Forest Service Global Change Research Strategy, 2009–2019

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Contents

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Executive Summary

Climate changes already observed and those predicted for the future differ considerably from those of the past.

Objective

In keeping with the research goals of the U.S. Climate Change Science Program, the Research and Development agenda of the Forest Service, U.S. Department of Agriculture (USDA), helps define climate change policy and develop best management practices for forests (both rural and urban) and grasslands. These actions are taken to sustain ecosystem health, adjust management for ecosystem services ("adaptation"), and increase carbon sequestration ("mitigation"), all under changing climate conditions. The fundamental research focus of the Forest Service Global Change Research Strategy is to increase understanding of forest, woodland, and grassland ecosystems so that they can be managed in a way that sustains and provides ecosystem services for future generations.

Basis

Climate changes already observed and those predicted for the future differ considerably from those of the past. Accordingly, ecosystem services in the future will differ from those of the past. Land management must be capable of enhancing adaptation of these ecosystems to increasing climate changes while removing carbon from the atmosphere through sequestration in ecosystems and wood/energy products. At the same time, geographic and temporal variability in climate also will increase. These geographic differences manifest in both biophysical conditions and socioeconomic systems. Therefore, land management plans and actions must differ locally to account for this variability. Yet, the sum of the impacts of these local actions must be considered in policy, which requires these local actions be linked to national plans.

To address these issues, a Forest Service Global Change Research Strategy and the concomitant research activities are needed to balance and coordinate scientific responses. This strategy is the scientific basis for a unified approach to managing ecosystems services within the range of uncertainty provided by a changing climate.

Approach

The Forest Service Global Change Research Strategy balances research across a range of management, science, and science delivery actions aimed at developing adaptation and mitigation approaches to sustain healthy ecosystems. The following research elements serve as the organizing mechanism.

1. **Research To Enhance Ecosystem Sustainability (Adaptation).** The first element focuses on research that will advance management options under a changing climate to enhance ecosystem health and sustainability; ensure the flow of ecosystem services, such as water, wildlife, biodiversity, recreation, forest and grassland products; and reduce losses of ecosystem function from climate-altered disturbances, such as wildfire, insects, and invasive species.
2. **Research To Increase Carbon Sequestration (Mitigation).** The second element focuses on research that will assist managers in (a) enhancing carbon sequestration via actions that could increase forest growth rates and area of forested lands; (b) enhancing biomass extraction and utilization research; and (c) understanding long-term carbon product storage pools. These capabilities cannot be realized without the sustainability being supported by research for the first element.
3. **Research To Provide Decision Support.** The third element integrates the first two research elements by developing decision-support tools and approaches for policymakers, planners, and land managers.
4. **Shared Research Needs: Infrastructure, Scientific Collaboration, and Science Delivery.** The fourth element is focused on the shared research needs for infrastructure, scientific collaboration, and science delivery that will incorporate the research and applications in the first three elements into natural resource planning and management.

Overview: A Forest Service Global Change Research Strategy for the Coming Decade, 2009–2019

The fundamental research focus of this strategy is to increase understanding of forest, woodland, and grassland ecosystems so that they can be managed in a way that sustains and provides ecosystem services for future generations.

Objective

A century of wildland policy and management has helped create large ecosystem commons in the United States that produce a wide variety of goods and services enjoyed by all Americans. These ecosystem commons, however, are threatened by several rapidly intensifying global forces, including climate change, land-use change, invasive species, and changes in the global competitiveness of the U.S. forest sector. In addition to traditional roles in supplying wood products, clean water and air, wildlife habitat, recreation, and so on, forests also play an important role in reducing the buildup of greenhouse gases in the atmosphere by sequestering carbon. Now, they are also being viewed as potentially important sources of biomass energy feedstocks. Alternatively, forests, woodlands, and grasslands can become unintended sources of carbon to the atmosphere when large wildfires and insect infestations arise, or land is converted to developed uses. Climate change and these naturally occurring disturbances altered by climate change will threaten ecosystem functions and the suite of ecosystem services from forests and grasslands. Adjustments in natural or human systems to the changing environment ("adaptation") may result in beneficial opportunities or moderately negative effects. And, while forest, woodland, and grassland health and productivity are increasingly vulnerable to climate change, these large ecosystem commons are habitats for plants and animals and will serve as landscapes where the process of natural adaptation to climate change is likely to occur.

Land managers are being asked to address the challenges of climate change with inadequate and often conflicting information. Decisions being made today by public and private land and resource managers will have implications through the next century, especially as they relate to the adaptation of ecosystems.

The Forest Service Global Change Research Strategy will help identify best management practices for urban and rural forests, woodlands, and grasslands to sustain ecosystem health and a range of ecosystem services ("adaptation"), while also increasing carbon sequestration ("mitigation")—all under changing climate conditions. The fundamental research focus of this strategy is to increase understanding of forest, woodland, and grassland ecosystems so that they can be managed in a way that sustains and provides ecosystem services for future generations.

This document describes the current and future Forest Service research strategy for global change. Global change encompasses all of the environmental phenomena related to global-scale anthropogenic forces: changing climate and climate variability, shifting land uses, changing atmospheric contaminants, increasing nitrogen deposition, and so on. The Forest Service Global Change Research Strategy reviews the basic functions the research must serve and the strategy needed to attain them. It is linked to related Forest Service research program strategies, including those focused on wildfire, invasive species, insects, and biomass and biofuels. Research defined herein will support the needs of the broad range of stakeholders we serve including National Forest System (NFS) planners and managers; other Federal, State, and local land managers; private landowners; industry; and others. The strategy overview is aimed at Forest Service

land managers and administrators; global change scientists and administrators in other Federal, State, and local agencies; and citizens that may wish to examine Forest Service research goals in global change.

Basis

The climate of the Earth is changing and will continue to change for many decades in response to the buildup of greenhouse gases (GHGs) in the atmosphere. The "fingerprint" of GHGs has been known for some time, including:

- Warming in the lower atmosphere (troposphere) while cooling in the upper atmosphere (stratosphere);
- Warming more at the poles than at the equator;
- Warming more over land than over the sea;
- Warming more in winter than in summer;
- Warming more at night than in daytime;
- Increasing intensity of the hydrological cycle, including more rain in high latitudes and less in the subtropics; and
- Increasing climate variability producing more large storms and longer, more intense droughts.

As a result, the climate changes already measured, and those predicted in the future, differ considerably from place to place. The Southwestern United States is encountering increasing drought; the Northwest is undergoing longer, dryer summers and declining snowpacks; and the Northeast has seen increased rainfall and flooding, warmer winters, and longer growing seasons. The Southeast has had warmer winters with dryer summers; and the tropics (Puerto Rico and Hawaii) have had increasing warmth and aridity, rising sea levels, and tropical storms of increasing intensity.

Forests and grasslands will experience regional and local changes in temperature and precipitation. They are also likely to experience increases in the variability of weather, such as droughts, storms, and heat waves. Further, other global forces—such as land use, air pollution, and invasive species—will interact with these climate changes, further affecting forests and grasslands across the United States. Because the ecosystems in these regions also differ, land management actions will need to vary widely in response to these differing climate changes and ecological effects. A fundamental challenge posed by changing climate must be resolved through land management—the need to remove carbon from the atmosphere by increasing its sequestration in ecosystems and wood/energy products, while enhancing the adaptation of these ecosystems to increasing changes due to climate. Additionally, managers in the NFS, in working to maintain the variety of ecosystem goods and services demanded by the public, may use quite different approaches in specific locales than those used by other landowners nearby because their goals and objectives may differ. For example, NFS could be surrounded by landowners focused only on wildlife, recreation, or commercial timber. All of these considerations argue for a localized approach to land management.

Land managers have conveyed a sense of urgency and a real-time need for information. They are faced with planning for and making climate-change-related decisions today. They need all available scientific information to support these decisions. The needs for this scientific information will be honed in real time if a healthy learning environment is developed where researchers and managers testing new adaptation strategies share their successes and failures across landscapes, regions, and agencies. Land managers recently reported a variety of research needs, which can generally be divided into four categories.

Because the ecosystems in these regions also differ, land management actions will need to vary widely in response to these differing climate changes and ecological effects.

First, there is the strong need simply to understand the basic concepts associated with global change relevant to land management (e.g., vocabulary, ecosystem responses, etc.).

Second is a need to understand how climate change can be integrated into multiple-use management (e.g., balancing stocking densities with other ecosystem services provisions, climate impacts on fire, etc.).

Third, tools are needed to implement climate change strategies in the specific forests being managed (e.g., local future

climate scenarios, vegetation projection models, vulnerabilities and risk predictions, etc.).

Fourth is the need for increased interagency cooperation and outreach to citizens and other stakeholders (e.g., adjacent landscape issues, stakeholder input to decisions and actions, etc.).

A Forest Service national global change strategy and the concomitant research needed to implement it must be in place to balance and coordinate the scientific basis for managing ecosystem services within the uncertainty of changing climates, land use, and atmospheric chemistry.

Approach

Forests, woodlands, and grasslands have an important role in mitigating climate change while adapting to climate change. Mitigation addresses ways that ecosystems can sequester carbon, ways to increase carbon stored in wood products, ways to reduce fossil fuel use in manufacturing, and ways that forests and woodlands can provide renewable energy from woody biomass to replace fossil fuel consumption. Mitigation also includes ways the agency can reduce its environmental footprint and lead by example in greening our practices. Adaptation in contrast is focused on:

- The vulnerabilities of ecosystems (e.g., vegetation, wildlife, water) to different future climates and disturbance regimes in diverse geographic regions;
- The adaptive capacity of ecological, economic, and social systems;
- Management actions that will help sustain ecosystem function and minimize losses of ecosystem services;
- Different sources of uncertainty (environmental conditions, models, data, resources); and
- Decision-support tools to assist managers as they plan for and adjust management in a future increasingly influenced by changes in climate.

This planning melds adaptation and mitigation inextricably: There can be no sustainable increase in the national inventory of carbon sequestered in our forests and grasslands without maintaining the health of the Nation's ecosystems. The understanding needed to attain these goals also requires integrated research on ecosystem dynamics and the basic terrestrial carbon cycle.

This document balances research across a range of management, science, and technology transfer actions. Research is aimed at developing adaptation and mitigation approaches to ensure that forests, woodlands, and grasslands have the capacity to maintain health, productivity, and diversity while meeting carbon sequestration needs. The strategy closely corresponds with the research focus and goals of the U.S. Climate Change Science Program (CCSP), in particular with the needs for management and research identified in the CCSP Synthesis and Assessment Product (SAP) 2.2, "The First State of the Carbon Cycle Report (SOCCR): the North American Carbon Budget and Implications for the Global Carbon Cycle;" CCSP SAP 4.2, "Thresholds of Climate Change in Ecosystems," CCSP SAP 4.3, "The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity;" and the CCSP SAP 4.4 report, "Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources."

This strategy contains four integrated elements aimed at enhancing the management of forests, woodlands, and grasslands under changing climate:

1. Research To Enhance Ecosystem Sustainability (Adaptation). The first element focuses on research that will advance management options under a changing climate to enhance ecosystem health and sustainability; ensure the flow of ecosystem services, such as water, wildlife, biodiversity, recreation, forest and grassland products; and reduce losses of ecosystem function from climate-altered disturbances, such as wildfire, insects, and invasive species.
2. Research To Increase Carbon Sequestration (Mitigation). The second element focuses on research that will assist managers in (a) enhancing carbon sequestration via actions that could increase forest growth rates and area of forested lands; (b) enhancing biomass extraction and utilization research; and (c) understanding long-term carbon product storage pools. These capabilities cannot be realized without the sustainability being supported by research for the first element.
3. Research To Provide Decision Support. The third element integrates the first two research elements by developing decision-support tools and approaches for policymakers, planners, and land managers.
4. Shared Research Needs: Infrastructure, Scientific Collaboration, and Science Delivery. The fourth element is focused on the shared research needs for infrastructure, scientific collaboration, and science delivery that will incorporate the research and applications of the first three elements into natural resource planning and management.

1. Research To Enhance Ecosystem Sustainability (Adaptation)

Photo by Larry Korhnak.

Because the climate changes in the 21st century are likely to be uniquely rapid and coupled with other stresses, including a landscape fragmented by urban and industrial development, natural adaptation processes may be limited.

Climate Change and Ecosystem Sustainability

Plants and animals are adapted to local climates. Paleoecological and historical ecological studies have documented that plants and animals have responded and adapted to past changes in these local climates. Natural adaptation can mean adapting to the local climate or migrating to reach a more favorable climate. These adaptations often result in new combinations of species redefining ecosystems. Because the climate changes in the 21st century are likely to be uniquely rapid and coupled with other stresses, including a landscape fragmented by urban and industrial development, natural adaptation processes may be limited. The capacity of forests and grasslands to maintain current health, productivity, diversity, and resilience will likely be compromised under this changing climate. The efficacy of current management practices applied under a changing climate will depend upon the nature of the climatic changes (spatial, temporal), the vulnerability of ecosystems to these changes, and the current status and degree of human alteration of the ecosystems (i.e., presence of invasives, departure from historical fire regimes, condition of watersheds). Species, varieties, and even whole ecosystems that are adapted to the climate of the past centuries may become progressively more stressed and dysfunctional. At the same time, plants and animals that may be appropriate to future climate in any given locale may currently exist in other locations, for example, at lower latitudes or at lower elevations in mountainous terrain. Developing an adaptation strategy to maintain and enhance forest and rangeland sustainability will involve evaluating different types of uncertainty (e.g., environmental conditions, models, data, resources, planning horizons, adaptive capacity tied to place) so that multiple adaptation options can be identified for the management of forest and grasslands under changing climates.

Current Research Goals

Research on adaptation is primarily focused on maintaining ecosystem health as much as possible, thereby protecting the goods and services ecosystems produce (e.g., removing air pollutants, providing clean and abundant water supplies, sustaining habitats to maintain wildlife and biodiversity, cycling important nutrients, reducing success of exotic invasive species, providing recreation and aesthetics). Identifying the key vulnerabilities will require an understanding of the magnitude of the potential impacts, the timing of impacts, the persistence and reversibility of impacts, the likelihood of impacts and confidence of those estimates, the potential for adaptation, the distributional aspect of impacts and vulnerabilities (disadvantaged sectors or communities), and the importance of the system at risk. Forest, woodland, and grassland ecosystems are set within a context of social and economic systems. Adaptation and sustaining health, productivity, and biodiversity of these ecosystems will be a function of the adaptive capacity and interactions of all of these combined systems.

The approach to adaptation is to affect ecosystem processes by altering growth, composition, and structure to better withstand the suite of environmental stresses from changing climate, pests, pollutants, storms, and unnaturally severe wildfire. As climatic stress increases in the future,

plant and animal population adjustments, range shifts, and other adaptations may need to be facilitated so that species and ecosystems are capable of establishing and maturing under new climate regimes without catastrophic failure. For example, reducing tree densities can enhance the water and nutrients available to remaining trees. Altering species composition and managing for uneven-age forests also increase tree resistance to pests, reduce the spread of wildfire, and enhance resistance to pollutants such as ozone and sulfur dioxide. Some species and ecosystems may require intensive management actions to maintain viability or resilience. Others may require reduction of current stressors, and still others may require less intensive management to sustain the production of the values and services that healthy forests provide.

Research Needs

Research actions to:

- Improve our understanding of the potential impacts of a changing climate on the functioning of ecosystems and of the management actions required to reduce the impacts.
- Enhance our understanding of the changing effects of climate on populations, communities, ecosystems, and landscapes, as well as on ecological processes at multiple scales.
- Expand our current knowledge of paleoecology and of paleoclimate-vegetation dynamics to identify metrics to monitor ecosystems under a changing climate and to define range of variability at local sites across ecosystems.
- Develop genetic information to identify species to plant and seed sources for reforestation, afforestation, and gene conservation.
- Document interactions between multiple stresses under a changing climate and potential for linear/nonlinear threshold responses to climate change.
- Enhance our understanding of the changing relationships between climate and climate-mediated disturbances, such as fire, insects, and disease.
- Develop needed scientific information and biotic and environmental monitoring methods and models (including scalability and uncertainty measures) for decisionmaking in resource management and greater understanding of human and organizational adaptation to climate change.
- Focus efforts to increase and retain the sustainability of ecosystem services, particularly of water supplies, wildlife and fish populations, endangered species, and forest and grassland products.
- Enhance understanding of the changing relationships between climate, land use change, and climate-mediated disturbances.
- Reduce the uncertainties in climate projections and ecosystem responses to increase adaptive management options and improve evaluation of tradeoffs when managing for all ecosystem services.
- Develop new methods to monitor and quantify the impacts of climate change and elevated carbon dioxide on ecosystem productivity and water, nutrient, and energy cycling.
- Begin experimental testing of management and adaptation options on the ground to develop strategies for risk-spreading and conserving/enhancing broad-sense ecosystem productivity and health.

Near-Term Research Products

The research goals attainable in the next decade (near-term research products) that involve enhancing ecosystem resilience under increasing climate stress will focus on developing and implementing a coordinated series of regional

The efficacy of current management practices applied under a changing climate will depend upon the nature of the climatic changes.

syntheses on the potential vulnerabilities and ecosystem responses to a changing climate for application by land managers. Specifically, Research and Development will:

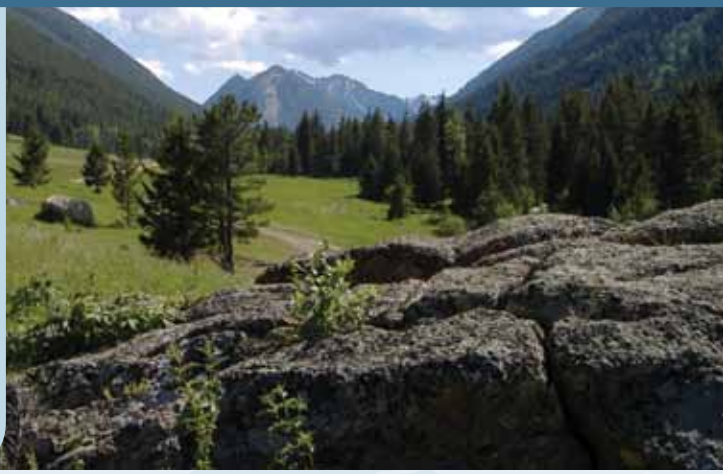
- Conduct integrated assessments of climate change impacts on ecosystems to determine potential impacts on ecosystem services, assess the vulnerabilities across different spatial scales including identification of potential "hotspots," assess potential management strategies, and uncover potential unintended consequences of mitigation and adaptation actions.
- Develop educational tools (courses, workshops, manuals, models) for all Forest Service personnel, teaching the principles of climate change science and its applications in planning and managing sustainable ecosystems under changing climate.
- Enhance existing quantitative tools used in land management and develop new tools to assist in the analysis of the impacts of climate change on terrestrial and aquatic systems and the appropriate management responses.
- Improve Resources Planning Act (RPA) assessments by adding analysis of climate change impacts on wildlife and water, in conjunction with the analysis of climate change impacts on forests linked to the analysis of carbon sequestration/biofuel/energy options and their impacts on ecosystems.
- Develop coordination for a large-scale research program and the associated means of support and execution aimed at predicting national climate change impacts.
- Use pilot projects, particularly in the National Experimental Forests and Ranges, to develop and test strategies and systems for conserving and enhancing resource (e.g., soil, water, habitat, biodiversity, vegetation) productivity and health.

Figure 1a. Adaptation to climate change: Eastside ponderosa pine forest, Lassen National Forest, with about 300 trees per acre. Stress on individual trees from warmth and drought can be relieved in part by thinning the stand while maintaining the age and size structure. *Photo from David Peterson, Forest Service, Pacific Northwest Research Station.*

Figure 1b. Eastside ponderosa pine forest, Lassen National Forest, after thinning to approximately 90 to 110 trees/acre. Removed 28.5 green tons per acre, 40-percent saw-logs, 60-percent chips and biomass. Thinning generated $124 per acre and increased the amount of water and nutrients available to each remaining tree. *Photo from David Peterson, Forest Service, Pacific Northwest Research Station.*

2. Research To Increase Carbon Sequestration (Mitigation)

Carbon sequestration research is focused on improving understanding of the exchange of carbon between the land, atmosphere, and oceans, and how global change affects these dynamics.



Climate Change and Carbon Sequestration

Mitigation research is aimed at reducing atmospheric CO_2 concentration by increasing the amount of CO_2 removed from the atmosphere by U.S. forest and grassland ecosystems (including agroforested and urban forest ecosystems). Transferring biomass out of forests and into wood products is critical to enhancing continued carbon sequestration into forests. Relative to some other materials, wood requires less fossil fuel in harvest and production processes. Sustainably managed forest and range resources can replace fossil fuels with fuels derived from biomass, which use carbon already present in the global carbon cycle, rather than obtaining new carbon from fossil fuels. Silvicultural and genetics research help to increase growth and enhance sustainability. Avoiding deforestation and preserving forests also have strategic roles.

Current Research Goals

Carbon sequestration research is focused on improving understanding of the exchange of carbon between the land, atmosphere, and oceans, and how global change affects these dynamics; assisting public, State, and private landowners and the forest industry with integrating carbon management into their forest management and production goals; and assisting policymakers in balancing carbon sequestration and forest resilience with requirements imposed by the need to sustain ecosystem services. Carbon sequestration research includes:

- Developing new concepts and information from monitoring and modeling of CO_2 dynamics of forests in response to management and disturbance, from studying land use changes and their causes, and from experiments to determine how increasing atmospheric CO_2 concentrations affect forest growth under changing climate and air pollutant stresses.
- Inventing new wood products from currently unused forest growth, developing new processes to generate fuels from cellulose more efficiently, and creating new equipment that minimizes transportation and fuel costs while processing small diameter woody biomass and other residues.
- Performing analyses to document and reduce the carbon "footprint" of forest management and administrative activities within and outside the Forest Service.
- Continuing and improving monitoring systems at multiple geographic and temporal scales that integrate data from extensive inventories, remote sensing, and intensive observation sites, such as Forest Service experimental forests and ranges.

Research Needs

Research actions to support increased carbon sequestration focus on evaluating the current processes and status of carbon sequestration and the fate of its removals to bioproducts, more specifically:

- Synthesize and analyze what we know and don't know with respect to net carbon sequestration in forests and wood products.
- Expand monitoring to more fully represent the U.S. forest and range landscape, including all of the ecosystem carbon pools that are likely to be affected by land management and natural disturbance.

- Determine the impact of land use and management activities (e.g., restoration, silviculture) and climate change on global warming potential, which includes carbon, albedo, transpiration, and trace greenhouse gases.
- Improve the understanding of factors controlling land-use change, the quantification of past trends, and the ability to make projections and estimates of long-term impacts on carbon stocks.
- Quantify and model spatial distribution of the forms of carbon in soil and the effects of management, climate, and land-use change on the time of residence for those forms.
- Provide estimates of local and national woody biomass supply to meet the increasing interest in fuels from biomass.
- Improve technical, ecological, economic, and carbon performance of forest operations to produce woody biomass for fuels at competitive costs.
- Develop and use life-cycle analysis to improve forest management and wood-use alternatives for bioenergy and other bioproducts.
- Provide integrated strategic evaluation of local, regional, and national policies and management actions.

- Develop cost-effective tools for verification of actual carbon sequestration at a local scale, including sequestration in soil, and address issues such as leakage and baseline setting.
- Quantify the uncertainty in estimates of future change in ecosystem carbon stocks and wood products in order to conduct risk analysis and build risk estimates into carbon management strategies.
- Identify market approaches to integrate carbon management, biofuels production, and timber management.
- Evaluate the social acceptance of alternate carbon management policies and management practices.

Near-Term Research Products

Carbon sequestration products will inform policymakers, land managers, and citizens on the many issues involved in this strategy. Specifically, Research and Development will:

- Develop a concise, approachable, and authoritative synthesis of the literature about what is known, uncertain, and unknown regarding carbon sequestration and management.
- Implement regional case studies on changes in land management that could increase carbon sequestration on land and in products that will serve as examples for managers.
- Augment existing decision-support tools to include life cycle inventory and analysis (measurement of greenhouse gas emissions and sinks, energy use, and costs and benefits from regeneration to harvest to material use and disposal).
- Improve RPA assessments by adding analysis of biofuels, carbon, and commodity market supply and demand to provide decisionmakers with important new information about future carbon sequestration potential.
- Work with emerging carbon markets and registries to ensure adoption of consistent and credible accounting rules and estimation guidelines.

Figure 2. Mitigation of climate change impacts: Monitoring forest carbon exchange with eddy-flux towers, here at Forest Service Northern Research Station facilities in Howland, ME. The towers support the apparatus used to measure the hourly uptake and release of CO_2 by trees and the soil and determine impacts on carbon storage by management treatments over daily, seasonal, and annual growth cycles. *Photo from John Lee, University of Maine.*

3. Research To Provide Decision Support

Research products designed for education of forestry personnel, as well as of other stakeholders and the general public, are designed to promote decisionmaking based on best available science.

Decision Support for Climate Change

Research to support policy, planning, and land management decisionmaking is aimed at translating the available scientific information into useable management and planning information. Research products designed for education of forestry personnel, as well as of other stakeholders and the general public, are designed to promote decisionmaking based on best available science. Adaptation and mitigation research will have little impact without clearly articulated needs by practitioners, decisionmakers, and policymakers or a clear understanding by the various publics. Hence, this research must be planned in response to specific decision-support needs expressed by the user community.

Current Research Goals

Research for decision support is primarily comprised of synthesis and assessment. and development of user-oriented models. Decision-support research allows us to integrate and optimize production of ecosystem services under climate change, to modify models currently used in land management that will incorporate impacts of climate change, to enhance data sets (including regional climate scenarios) and computing capabilities that will support model development and application, and to carefully analyze and synthesize information for different audiences.

Decision-support research involves:

- Increasing our understanding of environmental needs by species and ecosystems for successful adaptation.
- Assessing past, current, and future trends in carbon storage and release.
- Revising available forest growth and production models and wildlife habitat models to include climate and climate variability.
- Revising available physical (e.g., erosion) and hydrological models to include a wider range of extreme climatic events (e.g., intense rainfall).
- Developing carbon accounting tools for forest managers.
- Implementing pilot land management planning studies.
- Developing education programs to teach managers and policymakers how to use the decision-support models and documents.

It is notable that many of these decision support goals do not explicitly involve new scientific research per se, but must be based on sound science that has evolved enough to address emerging needs.

Research Needs

Research actions to enhance decision support are focused primarily on improving and creating management-friendly models that can predict ecosystem, population, and habitat responses at multiple scales of time and space. Specifically, actions include:

- Develop models that integrate linkages among climate and other stress agents and responses by biotic and physical components of the environment, on which understanding of multiple stressors and their interactions can be based.

- Determine the important emergent thresholds, tipping points, and phase transitions of landscapes under changing climates, by including these interactions in models used to investigate climate change, so that resource managers can anticipate those changes and plan accordingly.
- Continue the development of economic models and incorporate them into Integrated Assessment Models that simulate the complete system that begins with climate change and follows carbon sequestration, ecosystem resilience, ecosystem services, forest/range products, and biofuels.
- Develop partnerships among scientists, stakeholders, and communications experts to provide user-friendly information and access in a variety of formats.
- Continue to improve decision-support tools for managing carbon according to the needs of different stakeholders, with specific enhancements involving more complete accounting for all factors that affect global warming potential.
- Continue to seek opportunities to engage in cooperative research highlighting Forest Service expertise with expertise of other Federal and State researchers.

It is notable that many of these decision support goals do not explicitly involve new scientific research per se, but must be based on sound science that has evolved enough to address emerging needs.

Near-Term Research Products

Decision-support products expected during the next few years involve creating and modifying important resource management models to integrate climate change. Specifically, Research and Development will:

- Downscale climate-change-model output to provide climate change scenarios for local applications, alone and by working with other agencies (e.g., National Oceanic and Atmospheric Administration and the U.S. Department of the Interior) that are pursuing this goal.
- Modify the widely used planning model, FVS (Forest Vegetation Simulator), and other landscape models to include impacts of changing climate and atmospheric chemistry.
- Modify or develop continental or regional-scale models that can assess climate change and impacts of other stressors, such as land use and management, including feedbacks to the atmosphere and provision of user-friendly interfaces to models that currently lack them.
- Work with emerging carbon markets and registries to ensure consistent and credible accounting rules and estimation guidelines, and provide access to decision-support tools that facilitate carbon management.
- Support these actions with a comprehensive effort to consolidate existing data sets, to reformat data into common data structures, and to share these formats and data sets with researchers in other Federal and State agencies. In so doing, the Forest Service will cooperate with other Federal and State researchers to form a comprehensive program investigating climate change in the Nation's lands.

4. Shared Research Needs: Infrastructure, Scientific Collaboration, and Science Delivery

The Forest Service must be capable of modeling air, water, forests, woodlands, and grasslands, including processes in individual sites and stands, species populations, landscapes, and regions.

Corporate Strategies for Addressing Climate Change

The adaptation, mitigation, and decision support research required to generate the science and applications is best considered within each research element described above. However, certain infrastructure, personnel, and technology transfer needs sustain all three research elements and require a coordinated national effort within the Forest Service. This section describes the infrastructure, scientific collaboration, science delivery, and funding needs to support the research elements described above.

Infrastructure

There are national facilities and infrastructure needs critical to the success of Forest Service research in addressing climate change. A remote-sensing capability is necessary to attain goals for carbon sequestration, ecosystem resilience, bioproduct generation, and decision support. A strong program to format and downscale climate model projections for research and management use and the ability to monitor changes and the impacts of land management decisions are also critical infrastructure needs. Similarly, all three research elements depend on maintaining a strong research base in vegetation inventory and analysis (including Forest Inventory and Analysis), genetic analysis and selection, air/land/water monitoring, modeling at different scales, and integrated assessment modeling to reveal unintended consequences of future policies.

Even with good interagency cooperation, it is clear that the Forest Service needs to create a comprehensive environmental simulation modeling capacity with the required personnel and computing infrastructure specifically designed to meet the needs of Forest Service and State and private resource managers in land management planning and project management. The Forest Service must be capable of modeling air, water, forests, woodlands, and grasslands, including processes in individual sites and stands, species populations, landscapes, and regions. The Forest Service must be responsible for obtaining downscaled climate scenarios and formatting and maintaining data sets. The Forest Service also must be capable of providing the quantification and future projections needed for various assessments of climate-change-related questions.

Other actions the Forest Service should take to enhance common facilities and assets, before or during development of a modeling center, include the following:

- Coordinate Data. The collection, consolidation, and formatting of data for analysis and modeling must be significantly enhanced, as they are the basis for developing comprehensive, mechanistic understandings of climate change effects.
- Share Data. The Forest Inventory and Analysis program has the most complete and comprehensive monitoring database in the world. Moreover, many types of important global-change research data could be collected by Forest Inventory and Analysis at minimal cost to improve climate change research efforts.
- Use Experimental Forests and Ranges and Research Natural Areas. These cover most ecosystems in the United States and hence are very appropriate in future global change research. Experiments that define ecosystem responses to climate change along

Figure 3. Infrastructure needs to study climate change impacts: FACE (Free Air CO_2 Enrichment) experiment conducted at Forest Service Northern Research Station facilities in Rhinelander, WI. CO_2 is pumped out of pipes, controlled by sensitive anemometers, in order to assure a high CO_2 concentration at all times inside each ring. The photo shows several replicates of experimental (CO_2, ozone) fumigations, and the control rings (no fumigations). FACE experiments require $1 to 2 million in CO_2 supplies and maintenance, yearly. *Photo by David Karnosky, Michigan Technological University.*

temperature and precipitation gradients can be conducted entirely on experimental forests and ranges and research natural areas. Moreover, most of the experimental forests and ranges and some of the research natural areas have long-term, spatial data that could be provided to global change scientists at minimal cost.

- Provide a competitive grants program. A competitive grants program, either intra-agency or interagency, open to all Federal and non-Federal scientists, is an effective means to maintaining a cohesive and successful national research strategy.

Scientific Collaboration

Climate change science is complex and requires the interactive research by scientists from many different disciplines, only a few of which are represented at any one research station or laboratory. While there is already considerable collaboration and communication between scientists in the Forest Service research and management communities, much more can be done to facilitate and improve collaborative studies across station boundaries, including:

- Improving Interactions. An informal virtual communication structure (video conferencing, Web communication of preliminary results) would help Forest Service and other ecosystem scientists interact and share knowledge and data with climatologists, ecologists, hydrologists, modelers, and other specialists, and managers who are attempting to develop and implement adaptation and mitigation strategies on the ground. As funding and resources become available, a formal structure for communication could evolve that would facilitate communication and learning by all involved. In addition, the Forest Service needs to build executive-level efforts to link with climate change activities in other management agencies, such as the National Oceanic and Atmospheric Administration, the Bureau of Land Management, and the U.S. Fish and Wildlife Service.
- Improving Incentives. Forest Service scientists often perceive significant disincentives for cross-station activities, especially those that include participation in informal teams. Disincentives that are often cited include a panel process that stresses the preeminence of first-authored, peer-reviewed publications; a spatially diffuse organization that stresses service to local clients; and a tendency to award funds using station-specific trickle-down approaches. Each of these issues must be evaluated and significantly improved if the cross-station collaboration critical to progress on global change research issues is to take place.
- Improving Inter-Deputy Cooperation. The Forest Service is beginning to initiate, coordinate, facilitate, and review activities among and within the deputy areas to enhance the development and application of research to the NFS and State and Private Forestry Deputy areas. This Forest Service-wide effort, under the direction of a new Forest Service Climate Council, will also provide much-needed improvement to integrate the Forest Service Global Change Research Program and other Forest Service research programs, such as Forest Inventory and Analysis and the National Fire Plan.

Science Delivery

A primary force behind Forest Service research is the drive to produce results that make a difference in the condition of the Nation's forests, woodlands, and grasslands. The process of understanding the users and their information needs, targeting scientific studies to meet those needs, developing research products that make sense to users, and seeking user feedback to refine those products constitute a cycle of activities that ensure effective science delivery. Research and Development must enhance this cycle of activities. Scientists must become involved in a continuing two-way dialog with users to identify potential future issues that managers may encounter. At the same time, Research and Development must develop different strategies for different stakeholders, striving to deliver science to practitioners, private landowners, Federal and State resource managers, policymakers, and the public in general.

Science delivery is a challenging interface issue in the Forest Service, even where science delivery has a long tradition of occurring with success, such as in fire science and management. While research-management partnerships are often discussed, they must be institutionalized to ensure successful infusion of climate change science in management and planning. In addition, special effort is needed to transcend traditional or perceived barriers between research and management and between different disciplinary and administrative structures within the Forest Service. Activities to enhance science delivery within the Forest Service include the following:

- Make major changes in the scientist review process for meaningful participation by Forest Service research scientists in the science-delivery process. Currently, little advancement credit is given for non-research activities.
- Include a strategic plan to deliver science that describes the products desired, product life cycle, and chain of responsibility for those products for research projects at the program or team level.
- Ensure that large research teams have science-delivery personnel who are closely involved with research, familiar with the team's user community, and able to judge and implement the best mechanism for delivery.
- Facilitate collaboration over time with regularly scheduled meetings and designated personnel in both science and management who are responsible for climate change issues.
- Ensure that trained science communicators at the station and national level coordinate with individual scientists in the delivery of scientific knowledge to the public and policymakers.

A second important facet of science delivery will be the enhancement of relationships with organizations outside the Forest Service. The Forest Service should partner with other U.S. Department of Agriculture agencies, such as the Cooperative State Research, Education, and Extension Service, as well as with nongovernmental organizations, and, in particular, with private consultant groups, that are used often by private landowners seeking guidance on forest and grassland management. For example, modeling tools such as iTree and COLE were developed with partnerships between Forest Service, the private sector, and several non-government organizations.

Research efforts by other Federal science agencies are also critical to Forest Service science delivery efforts. The National Oceanic and Atmospheric Administration, for example, is developing regional climate scenarios in its Regional Integrated Sciences and Assessments Program. The Forest Service vegetation modeling efforts have a vital need for these scenarios. Another example is that the Forest Service hydrology projections depend on the stream gauge network that the U.S. Geological Survey operates. Forest Service research also will benefit by partnering with various scientific societies, such as the American Geophysical Union and the Ecological Society of America, that can be viewed as the honest brokers of scientific knowledge. These part-

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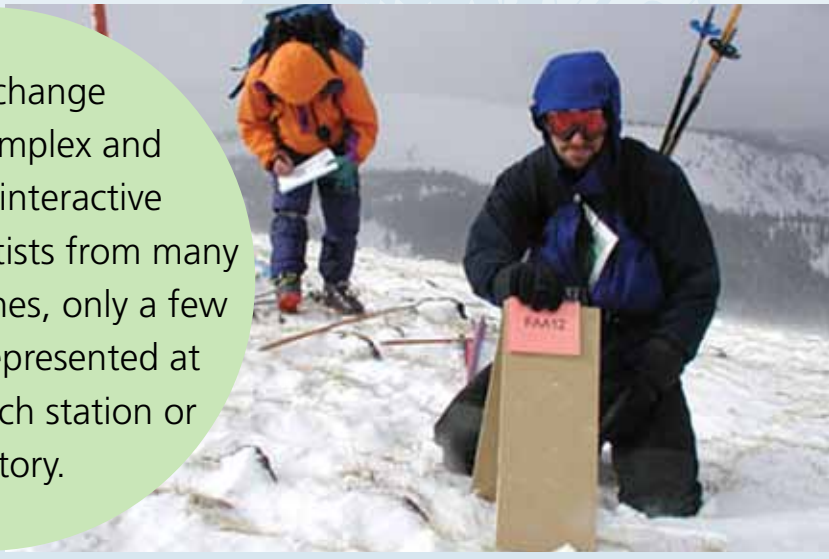

nerships can help to coordinate the synthesis, provide peer review, and develop various products beyond the typical peer-reviewed journal article. The results of these interactions should be a series of developments aimed specifically at effective and efficient science delivery to stakeholders, including:

- **Regional Centers of Excellence.** Locate several teams of geographic information system/modeling/climate change specialists around the country to provide managers with the regional resources and information they need to successfully complete planning and management projects.
- **User-Friendly Models.** Provide computer models, both qualitative and quantitative, as a set to simulate, synthesize, and summarize climate change effects into desirable formats that are easy to use, easy to parameterize, and easy to initialize.
- **Training Courses.** Develop a set of training courses to teach managers (1) how to integrate climate change into common analyses, and (2) how to run the models.
- **Certification Programs.** Develop a set of requirements to certify managers to deal with climate change issues. This would include training courses, modeling exercises, and practica.
- **Public Outreach.** Use existing networks to educate, inform, and elicit public preferences with respect to all aspects of adaptation to and mitigation of climate change. The Forest Service has extensive involvement with the public and a strong connection to local communities concerning management of all national forests.
- **Extension Scientists.** NFS and State and Private Forestry Deputy Areas should hire scientists and technicians specifically to direct the science delivery into manager's hands so that its use will be valid and credible. In addition, the Forest Service should work with the USDA Cooperative State Research, Education, and Extension Service, which includes approximately 350 land and forest extension agents who can provide global change science information to their clients.

5. Concluding Thoughts

The potential impacts on forest, woodland, and grassland ecosystems, and the ways these systems can provide mitigation options, are of the utmost importance.

Climate change is occurring and the Forest Service Research and Development branch is well poised to address this issue on various fronts, as well as to partner with other interested organizations to expand our knowledge base and capacity. The potential impacts on forest, woodland, and grassland ecosystems, and the ways these systems can provide mitigation options, are of the utmost importance.

The Forest Service Global Change Research Strategy Overview provides a synthesis and summary of the larger research strategy. This summary and synthesis is intended to lay out our current and planned future research program on climate change with land manager and decisionmaker needs at the forefront. It was synthesized from a much more detailed document, "US Forest Service Global Change Research Plan" available on the Forest Service global change web page in 2009. The Strategy is closely coordinated with other USDA global change strategy documents, including the "Global Climate Change Growth Platform, Forest Service, Research and Development Mission Area," the "Forest Service Strategic Framework for Climate Change," and the "USDA Strategic Plan for Climate Change Research, Education, and Extension," all currently under development for release in 2008.

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