It incorporates the entire Madrean Archipelago/ Sky Island region, along with a large strip of biotically-similar lands extending northwest. To identify conservation priorities and strategies for this ecoregion, we analyzed the current distribution of 223 target species and 26 terrestrial ecological systems. These were compared with a weighted road density and other constraints on ecosystem integrity, using an optimization algorithm to determine the most efficient set of areas needed to maintain current biodiversity. We also analyzed major threats to biodiversity and the status of land stewardship across the ecoregion. The result is a portfolio of 90 sites that include 5 million ha (12.5 million ac). The map of these sites will guide future conservation action by The Nature Conservancy, and may offer useful insights to others concerned with biodiversity. Several overarching strategies were identified, including the need for protection and restoration of grasslands, restoration or maintenance of natural fire regimes, and better understanding of probable effects of climate change.

Prioridades de conservación en la región ecológica del Altiplano Apache. La Región Ecológica del Altiplano Apache se extiende sobre 12 millones de hectáreas (30 millones de acres) en los Estados Unidos y México. Ella incorpora en su totalidad a la región Archipiélago Madrense/Islas del Desierto a lo largo de una gran franja de tierras bióticamente similares que se extiende hacia el noroeste. Para identificar las prioridades y estrategias de conservación para esta ecoregión, analizamos la distribución actual de 223 especies objetivo y 26 sistemas ecológicos terrestres. Estos fueron comparados con una densidad de caminos ponderada y otras obligaciones sobre la integridad del ecosistema, utilizando un algoritmo de optimización para determinar el grupo más eficiente de áreas necesarias para mantener la biodiversidad actual. También analizamos las mayores amenazas para la biodiversidad y el estatus de la tenencia de la tierra a lo largo de la ecoregión. El resultado es un portafolio de 90 sitios que incluyen 5 millones de hectáreas (12.5 millones de acres). El mapa de estos sitios guiará la acción futura de conservación de The Nature Conservancy, y puede ofrecer intuiciones útiles para otros interesados con la biodiversidad. Varias estrategias "umbrela" fueron identificadas, incluyendo la necesidad de protección y restauración de pastizales restauración o mantenimiento de regimenes naturales de fuego y un mejor entendimiento de probables efectos del cambio climático.

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Identifying areas of conservation priority for native fishes in the Southwest using GIS. The American Southwest provides a stark example of a depauperate and unique native fish fauna decimated by environmental depredation, introduced non-native species, and other factors. The fauna has declined to the point where most species are biologically imperiled. Due to the restricted availability of surface water and concern for the continued existence of the fauna, the region has been intensively sampled and substantial records exist from which to build a database. This "Minckley Sonfishes" database was compiled from museum records, primary, and "gray" literature and contains over 54,000 individual fish records for Southwestern drainages. Data were geographically referenced using GIS. Several components were incorporated into determining conservation priorities: present day richness for native species, threatened and endangered species richness, percentage and absolute decline in native fishes, and non-native species richness. Our results consist of a table containing those factors outlined above summarized by watersheds and stream reaches. These can then be easily graphically displayed and manipulated. The discussion will focus on various aspects relating to choosing between alternative conservation schemes as well as identifying areas of high conservation significance. A sample dataset is available from www.peter.unmack.net/gis/fish/colorado.

Identificando áreas prioritarias para la conservación de peces nativos en el Suroeste utilizando un SIG. El suroeste americano proporciona un crudo ejemplo de una fauna de peces empobrecida y única que ha sido diezmada por la depredación ambiental, especies introducidas no nativas y otros factores. La fauna ha disminuido a un punto donde la mayoría de las especies están biológicamente en peligro. Debido a la restringida disponibilidad de agua superficial y al interés por la continuación de la existencia de la fauna, la región ha sido intensivamente muestreada y existen datos substanciales con los que se puede crear una base de datos. Esta base de datos, llamada base de datos "Minckley Sonfishes," fue compilada de datos de museos, principalmente, y de literatura "gris" y contiene mas de 54,000 datos individuales sobre peces de las corrientes del suroeste. Los datos fueron geográficamente referenciados usando un SIG. Varios componentes fueron incorporados para determinar las prioridades de conservación: riqueza para especies nativas a la fecha, riqueza de especies amenazadas y en peligro, disminución porcentual y absoluta en peces nativos y riquezas de especies no nativas. Nuestros resultados consisten en una tabla que contienen los datos mencionados anteriormente en forma resumida por cuencas hidrológicas y corrientes. Estos pueden ser entonces fácilmente desplegados y manipulados gráficamente. La discusión se enfocará en varios aspectos relacionados a escoger entre esquemas alternativos de conservación, así como identificar áreas de alta conservación significativa. Una muestra de una serie de datos esta disponible en www.peter.unmack.net/gis/fish/colorado.

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Threats to cross-border wildlife linkages in the Sky Islands wildlands network. One of the greatest challenges facing conservationists in the Sky Islands region is finding a realistic means to maintain historic cross-border travel routes for wide-ranging species. This challenge is made difficult due to the perceived need of the federal government to install security infrastructure to stem the cross-border flow of undocumented aliens. Existing and proposed fencing, all-night lighting, vehicle barriers, roads, and low-level aircraft overflights are creating an impenetrable barrier to wildlife movement. Creative solutions are needed.

Amenazas para los enlaces de la vida silvestre a lo largo de la frontera en la red de terrenos naturales de las Islas del Cielo. Uno de los grandes desafíos que enfrentan los conservacionistas en la región de las islas del cielo es encontrar un significado realista para mantener las rutas históricas a través de la frontera para que viajen las especies de amplio rango. Este desafió se a hecho difícil debido a la necesidad del gobierno federal por instalar infraestructura de seguridad para detener el flujo de personas indocumentadas a través de la frontera. El cercado existente y propuesto, el alumbrado que dura toda la noche, barreras contra vehículos y vuelos de aviones a bajo nivel, están creando una barrera impenetrable para el movimiento de la fauna. Se necesitan soluciones creativas.

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The forgotten flora of la frontera. The border region in northeastern Sonora has been neglected botanically for over a century. Grassland and Chihuahuan desertscrub extend across the border from Arizona. Isolated Sky Island mountains support oak woodland and pine-oak forest in the northwestern outliers of the Sierra Madre Occidental, the Apachean Highlands Ecoregion. Foothills thornscrub occurs within 100 km of the border in a series of north-south river valleys. In 2001-2003, over 1500 plant collections including 177 species with few or no previous Sonoran records were made within 50-100 kilometers of the Arizona border in the municipios of Agua Prieta, Bacoáchi, Cananea, Fronteras, Imuris, Magdalena, Naco, Nacozari de García, Nogales, Santa Cruz, Sáric, and Tubutama. Specimens were deposited into the herbaria at the University of Arizona, Universidad de Sonora, and many others in Mexico and the United States. Forty-three species, including 12 native to the Old World, are new for Sonora. Thirteen species including six non-native weeds appear to be the first records for Mexico. Several collections of buffelgrass (*Pennisetum ciliare*) in Chihuahuan desertscrub at 1235-1320 m elevation east of Agua Prieta are high elevation records for this aggressive African savanna grass. These data will be important for regional conservation activities.

La flora olvidada de la frontera. Por más de un siglo, los botánicos no le han dado importancia a la región fronteriza del noreste de Sonora. Aquí es donde los pastizales y el matorral del desierto Chihuahuense se extienden desde los límites con Arizona; las montañas aisladas 'islas del cielo' ubicadas en los macizos más occidentales de la Sierra Madre Occidental, en lo que se conoce como la Región Ecológica del Altiplano Apache, contienen bosques de encino y de pino-encino. Del mismo modo, el matorral espinoso de pie de monte se presenta a 100 km de la frontera siguiendo una serie de valles ribereños que corren de norte a sur. El área considerada comprende desde la frontera con Arizona hasta 50-100 km de la misma en los municipios de Agua Prieta, Bacoáchi, Cananea, Fronteras, Imuris, Magdalena, Naco, Nacozari de García, Nogales, Santa Cruz, Sáric y Tubutama. Del 2001 al 2003 se hicieron más de 1500 colectas de herbario, incluyendo 176 especies con ningún o muy pocos registros para Sonora. Los ejemplares botánicos se depositaron en los herbarios de la University of Arizona, la Universidad de Sonora y otros en México y en los Estados Unidos. Cuarenta y tres especies, doce de ellas nativas al viejo continente, son registros nuevos para Sonora. Trece especies, incluyendo seis malezas exóticas, parecen ser los primeros registros para México. Así mismo se hicieron varias colectas del zacate buffel (*Pennisetum ciliare*) en el matorral del desierto Chihuahuense en elevaciones de 1235 a 1320 m al este de Agua Prieta. Estas colectas se consideran registros de elevaciones altas para este agresivo zacate de la sabana Africana. Toda esta información se considera de vital importancia para los esfuerzos de conservación en la región.

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Habitat partitioning by neotropical migrant birds along the lower Colorado River corridor. We examined foraging ecology of spring and fall migrant birds in native and introduced vegetation habitat patches along the Rio Hardy and Rio Colorado in Sonora, Mexico, and Cibola and Bill Williams National Wildlife Refuges in Arizona. We found that species' arrival and departure dates were more predictable during the spring migration period. Plant species abundance and phenology influenced location of warbler foraging. Preliminary analysis of foliage invertebrate samples revealed significant differences among tree species and particularly between native and introduced plants. Hence, access to different tree species in a vegetation patch (e.g. mesquite, which had the highest invertebrate numbers in our samples) may be important to foraging migrants. Warbler species partitioned foraging habitat in similar manners during migration, preferring native over introduced vegetation. Lucys Warblers preferred the highest vegetation strata, while Yellow Warblers occurred primarily in the middle foliage regions. Orange-crowned Warblers were observed most often in the lower third of the vertical vegetation strata, while Black-throated Grey, Wilson's, Nashville and MacGillivray's Warblers all preferred the lowest vegetation strata. We found a threshold of native plant species composition that appears to influence migrating warbler abundance, and this threshold is quite different for various avian guilds. It thus appears that plant species, structure, phenology, abundance, and insect prey base all affect migrating warbler foraging patterns along the lower Colorado River corridor. Poster.

División del hábitat por aves neotropicales migratorias a lo largo del corredor del bajo río Colorado. Examinamos la ecología de alimentación de aves migratorias de la primavera y el otoño en manchas de hábitat con vegetación nativa e introducida a lo largo del corredor del Río Hardy y el Río Colorado en Sonora, México y en los refugios nacionales Cibola y Bill Williams en Arizona. De nuestros censos y datos de captura con redes de niebla, encontramos que las fechas de arribo y salida de las especies fueron más predecibles durante el periodo de migración primaveral. Los patrones fenológicos y de abundancia de las especies vegetales influenciaron la ubicación de la alimentación del pájaro mosquitero. Análisis preliminares de muestras de invertebrados del follaje revelaron diferencias significativas entre especies de árboles y particularmente entre especies vegetales nativas e introducidas. De aquí que el acceso a diferentes especies de árboles en una mancha de vegetación (por ejemplo mezquite, el cual tuvo los números mas altos de invertebrados en nuestras muestras) puede ser importante para la alimentación de las aves migrantes. Encontramos que las especies de mosquiteros dividieron el hábitat de alimentación en maneras similares durante la migración, prefiriendo a la vegetación nativa sobre la introducida. Los mosquiteros Lucys prefirieron los estratos de vegetación más altos, mientras que los mosquiteros amarillos ocurrieron principalmente en las regiones de follaje medio. Los mosquiteros de corona anaranjada fueron observados más a menudo en el tercio inferior del estrato vertical de la vegetación, mientras que los mosquiteros grises de cuello negro, de Wilson, de Nashville y de MacGillivray prefirieron el estrato de vegetación mas bajo. Encontramos un umbral en la composición de especies vegetales nativas que parecen influenciar la abundancia de los mosquiteros migrantes dentro de las mancha de vegetación diferentes y este umbral es bastante diferente en varias sociedades de hábitat. Parece ser que las especies vegetales, estructura, fonología, abundancia y los insectos presa, juegan un papel en la estructura de los patrones de alimentación de los mosquiteros migrantes a lo largo del corredor del bajo Río Colorado. Póster.

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Transboundary ecosystem conservation, planning, and implementation: the findings of Border Institute VI. Biodiversity in the U.S.-Mexican binational/border region is vulnerable to various threats. Habitat loss to development, intense competition for water, multi-media pollution, invasive exotic species, illegal hunting, and trade of trophy species are all critical threats in the region. Focused binational attention and support is required to address the complex issues of mixed land ownership, water use, patchwork legal protection, and rampant economic development. The Border Institute, an annual binational think tank series, sponsored by SCERP (a consortium of U.S. and Mexican universities), EPA and SEMARNAT, the Border Trade Alliance, and the U.S.-Mexico Chamber of Commerce, (held in Rio Rico, Arizona in April 2004) will be dedicated to reconciling differences across the international border and jurisdictional boundaries to address coordinated collaboration for biodiversity, habitat, and ecosystem preservation and protection. Policy recommendations will be developed and disseminated to stakeholders on both sides of the border and to all sectors of civil society in the region. This talk will divulge solution sets developed at the conference. Some tools to be considered include binational land trusts, transfer of development rights, mitigation banks, eco-entrepreneurship, and critical habitat conservation plans.

Conservación, planificación e implementación de ecosistemas transfronterizos: los hallazgos del Instituto de la Frontera VI. La biodiversidad en la región fronteriza binacional E.E.U.U.-México es vulnerable ante varias amenazas. La pérdida del hábitat debido al desarrollo, la intensa competencia por agua, la contaminación multi-media, la invasión de especies exóticas, la cacería ilegal y el trato de especies trofeo, son amenazas criticas en la región. Se requiere una atención y soporte binacional enfocado a resolver los problemas complejos de mezclas en la tenencia de la tierra, uso del agua, protección legal fraccionada y desarrollo económico desenfrenado. El Instituto de la Frontera, una serie de pensamientos binacionales anuales, patrocinado por el SCERP (un consorcio de universidades mexicanas y americanas), el EPA y la SEMARNAT, la alianza para el tratado fronterizo y la Cámara de Comercio de USA-México (creado en Río Rico, Arizona en abril del 2004), estará dedicado a la reconciliación de diferencias a través de la frontera internacional y limites jurisdiccionales para sostener una colaboración coordinada para la biodiversidad, el hábitat y la preservación y protección del ecosistema. Se desarrollarán y diseminarán recomendaciones políticas a pequeños propietarios de ambos lados de la frontera y a todos los sectores de la sociedad civil de la región. Esta plática divulgara una serie de soluciones desarrolladas en la conferencia. Algunas herramientas para ser consideradas incluyen los tratados binacionales sobre tierras, la transferencia de derecho de desarrollo, bancos de mitigacion y planes críticos de conservación del hábitat.

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Sites of work on the upper San Pedro River basin on the Mexican side. On the San Pedro River we are working with two initiatives, both of them focused on restoration of soil and vegetation, with the goals of improving wildlife habitat and the compatibility of economic development like cattle raising. This is done with the help of a Geographical Information System, and some tools like ERDAS, ARCVIEW, IDRISI and ILWIS. The conservation targets are: groundwater-fed cienegas, black-tailed prairie dogs, nesting birds, aquatic communities, native grasslands, pine-oak forest from Sky Islands' communities, and riparian corridors. Our work consists of cattle exclusion from riparian corridors, gabions, extraction of mézquite, producing native grass seeds, replanting native vegetation, and installing hydraulic infrastructure for cattle hydration. On the other side are the agreements with the landowners and ejido owners to ensure the viability of our conservation targets in the basin. One important effort is the San Pedro Cross Border Team or San Pedro One River Team that has the objective of building a binational cooperative team that involves agencies and organizations interested in conservation of the San Pedro River watershed, serves as a model of cooperation for shared basins, improves planning and funding, and makes better decisions for the whole basin on both sides of the border. Poster.

Sitios de trabajo en la cuenca alta del Río San Pedro en el lado Mexicano. En el Río San Pedro, se esta trabajando con dos iniciativas enfocadas ambas a la restauración de suelos y vegetación, con las metas de mejorar el hábitat y la compatibilidad del desarrollo económico como la crianza de ganado. Esto se hace con la ayuda de sistemas de información geográfica y sus herramientas como son ERDAS, ARCVIEW, IDRISI e ILWIS. Los objetos de conservación son:- cienegas alimentadas por agua subterránea, perrito de la pradera de cola negra, aves anidantes, comunidades acuáticas, pastos nativos, bosques de pino-encino de las comunidades de las Islas del Cielo y corredores ribereño. Nuestro trabajo consiste en establecer exclusiones de ganado en los corredores ribereños, gaviones vegetativos o de piedra, extracción de mezquite, producción de semillas nativas, revegetación con plantas nativas y la instalación de infraestructura hidráulica para bebederos de ganado. El otro componente son los acuerdos con los propietarios privados y ejidatarios para asegurar la viabilidad de nuestros objetos de conservación. Un importante esfuerzo es la conformación del equipo transfronterizo del San Pedro (San Pedro cross border team), o el Un equipo para el Río San Pedro (San Pedro One River Team), cuyo objetivo es construir un equipo binacional de cooperación que envuelva agencias y organizaciones interesadas en la conservación de la cuenca del río san Pedro, para que sirva como un modelo de cooperación para cuencas compartidas, mejorar la planificación, fondos y acciones; y se puedan tomar mejores decisiones para toda la cuenca en ambos lados de la frontera. Póster.

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The Malpai Borderlands Group: a community-led effort to protect the "working wilderness" of the Sky Islands. One of the greatest conservation challenges facing the Sky Island region is the task of maintaining natural habitat connections across the valleys between mountain ranges for wildlife movement corridors, for watershed protection, and for the myriad biological values that depend on large, unfragmented landscapes. The Malpai Borderlands Group is a local landowner-led organization that has been working for ten years to protect and restore the borderlands region which encompasses the San Bernardino and Animas valleys and the Peloncillo and Animas mountains. This region covers over 800,000 acres, and includes the only contiguous woodland habitat linkage to the Sierra Madre Occidental of Mexico in the United States. The Malpai Group's work includes protecting the valley bottoms from subdivision through conservation easement agreements with ranchers, as well as restoration and sustainable management of grasslands and savanna woodlands through cooperative projects such as prescribed burning, grassbanking, and other projects that promote cooperation among ranchers in the region. So far, the group has protected 72,000 acres of private land with conservation easements, and it was instrumental in helping Coronado Forest conduct the 46,000 acre Baker II burn, the largest prescribed fire in U.S. history. The Group supports an extensive monitoring and research program to guide its cooperative management projects.

El Malpai Borderlands Group: un esfuerzo desarrollado por la comunidad para proteger "La Naturaleza Trabajando" en las Islas del Cielo. Uno de los retos mas grandes sobre conservación que enfrenta la región de las Islas del Cielo es el hecho de mantener las conexiones del hábitat natural a través de los valles entre los macizos montañosos para los corredores donde se mueve la fauna silvestre, para la protección de la cuenca hidrológica y para la gran cantidad de valores biológicos que dependen de paisajes no fragmentados y de gran tamaño. El Malpai Borderlands Group es una organización local de dueños de terrenos que ha estado trabajando por 10 años para proteger y restaurar las tierras fronterizas de la región las cuales abarcan los valles de San Bernardino y las Animas y las montañas Peloncillo y la Animas. Esta región cubre más de 400,000 hectáreas e incluye el único hábitat continuo de bosques ligado a la Sierra Madre Occidental de México, en los Estados Unidos. El trabajo del grupo Malpai incluye la protección de los suelos del valle de la subdivisión a través de acuerdos de conservación con los rancheros, así como la restauración y el manejo sostenible de pastizales y bosques de sabana mediante proyectos cooperativos tales como el fuego prescrito y otros proyectos que promueven la cooperación entre rancheros en la región. Así pues, el grupo a protegido 36,000 hectáreas de tierras privadas con servicios de conservación y fue un instrumento de ayuda para conducir el incendio Baker II de 23,000 hectáreas en el Bosque Coronado, el incendio prescrito más grande en la historia de los Estados Unidos. El grupo soporta un programa extensivo de monitoreo e investigación para guiar sus proyectos de manejo cooperativo.

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Hummingbird conservation: discovering diversity patterns in Southwestern USA. The Hummingbird Monitoring Network began in 2002 with the following goals: to determine the best long-term monitoring sites for hummingbirds in southwestern USA, to estimate hummingbird population sizes so that trends can be detected, and to use the resulting information to preserve and protect them. To accomplish these goals, we selected sites within the Madrean Archipelago region of Arizona and the isolated mountain ranges of southern California using geographic factors (elevation, latitude, and longitude) and vegetation types. Bird banding and other counting techniques are used to quantify the populations and patterns of diversity, levels of breeding activity, and stopover use during migration are used to evaluate each site's monitoring value. In 2002, we compared populations at 9 sites in Arizona and 2 in California. In 2003, we expanded to 14 in Arizona and 5 in California. At sites studied in both 2002 and 2003, hummingbird populations decreased significantly in 2003 in Arizona but not in California. Diversity patterns varied with elevation, where the mid-elevation sites supported the most species and the mid- to high-elevation sites had the greatest number of birds. Abundance patterns for common species differed among the Sky Islands, which suggests potential range and migration corridor boundaries.

Conservación de colibríes: descubriendo los patrones de diversidad en el suroeste del los Estados Unidos de América. La red de monitoreo de colibríes inició en 2002 con las siguientes metas: 1) determinar los mejores sitios de monitoreo a largo plazo para colibríes en el Suroeste de los Estados Unidos, 2) estimar los tamaños de las poblaciones de colibríes de tal manera que puedan ser detectadas sus tendencias y 3) usar la información resultante para preservarlos y protegerlos. Para alcanzar estas metas seleccionamos sitios dentro de la región del Archipiélago Madrense de Arizona y los macizos montañosos aislados del Sur de California usando factores geográficos (elevación, latitud y longitud) y tipos de vegetación. Bandadas de pájaros y otras técnicas de conteo son usadas para cuantificar las poblaciones y patrones de diversidad, niveles de consanguinidad y el uso de parajes durante la migración son usados para evaluar el valor de monitoreo de cada sitio. En 2002, comparamos poblaciones en 9 sitios en Arizona y 2 en California. En 2003, expandimos a 14 en Arizona y 5 en California. En los sitios estudiados, tanto en 2002 como en 2003, las poblaciones de colibríes disminuyeron significativamente en 2003 en Arizona, pero no en California. Los patrones de diversidad variaron con la elevación, donde los sitios con elevación media albergaron la mayoría de las especies y los sitios con elevación media a alta tuvieron el mayor número de aves. Los patrones de abundancia para las especies comunes difirieron entre las islas del cielo sugiriendo esto que existen fronteras de corredor potenciales de migración entre los macizos montañosos y los corredores.

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An alternative look at how disturbance regimes affect community dynamics: the influence of habitat complexity on ant/parasitoid interactions. The influence that a disturbance event such as fire or grazing has on natural communities is often studied through its direct effects on species abundance and diversity. A little-studied but important mechanism through which disturbance events can affect natural communities is changing the physical complexity of the habitat in which organisms interact. Indirect effects of habitat complexity on the outcome of species interactions may alter community composition. We applied a factorial design to investigate the importance of habitat complexity to interactions between the host ant *Pheidole diversipilosa*, its specialist parasitoid *Apocephalus sp. 8* and other competitor ant species. Decreased habitat complexity in the form of leaf litter had a significant negative effect on the number of soldiers colonies could maintain to harvest resources in the presence of parasitoids. This effect was more pronounced in the presence of competitors. However, increased habitat complexity may hinder a colony's ability to defend resources from competitors. These results suggest that disturbance events have the potential to affect the importance of top-down (parasite) and bottom-up (competitor) control over community structure if they alter habitat complexity. Fire and grazing would be expected to increase the relative importance of top-down (parasite) control over community structure.

Una visión alternativa hacia como los regimenes de disturbio afectan la dinámica de las comunidades: la influencia de la complejidad del hábitat sobre las interacciones hormiga/ parasitoide. La influencia que un evento de perturbación tal como el fuego o el pastoreo tiene sobre las comunidades naturales es a menudo estudiada a través de sus efectos directos sobre la abundancia y diversidad de las especies. Un mecanismo poco estudiado pero importante a través del cual los eventos de perturbación pueden afectar las comunidades naturales es cambiando la complejidad física del hábitat en el cual los organismos interactúan. Los efectos indirectos de la complejidad del hábitat sobre los resultados de las interacciones de las especies pueden alterar la composición de la comunidad. Nosotros implementamos un diseño factorial para investigar la importancia de la complejidad del hábitat para las interacciones entre la hormiga hospedera *Pheidole diversipilosa,* su parasitoide especialista *Apocephalus sp. 8* y otras especies de hormigas competidoras. La complejidad del hábitat disminuyó en la forma de que los restos de hojas tuvieron un efecto negativo significante en el número de colonias de soldados que podrían mantener para cosechar recursos en presencia de los parasitoides. Este efecto fue más pronunciado en presencia de competidores. Sin embargo la incrementada complejidad del hábitat puede dificultar la habilidad de la colonia para defender los recursos de los competidores. Estos resultados sugieren que los eventos de disturbio tienen el potencial para afectar la importancia del control de arriba hacia abajo (parásito) y de abajo hacia arriba (competidor) sobre la estructura de la comunidad si ellos alteran la complejidad del hábitat. Debería esperarse que el fuego y el pastoreo incrementaran la importancia relativa del control de arriba hacia abajo (parásito) sobre la estructura de la comunidad.

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Short-term effects of fire on Sky Island ant communities. Fire affects ant communities by changing the structure of habitat, such as the types of vegetation present, the amount of leaf litter, and the amount of available insolation. These structural changes can affect competitive interactions between species by reducing or increasing the number of dominant species present. Therefore, the composition of a burned area can be quite different from that of an unburned area. Few studies investigating effects of fire on ant communities have been conducted worldwide and none in the biologically diverse and fire prone region of the Sky Islands. To investigate any effects that fire may have on ant communities in the Sky Islands region, we established four plots, each with arrays of six pitfall traps in adjacent burned and unburned habitat, at the sites of two different fires. Measures of vegetation height, density, coverage, and richness were taken at all sample points. Based on preliminary examination of the data, ant diversity is significantly higher in burned areas, and this trend is the same at both fire sites. Predictable changes in species composition occur between unburned and burned sites, implying that the role of disturbance may be important for maintenance of diversity in Sky Island ant communities. Poster.

Efectos a corto plazo del fuego sobre comunidades de hormigas de las Islas del Cielo. El fuego afecta a las comunidades de hormigas cambiando la estructura del hábitat, tales como los tipos de vegetación presente, la cantidad de restos de hojas y la cantidad de insolación disponible. Estos cambios estructurales pueden afectar las interacciones de competencia entre especies al reducir o incrementar el número de especies dominantes presentes. Más aun, la composición de un área incendiada puede ser bastante diferente de un área no quemada. Se han realizado pocos estudios a nivel mundial que investiguen los efectos del fuego sobre comunidades de hormigas, y ninguno en la diversidad biológica y fuego en la región de las Islas del Cielo. Para investigar cualquier efecto que el fuego puede tener sobre comunidades de hormigas en la región de las Islas del Cielo, establecimos cuatro parcelas con arreglos de seis trampas en hábitats adyacentes incendiados y no incendiados, en los sitios de dos diferentes incendios. Se tomaron mediciones de altura, densidad, cobertura y riqueza de vegetación en todos los puntos de muestreo. Basados en un examen preliminar de los datos, la diversidad de hormigas es significativamente más alta en áreas incendiadas y esta tendencia es la misma para ambos sitios incendiados. Cambios predecibles en la composición de especies ocurren entre sitios quemados y no quemados, implicando que el papel del disturbio puede ser importante para el mantenimiento de la diversidad en comunidades de hormigas de las Islas del Cielo. Póster.

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