A LONG-TERM NATIONAL STUDY OF THE CONSEQUENCES OF FIRE AND FIRE SURROGATE TREATMENTS

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ABSTRACT

Many U.S. forests, especially those with historically short-interval, low- to moderate-severity fire regimes, are too dense and have excessive quantities of fuels. Widespread treatments are needed to restore ecological integrity and reduce the high risk of destructive, uncharacteristically severe fires in these forests. Among possible restorative treatments, however, the appropriate balance among cuttings, mechanical fuel treatments, and prescribed fire is often unclear. For improved decisionmaking, resource managers need much better information about the consequences of alternative management practices involving fire and mechanical/manual Afire surrogates.@ A group of scientists and land managers is designing an integrated national network of long-term research sites to address this need, with support from the U.S. Joint Fire Science Program. Most of the 11 sites in the proposed initial network are located in western coniferous forests, with a smaller number in southern pine and central hardwoods. All sites to date are in those high-priority forests with low-severity natural fire regimes. The proposed research is intended to assess a wide range of ecological, economic, and social consequences of several alternative fire hazard reduction and Aforest health@ treatments: (1) cuttings and mechanical fuel treatments alone; (2) prescribed fire alone; (3) a combination of cuttings, mechanical fuel treatments, and prescribed fire; and (4) untreated controls. Consistent with the long-term nature of the study, non-control treatments will be repeated over time. Each research site will include 3 or more replications of these 4 core treatments. Each treatment plot will be approximately 14 ha in size (including buffer). Where feasible, these relatively small replicated plots will be supplemented by much larger (200 to 400 ha or more), generally unreplicated areas treated to the same specifications, to facilitate the study of larger-scale ecological and economic/operational questions. Valid results at each site and meaningful comparisons across sites will be enabled by a common or Acore@ research design, one key aspect of which is a large set of core response variables and measurement protocols. Core variables encompass several broad disciplinary areas, including fire and fuels, vegetation, wildlife, entomology, pathology, soils/hydrology, utilization/economics, and social science. Investigators at each site will have the freedom to add treatments and/or response variables to the core design as appropriate to local interests and available resources and expertise. The steering group and other participants in the study represent a number of federal and state agencies, universities, and private entities. For more information, see: **http://ffs.psw.fs.fed.us/**

Keywords: forest fuel treatments, prescribed burning, silviculture, long-term interdisciplinary research

INTRODUCTION

Current forests in many fire-dependent ecosystems of the United States are denser and more spatially uniform, have many more small trees and fewer large trees, and have much greater quantities of forest fuels than did their presettlement counterparts (Bonnicksen and Stone 1982; Chang 1996; Parker 1984; Parsons and DeBenedetti 1979). Causes include fire suppression, past livestock grazing and timber harvests, farm abandonment (especially in the south), and changes in climate (Arno et al. 1997; Skinner and Chang 1996). The results include a general deterioration in forest ecosystem integrity and an increased probability of large, high-severity wildfires (Dahms and Geils 1997; Patton-Mallory 1997; Stephens 1998; Weatherspoon and Skinner 1996). Such conditions are prevalent nationally, especially in forests with historically short-interval, low- to moderate-severity fire regimes (Agee 1991, 1993, 1994; Arno 1980; Barden 1997; Caprio and Swetnam 1993; Cowell 1998; Dieterich 1980; Guyette and Cutter 1997; Kilgore and Taylor 1979; Mutch and Cook 1996; Phillips 1999; Swetnam 1990; Taylor and Skinner 1998; Sutherland 1997; Touchan et al. 1996; Van Lear and Waldrop 1989; Waldrop et al. 1987; Wills and Stuart 1994; Wright 1996; Yaussy and Sutherland 1993). The report of the Sierra Nevada Ecosystem Project highlighted these problems and explained the need for large-scale and strategically-located thinning (especially of small trees), fuel treatment, and use of prescribed fire (SNEP 1996; Weatherspoon and Skinner 1996). A recent speech by Interior Secretary Babbitt (1997) pointed out that similar problems and the need for similar solutions are now being acknowledged by national policymakers.

The need for widespread use of restorative management practices is clear (e.g., Hardy and Arno 1996). Less clear, however, is the appropriate balance among cuttings, mechanical fuel treatments, and prescribed fire (SNEP 1996; Stephens 1998; van Wagtendonk 1996; Weatherspoon 1996). Economic and technical feasibility of various treatments across different stands and landscapes, as well as social and political acceptability, are important considerations in managers' decisions about tools to use. However, to achieve goals for ecosystem integrity and sustainability, we also need much better information about the ecological consequences and tradeoffs of alternative management practices. The frequent, low- to moderate-severity fires that characterized presettlement disturbance regimes in many of our forests affected not only overall forest structure, composition, and fuel levels, but also a wide range of other ecosystem components and processes (Agee 1993, Chang 1996). What components or processes are changed or lost, and with what effects, if Afire surrogates" such as cuttings and mechanical fuel treatments are used instead of fire, or in combination with fire? For the most part, information necessary to answer such key questions is anecdotal or absent.

Long-term, interdisciplinary research thus should be initiated to quantify the consequences and tradeoffs of alternative fire and fire surrogate treatments. Ecological, economic and social aspects must all be included as integral components. The research needs to be experimental, rather than retrospective or correlative, to permit stronger inferences about cause-and-effect relationships. Only through such research will it be possible to determine which ecosystem functions of fire can be emulated satisfactorily by other means, which may be irreplaceable, and the implications for management. The human dimensions of the problem are equally important. Treatment costs and utilization economics, as well as social and political acceptability, strongly influence decisions about treatment alternatives. Such an effort must be collaborative, involving land managers, researchers, and interested public.

A team of scientists and land managers has designed an integrated national network of long-term research sites to address this need, with support from the USDI/USDA Joint Fire Science Program (http://www.nifc.gov/joint_fire_sci/index.html). The steering committee (see Appendix) and other participants in this national AFire/Fire Surrogate@ (FFS) study represent a number of federal and state agencies, universities, and private entities, as well as a wide range of disciplines and geographic regions. The study will use a common experimental design to facilitate broad applicability of results. Steering committee members currently are finalizing the FFS proposal for submission to the Joint Fire Science Program.

OBJECTIVES

The overall goal of the proposed research is to quantify the ecological, economic, and social consequences of fire and fire surrogate treatments in a number of forest types and conditions in the United States. Priority is given to forests with low- to moderate-severity natural fire regimes.

Objectives of the FFS study are:

1. Quantify the effects of fire and fire surrogate treatments on a number of specific core response variables within the general groupings of (a) fuel and fire behavior, (b) vegetation, (c) soils and forest floor/hydrology, (d) wildlife, (e) entomology, (f) pathology, (g) treatment costs and utilization/economics, and (h) social sciences.
2. Provide an overall research design that (a) establishes and maintains the study as an integrated national network of long-term interdisciplinary research sites utilizing a common Acore@ design to facilitate broad applicability of results, (b) allows each site to be independent for purposes of statistical analysis and modeling, as well as being a component of the national network, and (c) provides flexibility for investigators and other participants responsible for each research site to augmentCwithout compromisingCthe core design as desired to address locally-important issues and to exploit expertise and other resources available to local sites.
3. Develop and validate models of ecosystem structure and function, and successively refine recommendations for ecosystem management.
4. Within the first five years of the study, establish cooperative relationships, identify and establish network research sites, collect baseline data, implement initial treatments, document treatment costs and short-term human and ecological responses to treatments, report results, and designate FFS research sites as demonstration areas for technology transfer to professionals and for the education of students and the public.
5. Develop and maintain an integrated and spatially-referenced database format to be used to archive data for all network sites, facilitate the development of interdisciplinary and multi-scale models, and integrate results across the network.
6. Identify and field test, in concert with resource managers and users, a suite of response variables or measures that are: (a) sensitive to the fire and fire surrogate treatments, and (b) both technically and logistically feasible for widespread use in management contexts. This suite of measures will form much of the basis for management monitoring of operational treatments designed to restore ecological integrity and reduce wildfire hazard.

RESEARCH APPROACH

Experimental Design

The benefits of an integrated study with multiple experimental sites located around the country clearly can be enhanced if a common or Acore@ experimental design is utilized. The core experimental design for the FFS studyCi.e., those elements of the design common to all research sites in the network**C**consists of common (1) treatments, (2) replication and plot size, and (3) response variables.

Treatments The proposed FFS treatments consist of various combinations of the most common manipulative management activities utilized in forested ecosystems: cutting trees or other vegetation, using prescribed fire, and mechanically treating residues or scarifying the soil. Treatments include those that address widely-shared concerns about forest health and wildfire hazard, those that deal with environmental concerns, and those most practical from an operational standpoint. Consistent with the long-term focus of the study, treatments will be repeated periodically to represent real management approaches.

The following suite of four FFS treatments will be implemented at each research site:

1. Untreated control
2. Prescribed fire only, with periodic reburns
3. Initial and periodic cutting, each time followed by mechanical fuel treatment and/or physical removal of residue; no use of prescribed fire
4. Initial and periodic cutting, each time followed by prescribed fire; fire alone also could be used one or more times between cutting intervals

Cuttings in treatments 3 and 4 will be repeated at intervals appropriate to the forest type and site conditions**C**e.g., 20 years. Periodic prescribed burns in treatments 2 and 4 normally will be based on the best available information about presettlement fire intervals on the kinds of sites represented by the research site. Irregular rather than fixed burn intervals are preferable where supported by fire history evidence, since it seems likely that important elements of ecosystem diversity were promoted historically by natural variability in fire intervals (Agee 1993; Skinner and Chang 1996).

Definitions of the 4 FFS treatments are necessarily rather generic, and can encompass considerable variability in both cutting/mechanical and fire treatments that may significantly affect ecological responses of interest. More precise definitions would be helpful from the standpoint of reducing treatment variability among research sites. Applying uniform treatment specifications across so diverse an array of sites, however, is neither feasible nor desirable. The real world of forest ecosystems and resource management would not be represented appropriately with such a Aone-size-fits-all@ approach. This does, however, increase the need for (1) local replication to allow each research site to stand on its own statistically, and (2) good characterization of treatments actually applied at each research site to help explain observed differences among sites.

The non-control FFS treatments (treatments 2, 3, and 4) must be guided by a desired future condition (DFC) or target stand condition. The DFC will be defined mainly in terms of the tree component of the ecosystem**C**specifying such targets as diameter distribution, species composition, canopy closure, and spatial arrangements**C**and live and dead fuel characteristics. As with the FFS treatments, it is not feasible to prescribe a core DFC with any level of specificity that would apply across all research sites. We have, however, set a fire-related minimum standard or "least common denominator@ that will serve as a starting point for DFCs throughout the FFS network. That standard is based on predicted effects of a hypothetical wildfire occurring on the site after treatments have been implemented:

> Each non-control treatment shall be designed to achieve stand and fuel conditions such that, if impacted by a head fire under 80th percentile weather conditions, at least 80 percent of the basal area of overstory (dominant and codominant) trees will survive. The definition of 80th percentile weather conditions will be based on an analysis of fire season conditions, calculated for mid-afternoon, over a period of 10 to 20 years at the closest fire weather station. The prescription to implement the treatment will be developed based on fire behavior modeling (e.g.,

FARSITE) and predicted fire effects. Effects will be predicted using techniques such as FOFEM (First Order Fire Effects Model) and/or other modeling efforts that may include expert opinion.

The standard presumes the retention of a viable residual stand following treatment. Thus, clearcutting would not be an acceptable treatment option. In many cases, early treatments may take the form of some variation of thinning from below (or the equivalent via a series of burns), since this often addresses the greatest short-term restoration need. In the long-term, however, provisions will need to be made for recruitment of tree regeneration and development of a sustainable age-class structure.

Because of vegetation growth and fuel accretion, treatments will need to be repeated periodically for the standard to continue to be met. In most cases, surface fuels will require retreatmentCby fire or mechanical techniques, as appropriate to the treatment typeCmore often than stand structure.

Participants at each research site will define a DFC (and associated treatment prescriptions and retreatment schedules) that meets this fire-related standard. Given that this standard is met, however, the DFC can and should incorporate any additional management goals appropriate to the site, to stand conditions, and to the expectations of resource managers and other stakeholders. For sites that employ a randomized block design with blocks that differ significantly in site or stand conditions, DFC could vary somewhat among the experimental blocks within a research site. It is important for a DFC to be well-defined, and implemented using a specific prescription to ensure consistency among treatment plots.

Assuming the same starting point of stand and fuel conditions, moving toward a given DFC using FFS treatment 2 (fire only) clearly will be a much less precise process than using FFS treatments 3 and 4 (cuttings) and will also require a number of successive burns. Some desired changes in stand structureCe.g., Athinning@ relatively large trees without doing excessive damage to the overall standCmay not be feasible. However, skilled and innovative use of prescriptions, firing techniques, and other methods such as stage burning should, over several successive burns, permit considerable progress toward most DFCs using prescribed fire alone. It should be noted that opportunities for significant reshaping of stand structureCe.g., killing groups of trees to create openingsCmay be greater with initial relatively heavy fuel loads than after most fuels have been consumed.

<u>Replication and Plot Size</u> Replication at each research site is necessary to allow each site to be analyzed independently. As part of the core experimental design, each treatment will be replicated 3 times at each research site, using either a completely randomized or randomized block design as appropriate to the research site. The core set of 4 treatments thus will be represented in 12 treatment plots at a research site.

Each of the 12 core treatment plots at a research site will consist of a 10-ha measurement plot, within which core variables will be measured, surrounded by a treated buffer. The 10-ha size is a compromise between advantages of smaller plots (e.g., reduced costs, reduced intraplot variability) and those of larger plots (e.g., need to represent natural variability in stands and in DFC(s) at a more nearly operational scale, need to accommodate some larger-scale ecological responses). Size of measurement plots and appropriate core response variables are closely related and interdependent. To keep the perimeter-to-area ratio low and reasonably consistent, the length-to-width ratio should not exceed 1.5.

The buffer, which is to be treated in the same way as the measurement plot it surrounds, will have a width at least equal to the height of a best site potential tree. A 30-m treated buffer, for example, would bring the total size of the treatment plot to about 14 ha. Local participants may decide to adopt wider buffers than the minimum specified. Furthermore, it is left to participants at each research site to determine appropriate separation of treatment plots and the nature of treatment (or nontreatment) in the matrix between plots.

We recognize that many aspects of wider-ranging wildlife species, fisheries, watershed-scale hydrology, other landscape-level responses, and some economic and social questions can be studied at the 10-ha scale only indirectlyCe.g., via habitat attributes and modeling methods. Where feasible at a given research site, two additional approaches may help in addressing larger-scale issues: (1) Larger replicated treatment plots (i.e., larger buffers) can be used, provided that the core 10-ha plots are embedded within them and are utilized for measurement of core response variables. Additional, larger-scale variables could then be measured on the larger treatment plots. (2) The core 10-ha replicated plots can be augmented with much larger (200 to 400 ha or more), generally unreplicated areas nearby treated to the same specifications. These large treatment areas could provide useful information concerning operational-scale economics and practicability, as well as larger-scale ecological responses, especially if linked to the smaller replicated plots via appropriate models.

Response Variables A major aspect of the common design proposed for this study is a set of core response variables to be measured at all network sites, using common measurement protocols to the extent possible and a consistent intraplot sampling approach. Additional responses can be studied at one or more sites, depending on interests and available expertise and resources. The proposed research is designed to be open-ended in terms of scientific disciplines and associated response variables that can be accommodated.

Several members of our FFS steering committee (Appendix) have been serving as disciplinary group leaders with responsibility for developing major sets of response variables (Table 1). Each group leader has worked with a team of people with appropriate expertise to identify a core set of response variables that would be measured consistently across all research sites. Their activities also have included cross-group coordination to ensure consistency, compatibility, and non-duplication of data collection efforts. We anticipate that their responsibilities will continue into the implementation phase of the project to ensure that data collection protocols are followed consistently at all the sites. (Where deviations from common measurement protocols are necessary for specific variables, they will be documented and justified.) This may include training, oversight of field crews, or other measures as appropriate.

Intraplot sampling of all variables will be keyed to a 50-m square grid of permanent sample points to be established and maintained within each measurement plot. Any number of grid points in a measurement plot may be utilized for a given variable depending on the nature and appropriate intensity of sampling for that variable. Spatial referencing of all data to the grid will facilitate spatial analyses in conjunction with planned acquisition and analysis of high-resolution digital orthophotography and utilization of a GIS-based data base. Co-location (or consistent proximity) of multi-disciplinary data facilitated by use of the grid also will promote analyses that should elucidate cross-disciplinary relationships and suggest interdisciplinary hypotheses.

Table 1. Disciplinary groups and group leaders.

Fire and fuels
Sally Haase, PSW Station, and Bob Vihnanek, PNW Station

Vegetation
Jon Keeley, USGS, Sequoia-Kings Canyon National Parks

Soils and forest floor/hydrology
Ralph Boerner, Ohio State University

Wildlife
Steve Zack, Wildlife Conservation Society

Entomology (primarily bark beetles)
Patrick Shea, PSW Station

Tree pathology
Bill Otrosina, SO Station

Treatment costs and utilization/economics
Jamie Barbour, PNW Station

Social sciences
Ron Hodgson, California State University Chico

<u>Augmenting the Core Design</u> As suggested in Project Objective #2, the overall study is designed to balance the values of an integrated national network of research sites having a common design against the needs for each site to retain flexibility in addressing important local issues and in exploiting expertise and other resources available to that site. Accordingly, at the discretion of investigators, managers, and other participants involved in a given site, the core design may be augmented (provided it is not compromised) at that site by adding FFS treatments, adding one or more DFCs, adding replications, increasing treatment plot size (by increasing buffer width; the 10-ha measurement plot and core data collected within it would remain unchanged), and/or adding response variables. In general, however, we will request support through the Fire Science Program only for implementing the core design at each site.

Research Site Locations

<u>Criteria for Site Selection</u> A network of research sites using a common experimental design has the potential for synergistic output exceeding what could be accomplished by a series of separate, uncoordinated studies. In selecting research sites we have developed and used the set of criteria given in Table 2. All of the initial sites identified for inclusion in the network have met or will meet these criteria.

<u>Proposed Initial Sites</u> The proposed initial network (Table 3) comprises 10 main sites and 1 satellite site (satellite will have less than the full suite of core treatments). All of these initial sites represent forests with a historically short-interval, low- to moderate-severity fire regime. Eight sites are in western coniferous forests, ranging from the Pacific Northwest to the Southwest. These sites all share the fact that ponderosa pine is an important tree component, but sites vary in composition of other conifers and differ substantially in topographic and soil parameters. Two sites are in the southeastern U.S.Cone in the Piedmont and one on the Coastal PlainCand are dominated by mixtures of southern pines with hardwood understories. Rounding out the network is a site in the midwestern oak-hickory type of Ohio. Collectively, these sites comprise a network that is truly national in scope. Represented in this network is a mixture of land ownerships, including federal, state, university experimental forests, and private holdings.

We recognize that the proposed initial network does not represent all forest types and conditions with serious fire hazard and forest health problems. However, its composition is a reasonable compromise considering the widespread need for the information, anticipated availability of funding, and available expertise and commitment. It is our expectation that the network will provide us with widely applicable results. Depending on the level of interest and support available, future sites in the same or other fire regimes may be added to the network. Possibilities for using the FFS study as a model for similar international studies have been discussed.

Table 2. Criteria used in site selection.

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1. Site is representative of forests with a historically short-interval, low- to moderate-severity fire regime and a currently high risk of uncharacteristically severe fire.

2. Site is representative of widespread forest conditions (site characteristics, forest type and structure, treatment history) that are in need of, and likely to benefit from, fire or fire surrogate treatments, and in which such treatments are feasible.
3. Site contributes significantly to balancing the overall network in terms of regional representation and/or land ownership type.
4. Partners and cooperators are committed to and capable of participating in the program. This involves several factors, including: active support and interest in involvement on the part of partners/cooperators; available land base for the study; ability and willingness of land managers to implement the full suite of experimental treatments successfully within required time frame, repeat treatments over time as appropriate, commit selected sites for long-term research uses, and document these commitments in amendments to long-term land management plans.
5. On federal lands, treatment costs are borne by lead agency or partner.
6. Partnerships exist across agencies and with universities, and between researchers and managers.

ADDITIONAL INFORMATION

A web site for the FFS study (**http://ffs.psw.fs.fed.us/**) was created and is being maintained by Carl Skinner, a member of the steering committee (Appendix). This site is designed primarily to assist the work of the steering committee, but is open also to the public. It includes the current draft of the FFS proposal, which contains considerably more detail in a number of areasCe.g., specific core variables and protocols, characteristics of research sites, plans for network administration and database managementCthan can be summarized adequately in this paper. The site also documents the background of the proposal, including several steering committee workshops held to work out numerous aspects of the study design. Readers interested in more details about the proposed FFS study are referred to this web site.

Table 3. Proposed initial research sites and principal contacts.

Mission Creek, north-central Washington, Wenatchee National Forest.
Contact: James K. Agee, University of Washington.

Hungry Bob, Blue Mountains of northeast Oregon, Wallowa-Whitman National Forest.
Contacts: James McIver, Andy Youngblood, PNW Research Station.

Lubrecht Forest, University of Montana, northern Rockies, western Montana.
Contacts: Carl Fiedler, University of Montana; Michael Harrington, RM Research Station.

Klamath Province, northwestern California, one or more national forests, possibly other ownerships.
Contacts: Gary Fiddler, Carl Skinner, and Phil Weatherspoon, PSW Research Station.

Kings District Administrative Study Area, Sierra National Forest, southern Sierra Nevada, California.
Contacts: Scott Stephens, California Polytechnic State University, San Luis Obispo; Mark Smith and Alan Quan, Sierra National Forest.

Sequoia-Kings Canyon Satellite, Sequoia National Park, southern Sierra Nevada, California (satellite to Kings District Administrative Study Area site).
Contacts: Jon E. Keeley and Nathan L. Stephenson, USGS, Sequoia-Kings Canyon Field Station; Anthony C. Caprio, NPS, Sequoia-Kings Canyon National Parks.

Flagstaff and Williams Arizona, Coconino and Kaibab National Forests, northern Arizona.
Contact: Carl Edminster, RM Research Station.

Jemez Mountains New Mexico, Santa Fe National Forest, northern New Mexico.
Contact: Carl Edminster, RM Research Station.

Ohio Hill Country, lands managed by the Wayne National Forest, the Ohio Division of Forestry, Mead Paper Corporation, and The Nature Conservancy, southern Ohio.

Contacts: Daniel A. Yaussy, Todd Hutchinson, NE Research Station; Elaine Kennedy Sutherland, RM Research Station.

Southeastern Piedmont, Clemson Experimental Forest, northwestern South Carolina.
Contact: Thomas A. Waldrop, SO Research Station.
Florida Coastal Plain, Myakka River State Park, southwest Florida.
Contacts: Thomas A. Waldrop, SO Research Station; Robert Dye, Park Manager; Dale D. Wade, SO Research Station.

ACKNOWLEDGMENTS

I feel fortunate to be working with a steering committee consisting of such a highly competent and diverse group of people (see Appendix). I gladly acknowledge their many contributions to the concepts and research design outlined in this paper. I also wish to thank the USDI/USDA Joint Fire Science Program for their support of a series of steering committee and site workshops necessary to finalize the FFS proposal.

REFERENCES

Agee, J.K. (1991). Fire history along an elevational gradient in the Siskiyou Mountains, Oregon. *Northwest Science*, 65:188-199.
Agee, J.K. (1993). *Fire Ecology of Pacific Northwest Forests*. Washington, D.C. Island Press; 493 p.
Agee, J.K. (1994). Fire and other disturbances of terrestrial ecosystems in the eastern Cascades. USDA Forest Service General Technical Report PNW-GTR-344.
Arno, S.F. (1980). Forest fire history of the northern Rockies. *Journal of Forestry*, 78:460-465.
Arno, S.F., H.Y. Smith, and M.A. Krebs. (1997). Old growth ponderosa pine and western larch stand structures: Influences of pre-1900 fires and fire exclusion. USDA Forest Service Research Paper INT-RP-495.
Babbitt, B. (1997). A coordinated campaign: fight fire with fire. Unpublished speech by U.S. Secretary of the Interior Bruce Babbitt at Boise State University, Idaho, February 11, 1997.
Barden, L.S. (1997). Historic prairies in the Piedmont of North and South Carolina, USA. *Natural Areas Journal*, 17:149-152.
Bonnicksen, T.M., and E.P. Stone. (1982). Reconstruction of a presettlement giant sequoia-mixed conifer forest community using the aggregation approach. *Ecology*, 63:1134-1148.
Caprio, A.C., and T.W. Swetnam. (1993). Historic fire regimes along an elevational gradient on the west slope of the Sierra Nevada, California. USDA Forest Service General Technical Report INT-GTR-320. pp. 173-179.
Chang, C. (1996). Ecosystem responses to fire and variations in fire regimes. In: *Sierra Nevada Ecosystem Project: Final report to Congress. Vol. II Assessments and Scientific Basis for Management Options*. Wildland Resources Center Report No. 37. Davis: Centers for Water and Wildland Resources, University of California; 1071-1099.
Cowell, C.M. (1998). Historical change in vegetation and disturbance on the Georgia Piedmont. *American Midland Naturalist*, 140:78-89.
Dahms, C.W., and B.W. Geils, tech eds. (1997). An assessment of forest ecosystem health in the Southwest. USDA Forest Service General Technical Report RM-GTR-295.
Dieterich, J.H. (1980). Chimney Spring forest fire history. USDA Forest Service Research Paper RM-RP-220.
Guyette, R.P., and B.E. Cutter. (1997). Fire history, population, and calcium cycling in the Current River watershed. In: Pallardy, S.G., R.A. Cecich, H.E. Garrett, and P.S. Johnson, eds. *Proceedings, 11th Central Hardwood Forest Conference*; 355-372. St. Paul, MN: USDA Forest Service North Central Forest Experiment Station.
Hardy, C.C., and S.F. Arno, eds. (1996). The use of fire in forest restoration: a general session at the annual meeting of the Society for Ecological Restoration. USDA Forest Service General Technical Report INT-GTR-341.
Kilgore, B.M., and D. Taylor. (1979). Fire history of a sequoia mixed conifer forest. *Ecology*, 60:129-142.
Mutch, R.W., and W.A. Cook. (1996). Restoring fire to ecosystems: methods vary with land management goals. In: Hardy, C.C., and S.F. Arno, eds. The use of fire in forest restoration. USDA Forest Service General Technical Report INT-GTR-341; 9-11.
Parker, A.J. (1984). A comparison of structural properties and compositional trends in conifer forests of Yosemite and Glacier National Parks, USA. *Northwest Science*, 58:131-141.
Parsons, D.J., and S.H. DeBenedetti. (1979). Impact of fire suppression on a mixed-conifer forest. *Forest Ecology and Management*, 2:21-33.
Patton-Mallory, M. (1997). Southwest wildland/urban interface fire risk reduction workshop, Flagstaff, AZ, August 4-5, 1997. Unpublished summary report on file. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p.
Phillips, C. (In press). Fire return intervals in mixed-conifer forests of the Kings River Sustainable Forest Ecosystem Project area. USDA Forest Service General Technical Report.
Skinner, C.N., and C. Chang. (1996). Fire regimes, past and present. In: *Sierra Nevada Ecosystem Project: Final report to Congress. Vol. II Assessments and Scientific Basis for Management Options.* Wildland Resources Center Report No. 37. Davis: Centers for Water and Wildland Resources, University of California; 1041-1069.

SNEP. (1996). *Sierra Nevada Ecosystem Project: Final report to Congress. Vol. I, Assessment summaries and management strategies.* Wildland Resources Center Report No. 36. Davis: Centers for Water and Wildland Resources, University of California; 209 p. + plates.

Stephens, S.L. (1998). Effects of fuels and silvicultural treatments on potential fire behavior in mixed conifer forests of the Sierra Nevada, CA. *Forest Ecology and Management*, 105:21-34.

Sutherland, E.K. (1997). The history of fire in a southern Ohio second-growth mixed-oak forest. In: Pallardy, S.G., R.A. Cecich, H.E. Garrett, and P.S. Johnson, eds. *Proceedings, 11th Central Hardwood Forest Conference*; 172-183. St. Paul, MN: USDA Forest Service North Central Forest Experiment Station.

Swetnam, T.W. (1990). Fire history and climate in the southwestern United States. p.6-17. In: Krammes, J.S., tech. coord. *Effects of Fire Management of Southwestern Natural Resources, Proceedings of the Symposium.* Nov. 15-17, 1988, Tucson, AZ. USDA Forest Service General Technical Report RM-GTR-191

Taylor, A.H., and C.N. Skinner. (1998). Fire history and landscape dynamics in a late-successional reserve, Klamath Mountains, California, USA. *Forest Ecology and Management*, 111:285-301.

Touchan, R., C.D. Allen, and T.W. Swetnam. (1996). Fire history and climatic patterns in ponderosa pine and mixed-conifer forests of the Jemez Mountains, Northern New Mexico. p. 33-46. In: Allen, C.D., tech. ed. *Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium*, 1994 March 29-31; Los Alamos, New Mexico. USDA Forest Service General Technical Report RM-GTR-286.

Van Lear, D.H., and T.A. Waldrop. (1989). History, use, and effects of fire in the Appalachians. USDA Forest Service General Technical Report SE-GTR-54.

Van Wagtendonk, J.W. (1996). Use of a deterministic fire growth model to test fuel treatments. In: *Sierra Nevada Ecosystem Project, Final Report to Congress. Vol. II Assessments and Scientific Basis for Management Options.* Wildland Resources Center Report No. 37. Davis: Centers for Water and Wildland Resources, University of California; 1041-1069.

Waldrop, T.A., D.H. Van Lear, F.T. Lloyd, and W.R. Harms. (1987). Long-term studies of prescribed burning in loblolly pine forests of the Southeastern Coastal Plain. USDA Forest Service General Technical Report SE-GTR-45.

Weatherspoon, C.P. (1996). Fire-silviculture relationships in Sierra forests. In: *Sierra Nevada Ecosystem Project, Final Report to Congress. Vol. II Assessments and Scientific Basis for Management Options*. Wildland Resources Center Report No. 37. Davis: Centers for Water and Wildland Resources, University of California; 1167-1176.

Weatherspoon, C.P., and C.N. Skinner. (1996). Landscape-level strategies for forest fuel management. In: *Sierra Nevada Ecosystem Project: Final report to Congress. Vol. II Assessments and Scientific Basis for Management Options*. Wildland Resources Center Report No. 37. Davis: Centers for Water and Wildland Resources, University of California; 1471-1492.

Wills, R.D., and J.D. Stuart. (1994). Fire history and stand development of a Douglas-fir hardwood forest in northern California. *Northwest Science*, 68:205-212.

Wright, C.B. (1996). Fire history of the Teanaway Valley, Washington. M.S. thesis, University of Washington, Seattle.

Yaussy, D.A., and E.K. Sutherland. (1993). Fire history in the Ohio River Valley and its relation to climate. In: *12th Conference on Fire and Forest Meteorology: Fire, Meteorology, and the Landscape*; 777-86. Bethesda, MD.: Society of American Foresters.

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