United States Department of Agriculture
Forest Service
Research and Development

Global Change Research Strategy

2009-2019

Synthesis

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US Forest Service Global Change Research Strategy
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Executive Summary
US Forest Service Global Change Research Strategy
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Objective: In keeping with the research goals of the US Climate Change Science Program, the USDA Forest Service (FS) Research and Development agenda helps define climate change policy and develop best management practices for forests (both rural and urban) and grasslands in order to sustain ecosystem health, optimize ecosystem services ("adaptation"), and increase carbon sequestration ("mitigation"), all under changing climate conditions. The fundamental research focus of the FS Global Change Research Strategy is to increase understanding of forests, woodlands, and grasslands 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 conditions of the past and present, and have high geographic variability. These geographic differences manifest in both biophysical conditions and socioeconomic systems, and as such, land management plans and actions must differ locally to account for this variability. There are also national needs to link these local actions so the sum of their impacts can be considered and evaluated. A challenge posed by changing climate that must be resolved through land management is 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.

To support this, a FS Global Change Research Strategy and the concomitant research are needed to balance and coordinate responses. This strategy is the basis for a unified approach to managing within the range of uncertainty provided by a changing climate.

Approach: The following document provides a summary of the FS Global Change Research Strategy. It balances research across a range of management, science, and technology transfer actions aimed at developing adaptation and mitigation approaches to sustain healthy trees and ecosystems. The following are research elements that serve as the organizing mechanism for this document.

1. The first element includes current and future FS research to enhance ecosystem health and sustainability, increase retention of newly sequestered carbon, and avoid carbon losses from major disturbances.
2. The second element focuses on research that will assist managers in enhancing carbon sequestration via management that could increase forest growth rates and area of forested lands; enhanced biomass extraction and utilization research and understanding long term carbon product storage pools.
3. The third element integrates the first two research elements by developing decision support tools and approaches for policymakers and land managers.
4. A fourth element is focused on the shared research needs for infrastructure, scientific collaboration, and technology transfer needed over the next decade to facilitate and implement in natural resource planning, the research and applications in the first three elements.

Synthesis: A US Forest Service Global Change Research Strategy for the Coming Decade 2009-2019

The Objective. A century of wildland policy and management has created large ecosystem commons in the US. These large commons produce a wide variety of goods and services enjoyed by all Americans; but they are threatened by several global forces including: climate change, land use change, invasive species, and changes in the global competitiveness of the US forest sector. In addition to traditional forest roles in supplying wood products, clean water and air, wildlife habitat, recreation, and so on; forests also play an important role in reducing the build up of greenhouse gases in the atmosphere by sequestering carbon. Now, they are also being viewed as potentially important sources of biomass energy feed stocks. Forest, woodland and grassland health and productivity are increasingly vulnerable to climate change, and can become unintended sources of carbon to the atmosphere when large wildfires and insect infestations arise, or land is converted to developed uses. For example, recent estimates are that about 10% of annual US fossil fuel emissions are sequestered in US forest growth every year, but increased wildfires are releasing some of that carbon back into the atmosphere.

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 it relates to the adaptation of ecosystems.

The Forest Service (FS) Global Change Research Strategy will help identify best management practices for urban and rural forests, woodlands and grasslands to sustain ecosystem health and a wide range of ecosystem services ("adaptation"); while also increasing carbon sequestration ("mitigation")—all under changing climate conditions. The fundamental research focus of the FS Global Change Research Strategy is to increase understanding of forests, woodlands, and grasslands 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 FS research strategy for climate change. It describes the basic functions the research must serve and the strategy needed to fulfill this. Research defined herein will support the needs of the broad range of stakeholders we serve including National Forest and Grassland (NFS) managers, other federal, state and local land managers, private landowners, industry and others.

The 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: warming in the lower atmosphere (troposphere) while cooling in the upper atmosphere (stratosphere); warming more at the poles than at the equator; more over land than over the sea; more in winter than in summer; more at night than in daytime; less rain in the subtropics and more in high latitudes; and increasing climate variability producing more large storms and longer, more intense droughts, etc..

As a result, the climate changes already measured and those predicted in the future differ considerably from place to place. The southwestern US is encountering increasing drought, the Northwest is undergoing longer, dryer summers and declining snowpacks, the Northeast has seen increased rainfall and flooding, warmer winters, and longer growing seasons; the Southeast, warmer winters with dryer summers; and the neotropics (Puerto Rico and Hawaii), 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, and are likely to experience increases in the variability of weather, such as droughts, storms and heat waves. 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, the approaches to be employed by managers in the NFS, in working to maintain the variety of ecosystem goods and services demanded by the public, may be quite different in specific locales from those employed by other landowners nearby, as their goals and objectives may differ. These considerations argue for a localized approach to land management.

Land managers have conveyed a sense of urgency, a real-time need for information. They are faced with planning for and making climate change related decisions today and 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 (see Appendix X).

- First, 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 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 landscapes, stakeholder input to decisions and actions, etc.).

A FS National Global Change Strategy and the concomitant research needed to implement it must be in place to balance and coordinate responses to these differences, as the basis for a unified approach to managing within the uncertainty of changing climates.

The Approach. Forests, woodlands and grasslands have an important role in mitigating and adapting to climate change. "Mitigation" addresses ways that ecosystems can sequester carbon, ways that carbon loss can be minimized, 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 (e.g., carbon, energy, pollution, etc.), and lead by example in greening our practices. "Adaptation" focuses on identifying the vulnerabilities of ecosystems (e.g., vegetation, wildlife, water) to different climate scenarios in diverse geographic regions; what management actions will sustain ecosystem services under a changing climate; and, how land managers can address different sources of uncertainty (environmental conditions, models, data, resources, planning horizons) as they plan for a future increasingly influenced by changes in climate. This planning includes minimizing carbon losses, and it melds adaptation and mitigation inextricably: there can be no increase in carbon sequestered without maintaining ecosystem health.

This document balances research across a range of management, science and technology transfer actions—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 US Climate Change Science Program.

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

1. The first element includes current and future FS research to enhance ecosystem health and sustainability, increase retention of newly sequestered carbon, and avoid carbon losses from major disturbances.
2. The second element focuses on research that will assist managers in enhancing carbon sequestration via management that could increase forest growth rates and area of forested lands; enhanced biomass extraction and utilization research and understanding long term carbon product storage pools.
3. The third element integrates the first two research elements by developing decision support tools and approaches for policymakers and land managers.
4. A fourth element is focused on the shared research needs for infrastructure, scientific collaboration, and technology transfer needed over the next decade to facilitate and implement in natural resource planning, the research and applications in the first three elements.

Elements of the Research Strategy.

1. Research to Enhance Ecosystem Sustainability (Adaptation)

Climate Change and Ecosystem Sustainability

The capacity of forests and grasslands to maintain current health, productivity, diversity, and resilience will likely be compromised under a changing climate. The efficacy of current management practices 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 ecosystem (i.e., presence of invasives, departure from historical fire regimes, condition of watersheds). 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

Research on adaptation is primarily focused on maintaining ecosystem health as much as possible, thereby protecting the goods and services ecosystems produce (e.g., air pollutant removal, clean and abundant water supplies, habitats to maintain wildlife and biodiversity, cycling of important nutrients, reducing success of exotic invasive species, recreation and aesthetics, etc.). 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. Forests, woodlands, and grasslands 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 strategy 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, altering species composition, reducing tree densities, and managing for uneven-age forests are some of the options that can enhance the water and nutrients available to remaining trees, thereby also increasing tree resistance to pests, reducing the spread of wildfire, and enhancing 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, less intensive management to sustain the production of the values and services that healthy forests provide.

Research Needs

- Improving our understanding of the potential impacts of a changing climate on the physical environment (e.g. erosion) and watershed dynamics.

- Enhancing 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 paleo-ecology and of paleo climate-vegetation dynamics to identify metrics to monitor ecosystems under a changing climate, and to define range of variability at local sites across ecosystems.
- Developing genetics information to identify species to plant and seed sources for reforestation, afforestation and gene conservation.
- Documenting interactions between multiple stresses under a changing climate, and potential for linear/nonlinear threshold responses to climate change,
- Enhancing our understanding of the changing relationships between climate and climate-mediated disturbances such as fire, insects, and disease.
- Developing needed scientific information, biotic and environmental monitoring methods, and models (including scalability and uncertainty measures) for decision-making in resource management and greater understanding of human and organizational adaptation to climate change.
- Focusing on understandings to increase and retain the sustainability of ecosystem services, particularly of water supplies, wildlife and fish populations, endangered species, and forest and grassland products.
- Enhancing understanding of the changing relationships between climate, land use change and climate-mediated disturbances.
- Reducing 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.
- Beginning 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

Research on enhancing ecosystem resilience under increasing climate stress will focus on developing and implementing a coordinated series of regional syntheses on the potential vulnerabilities and ecosystem responses to a changing climate for application by land managers.

- We will undertake 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.
- We will develop educational tools (courses, workshops, manuals, models) for all FS personnel, to teach the principles of climate change science and their applications in planning and managing sustainable ecosystems under changing climate.

- We will 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.
- We will 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.
- We will develop coordination for a large-scale research program and the associated means of support and execution aimed at predicting national climate change impacts.
- We will use pilot projects, particularly in the national Experimental Forests and Ranges, to develop and test strategies and systems for conserving and enhancing resource productivity and health (e.g., soil, water, habitat, biodiversity, vegetation, etc.).

2. Research to Increase Carbon Sequestration (Mitigation)

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 US 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, and relative to some other materials, wood may require less fossil fuel in harvest and production processes. Sustainably managed forest and range resources can replace fossil fuels with fuels derived from biomass, which utilize carbon already present in the global carbon cycle, rather than creating new carbon. Silvicultural and genetics research help to increase growth and enhance sustainability. Avoided deforestation and forest preservation also have strategic roles.

Current Research

Carbon sequestration research is focused on assisting public, state, and private landowners and the forest industry with integrating carbon management into their forest management and production goals, and in assisting policy makers in balancing carbon and forest resilience with requirements imposed by economic exigencies. Carbon research includes:

- Development of 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.
- Invention of new wood products from currently unused forest growth, the development of new processes to generate fuels from cellulose more efficiently, and the creation of new equipment that minimizes transportation and fuel costs while processing small diameter woody biomass and other residues.
- Analyses to document and reduce the carbon "footprint" of forest management and administrative activities within and outside the FS.

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 bio-products, more specifically:

- Synthesizing and analyzing what we know and don't know with respect to net carbon sequestration in forests and wood products.
- Determining the impact of land management activities (e.g., restoration, silviculture) and climate change on global warming potential, which includes carbon, albedo and trace greenhouse gases.
- Improving the understanding of factors controlling land-use change, the ability to quantify past trends and to make projections and estimates of long-term impacts on carbon stocks.
- Quantifying and modeling spatial distribution of the forms of carbon in soil, and the effects of management, climate, and land use change on residence time of those forms.
- Providing estimates of local and national woody biomass supply to meet the increasing interest in fuels from biomass.
- Improving technical, ecological, economic, and carbon performance of forest operations to produce woody biomass for fuels at competitive costs.
- Developing and using life cycle analysis to improve forest management and wood use alternatives for bio-energy and other bio-products.
- Providing integrated strategic evaluation of local, regional and national policies and management actions.
- Developing cost-effective tools for verification of actual carbon sequestration at a local scale, including sequestration in soil, and considering issues such as leakage and baseline setting.
- Quantifying 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.
- Identifying market approaches to integrate carbon management, bio-fuels production, and timber management
- Evaluating the social acceptance of alternate carbon management policies and management practices.

Near-Term Research Products

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

- We will develop a concise, approachable, and authoritative synthesis of the literature regarding what is known, uncertain and unknown regarding carbon sequestration and management.
- We will 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.
- We will augment existing decision-support tools to include inventory/life cycle analysis (measurement of carbon and dollar costs and benefits from harvest at the stump to material disposal or use, e.g. in bio-energy).

- We will improve RPA assessments by adding analysis of bio-fuels, carbon, and commodity market supply and demand, to provide decision-makers with important new information about future carbon sequestration potential.
- We will work with emerging carbon markets and registries to ensure adoption of consistent and credible accounting rules and estimation guidelines.

3. Research to Provide Decision Support

Decision Support for Climate Change

Research to support policy and land manager decision-making is aimed at translating the available scientific information into useable management and planning information. Adaptation and mitigation research will have little impact without clearly articulated needs by practitioners, decision makers and policy makers. Hence, that research must be planned in response to specific decision support needs expressed by the user community.

Current Research

Decision support research involves: increasing our understanding of environmental needs by species and ecosystems for successful adaptation; the assessment of past, current, and future trends in carbon storage and release; the revision of available forest growth and production models and wildlife habitat models to include climate and climate variability; the revision of available physical (e.g., erosion) and hydrological models to include a wider range of extreme climatic events (e.g., intense rainfall); the development of carbon accounting tools for forest managers, the implementation of pilot land management planning studies; and, the development of education programs to teach managers and policymakers how to use the decision support models and documents. It is notable that many of these 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 for decision support is primarily comprised of modeling and assessment: the creation of new models to integrate and optimize production of ecosystem services under climate change; the modification of models currently used in land management to incorporate impacts of climate change; the enhancement of data sets (including regional climate scenarios) and computing capabilities to support model development and application; and the careful analysis and synthesis of information for different audiences.

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,

- Developing models that integrate linkages among climate and other stress agents, and responses by biotic and physical components of the environment, if we are to understand multiple stressors and their interactions.
- Determining 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.

- Continuing 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 bio-fuels.
- Partnering scientists and communications experts together to provide user friendly information and access in a variety of formats.
- Continuing 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.
- Continuing to seek opportunities to engage in cooperative research highlighting FS expertise with expertise of other federal and state researchers.

Near-Term Research Products

Decision support products expected during the next several years involve creation and modification of important resource management models to integrate climate change.

- We will downscale climate change model output to provide climate change scenarios for local applications, alone and by working with other agencies (e.g., NOAA) that are pursuing this goal.
- We will modify the widely-used planning model, FVS (Forest Vegetation Simulator) and other landscape models to include impacts of changing climate and atmospheric chemistry.
- We will modify or develop continental or regional-scale models that can assess climate change and impacts of other stressors and land-use or management, including feedbacks to the atmosphere and provision of user-friendly interfaces to models which currently lack them.
- We will 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.
- We will support these efforts 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 FS 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, Technology Transfer

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 FS. This section describes the **infrastructure, scientific collaboration, science delivery and funding needs** to support the above described research elements.

Infrastructure. There are national facilities and infrastructure needs critical to FS research succeeding in addressing climate change. A remote sensing capability is necessary to attain goals for carbon sequestration, ecosystem resilience, bio-product 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 require capabilities in vegetation inventory and analysis (including Forest Inventory and Analysis), genetic analysis and selection, air/land/water monitoring, modeling at several different scales, and integrated assessment modeling to reveal unintended consequences of future policies.

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

Other actions the FS 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 (FIA) 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 FIA at minimal cost to improve climate change research efforts.
- *Experimental Forests and Ranges (EFRs) and Research Natural Areas (RNAs)* must be used in future global change research. Experiments that define ecosystem responses to climate change along temperature and precipitation gradients can be conducted entirely on EFRs and RNAs. Moreover, most of the EFRs and some of the RNAs have long-term, spatial data that could be provided to global change scientists at minimal cost.
- *An intra-agency competitive grants program*, or an interagency program open to all federal and nonfederal 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 FS research and management communities, much more can be done to facilitate and improve collaborative studies across station boundaries.

- *Improving Interactions.* An informal virtual communication structure (video conferencing; web communication of preliminary results) would help FS 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 became available, a formal structure for communication could evolve which would facilitate communication and learning by all involved. In addition, we need to build of executive level efforts to link with climate change activities in other land management agencies such as the US Geologic Survey, the Bureau of Land Management and the US Fish and Wildlife Service.
- *Improving Incentives.* FS scientists often perceive significant disincentives for cross station activities, especially those that include participation in informal teams. Evidence of these disincentives 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 FS 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 S&PF. This FS-wide effort will also provide the much needed improvement to integration between the FS Global Change Research Program and other research programs of the FS such as FIA and the National Fire Plan.

Science Delivery. A primary force behind FS 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 constitutes a cycle of activities that ensure effective science delivery. FS 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, FS research must develop different strategies for different stakeholders, as we strive to deliver science to practitioners, private landowners, federal and state resource managers, policy makers, and the public in general.

Technology transfer is a challenging interface issue in the FS, even where technology transfer 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 FS. Activities to enhance technology transfer within the FS include the following:

- Major changes in the scientist review process (currently no advancement credit is given for non-research activities) must be made for meaningful participation by FS research scientists in the science delivery process.
- Research projects at the program or team level must include a strategic plan to deliver science that describes the products desired, product life cycle, and chain of responsibility for those products.
- Large research teams should have science delivery personnel who are closely involved with research, familiar with the team's user community and able to judge the best mechanism for delivery.
- Regularly scheduled meetings and designated personnel in both science and management, responsible for climate-change issues, will facilitate collaboration over time.
- Trained science communicators at the Station and National level must coordinate with individual scientists in the delivery of scientific knowledge to the public and policy makers.

A second important facet of science delivery will be enhancement of relationships with organizations outside the FS. There is a need for the FS to partner with the other Department of Agriculture agencies such as Cooperative Extension as well as with non-governmental organizations (NGOs), and in particular with private consultant groups, which are often utilized by private land owners seeking guidance on forest and grassland management. For example, modeling tools such as iTree and COLE were developed with partnerships between FS, the private sector, and several NGOs. Other federal science agencies are also critical to FS technology transfer efforts. The National Oceanic and Atmospheric Administration, for example, is developing regional climate scenarios in its Regional Integrated Sciences and Assessments Program for which FS vegetation modeling efforts have a vital need, and US Geologic Survey operates the stream gauge network on which FS hydrology projections depend. FS Research also will benefit by partnering with various scientific societies, such as the American Geophysical Union or Ecological Society of America which can be viewed as the "honest brokers of scientific knowledge," to coordinate the synthesis, provide peer review, and to develop various products beyond the typical peer reviewed journal article. The results of these interactions should be a series of actions aimed specifically at effective and efficient technology transfer to stakeholders, as follows:

- *Regional Centers of Excellence.* Several teams of GIS/Modeling/Climate change specialists should be located around the country to provide managers with the regional resources and information they need to successfully complete a project.
- *User-Friendly Models.* Computer models, both qualitative and quantitative, should be provided 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.* A set of training courses should be developed to teach managers 1) how to integrate climate change into common analyses and 2) how to run the models.
- *Certification Programs.* A set of requirements should be developed so that a manager can be certified to deal with climate change issues. This would include training courses, modeling exercises, and practica.

- *Public Outreach.* The FS has extensive involvement with the public and a strong connection to local communities concerning management of all National Forests. This network offers unparalleled opportunities to educate, inform, and elicit public preferences with respect to all aspects of adaptation to and mitigation of climate change.
- *Extension Scientists.* NFS and S&PF should hire scientists and technicians specifically to direct the science delivery into manager's hands so that it will be used in the correctly.

Costs: Implementing the programmatic goals enunciated in the four strategy elements above will take forests and grasslands in the US a considerable distance down the road of adapting to and mitigating current and future climate change impacts. The expenditure of approximately $75-$100 million each year for the next 10 years will be required to implement this program. The cost is moderate compared with many research programs of less obvious value, yet the cost is also real and must be met if this strategy is to be implemented effectively.

Concluding Thoughts.

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

The FS Global Change Research Strategy Synthesis provides an overall summary of the larger research strategy. This summary is intended to present our current and planned future research program on climate change with land manager and decision-maker needs at the forefront. The larger strategy will be made available and provides extensive detail for each of the suggested elements and topics.

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