WORKSHOP: Climate Change and Managing Fish and Wildlife

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[Editors' note: The following paper was an exemplary contribution to the all-day workshop on Tuesday, March 17. It and some of the other workshop presentations will be featured in the Projects window at www.wildlifemanagementinstitute.org.]

Managing Fish and Wildlife Habitat in the Face of Climate Change: USDA Forest Service Perspective

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Introduction

The spatial and temporal scope of environmental change anticipated during the next century as a result of climate change presents unprecedented challenges for fish and wildlife management. The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007) suggested impacts from climate change on natural systems will be more grave than earlier projections. Recent reports on emissions, glacial melting, and sea level rise (Kintisch 2009) intimate that even the 2007 IPCC report is conservative in its assessment. The challenges posed by climate change cut across all aspects of land and resource management – difficult decisions will need to be made in the areas of agency policy, scientific research, and prioritization of resource management actions.

Crafting land management in the face of long-term climate change adds new complexities to an already difficult task of managing habitat to support sustainable populations of fish and wildlife. For instance, uncertainties in the trajectories of climate and ecosystem response alter the way the managers must deal with uncertainty and employ science to meet management goals and objectives (Millar et al. 2007, Safford et al. 2008). Furthermore, biologists must manage species in a world where stationarity cannot be assumed— the management environment will change in a directional way rather than varying around some mean condition (Milly et al. 2008). Finally, planning must focus on spatial and temporal scales that are broader and longer than typically considered.

Over a century of managing National Forests and Grasslands provides the Forest Service unparalleled experience in the social, political, and ecological complexities of broad-scale land and resource management. The complexity posed by climate change is, for the most part, not new. As noted in the U.S. Climate Change Science Program's Synthesis and Assessment Product 4.4 (Julius et al. 2008:1-2) "[m]any existing best management practices for 'traditional' stressors… have the added benefit of reducing climate change exacerbations." Forest Service resource managers have always worked in an environment of uncertainty and the agency has access to a wide array of management tools to meet even the most novel resource needs, including a research branch to constantly modernize the tool box. Although climate change represents a major challenge for fish and wildlife management, the Forest Service is uniquely well-positioned to meet the challenge.

The U.S. Forest Service recently mobilized to meet the challenges posed by climate change. Building on a century of climate-related studies, for the last two decades Forest Service Research and Development has directly investigated climate change and its implications for the nation's ecosystems. In 2008, agency leadership developed a set of strategic focus areas to guide coordinated research/management action to confront the challenges of climate change on National Forest and Grasslands. This focus on climate change harnessed significant energy and interest within agency personnel and motivated a myriad of local and national activities to manage fish and wildlife in the face of climate change.

This invited review explores progress that the research and management branches of the Forest Service have made addressing fish and wildlife management in the face of climate change. In this paper, we begin by providing an overview of the agency's research and management context. Key to this overview is the Forest Service Strategic Framework (U.S. Forest Service 2008a) for responding to climate change, which defines three broad categories of agency goals that guide the incorporation of climate change into natural resource management. Through a series of case studies we demonstrate progress the agency has made in each of those broad goal categories. We conclude by reviewing those features of the Forest Service that position it as an important partner in addressing climate change, and by highlighting some of the management, research, and policy opportunities that must be seized if fish and wildlife are to be successfully managed in the face of climate change.

Forest Service Management Context

Organizational, Ecological, and Geographic Context

The outcome of resource management depends critically on the social, ecologic, and geographic context of management (Groves et al. 2002, Stokstad 2005, Lindenmayer et al. 2008). Therefore, understanding the dominant factors establishing the management context for the agency helps define the limitations and opportunities for management of fish and wildlife habitat by the agency.

Organizational context. Throughout a century of land management, the Forest Service has responded to uncertainty and gaps in knowledge through research/ management partnerships The organizational structure of the Forest Service provides a strong science-management link that facilitates rapid development and testing of management approaches. In particular, close research/ management relationships afforded by a shared administration for both the management and research arms in a single agency provide the opportunity for clinical trials and formal adaptive resource management (Walters 1986). A broad system of 80 experimental forests and ranges along with 193 million acres of National Forest System lands provide unparalleled opportunities to observe and manipulate ecosystems, organisms, and ecological processes in the field. Pertinent examples include ground-breaking studies of watershed processes (Likens and Bormann 1995), long-term response of forest to disturbance (Troendle and King 1985), and approaches to actively managing forest to support old forest associated wildlife (Carey 1995, 2000). The support provided by Forest Service research extends directly to evaluating fish and wildlife management in the face of climate change (Koopman et al. 2009).

Ecological and geographic context. Among land owners and stewards in North America, the Forest Service is in a unique position to influence fish and wildlife resources owing to the size of its geographic footprint. The Forest Service is directly responsible for stewardship of over 193 million acres (78.1 million ha) of wildlands from Alaska to Puerto Rico and influences management of nearly 430 million acres (174 million ha) of state, private, and tribal forests through partnerships with states, tribes, and private landowners. The vast geographic range of Forest Service jurisdiction extends from approximately 18° to over 61° north latitude, representing ecosystems from tropical rainforests to deserts, coastal ecosystems to high alpine sites, grasslands and shrublands to hardwood and conifer forest. This results in considerable variation, not only in the environments themselves, but in the climate change trends these environments are likely to experience.

Layered upon the foundation of ecological and environmental variation is an extremely complex geographic pattern of land ownership. Interactions between these ecological and jurisdictional patterns influence the array of management options and scope of influence the Forest Service has on fish and wildlife habitat management.

- East of the Missouri and Mississippi Rivers, the Forest Service manages a minor portion of the landscape that consists primarily of former private lands that were abandoned at the beginning of the last century after failed attempts at agriculture. Forest Service ownership in the midwestern and eastern United States is comprised mostly of relatively small parcels dispersed across many states and jurisdictions. The complex pattern of land ownership presents a major challenge to coordinating management in response to climate change across this broad and diverse area.
- In contrast to the ownership pattern in the eastern United States, the Forest Service is responsible for management of vast areas of contiguous landscapes in 11 western states and Alaska. This ownership pattern presents opportunities for broad coordinated planning and implementation not possible in the East. Despite broad similarities in land ownership patterns across the western states — for example the Forest Service generally manages most middle- to high-elevation lands — patterns of climate change are expected to differ in the direction

and magnitude of change in precipitation, temperature, and seasonal patterns. Hence, in the West, impediments to Forest Service efforts to manage fish and wildlife habitats under changing climates will probably be due to strong ecological and climate gradients and the scale of the problem rather than jurisdictional complications.

- Checkerboard ownership on many National Grassland units in the Great Plains presents a particularly challenging context for executing consistent management across broad areas. Given limited topographic relief in the Great Plains, the consequences of climate change may result in especially dramatic shifts in species distributions and unique challenges for managers (Peterson 2003, Johnson et al. 2005). In this region, the patchy nature of remaining Great Plains habitat, a diverse and changing economy, and varied land ownership patterns may interact with climate to create a “wicked” problem in fish and wildlife conservation (*sensu* Rittel and Webber 1973).

The effectiveness of actions taken by the Forest Service to manage fish and wildlife habitat in the face of climate change will depend critically on the particular ecosystems being managed and geographic variation in patterns of neighboring land ownership. History, geography, ecological conditions, and patterns of climate change have influenced, and will continue to influence, agency management of fish and wildlife habitat. Careful, deliberate consideration of context will improve the development of policy, crafting of adaptation and mitigation plans, and implementation of active management. Before reviewing several case studies, we first provide an overview of the agency’s strategic framework and use it to organize our case study examples.

Strategic Framework

In 2008, the Forest Service drafted and adopted a “Strategic Framework for Responding to Climate Change” (hereafter referred to as “Framework”) to provide broad guidance as the agency plans and implements land management activities in a climate change context (U.S. Forest Service 2008a). The document includes seven “strategic elements” that, for the purposes of this paper, are grouped into three goal categories: Foundational, Structural, and Action goals. These categories and the accompanying strategic elements, outlined in Table 1, are discussed in further detail below.

Foundational Goals: Science and Education strategic elements. The two strategic elements in the “Foundational Goals” group, science and education, address core information and awareness needs of the agency. The “Science” strategic element identifies the need to enhance the environmental, social, and economic knowledge and information base that informs actions on the ground, particularly mitigation and adaptation activities. This includes, but is not limited to, application of downscaled models, vulnerability analyses, and evaluating trade-offs in management considerations.

The “Education” strategic element highlights the essential importance of common understanding and awareness of climate change among agency employees and the public. As the climate changes, acclimating managers to this new language, its application, and the changing demands on management is a high priority.

Structural Goals: Policy and Alliances strategic elements. As a governmental entity and public lands manager, the Forest Service must have certain “infrastructure” in place in order to make decisions and carry out management. This must be done legally, appropriately, and in keeping with scientific information, management needs, and the public’s vision. The two key pieces of this “infrastructure” include climate change relevant and responsive policy (“Policy” strategic element) and collaborators within and beyond National Forest System boundaries to broaden and deepen the Forest Service’s own expertise, perspective, and effectiveness (“Alliances” strategic element).

Action Goals: Adaptation, Mitigation, and Sustainable Operations strategic elements. Climate change literature relevant to management actions has converged on the “adaptation” and “mitigation” breakdown (language adopted by the Forest Service in the Framework). Specifically, adaptation addresses those actions that enable or enhance the capacity of natural systems to adapt to climate change stressors and maintain ecosystem functions and services, while mitigation accounts for those activities that address ecosystem capacity to store carbon.

Successful mitigation is contingent on well-adapted systems, and this relationship is an important consideration in future management. In order to emphasize the key importance of adaptation in management success, agency leadership has emphasized that the Forest Service should be an “international model of excellence in sustaining forest health, diversity, and productivity in the face of climate change” (U.S. Forest Service 2008b). Given management’s uncertainty associated with climate change, collaboration between research and management that is focused on experimentation and monitoring, with an eye toward modifying approaches, will be invaluable as climate change adaptation becomes a focus of fish and wildlife habitat management.

The Forest Service also acknowledges its responsibility and contribution to greenhouse gas (GHG) emissions. As such, the Framework includes a “Sustainable Operations” strategic element. Under this element, the agency observes and modifies business practices and other operations for potential GHG emissions reductions opportunities (Table 1).

Case Studies

Forest Service efforts to manage fish and wildlife habitat under changing climates vary from recent actions motivated entirely by climate change concerns, to existing projects or plans that have been modified to accommodate anticipated climate shifts. In this section, we highlight a small subset of actions being taken by the Forest Service at national, regional, and local scales to illustrate the scope and breadth of climate change response in Forest Service management. Our case studies are organized by the three Framework goal categories described above (Table 1). We stress programs and projects focused on adaptation strategies rather than mitigation, since these more directly relate to fish and wildlife habitat conservation and management.

Table 1. Overview of U.S. Forest Service "Strategic Framework for Responding to Climate Change." (U.S. Forest Service 2008a).

Goal Category	Strategic Elements
Foundational	**Science:** Advance our understanding of the environmental, economic, and social implications of climate change and related adaptation and mitigation activities on forests and grasslands.
	Education: Advance agency and public awareness and understanding regarding principles and methods for sustaining forests and grasslands, and sustainable resource consumption, in a changing climate.
Structural	**Policy:** Integrate climate change, as appropriate, into Forest Service policies, program guidance, and communications and put in place effective mechanisms to coordinate activities across the management, research, and extension branches of the agency.
	Alliances: Establish, enhance, and retain strong alliances and partnerships with federal agencies, state and local governments, tribes, private landowners, non-governmental organizations, and international partners to provide sustainable forests and grasslands for present and future generations.
Action	**Adaptation:** Enhance the capacity of forests and grasslands to adapt to the environmental stresses of climate change and maintain ecosystem services.
	Mitigation: Promote the management of forests and grasslands to reduce the buildup of greenhouse gases, while sustaining the multiple benefits and services of these ecosystems.
	Sustainable Operations: Establish the Forest Service as a leading example of example of a green organization by reducing our operations environmental footprint.

Foundational Goals

Forest Service resource managers are poised to take action to adapt to climate change. However, uncertainty regarding the actual trajectories of change may encourage the status quo and a reluctance to modify traditional management practices. A period of delay in applying climate change motivated action unavoidably occurs. Specifically, science must develop an informational basis for action, management must consider uncertain outcomes of given actions, and agency leadership needs to build new policy and strategies. Furthermore, outreach and education programs must be developed to inform agency personnel and the public of the rationale for management response to climate change. During the next few years, considerable energy and attention will be given to activities related to the foundational elements of the climate change strategic plan, Science and Education. Three projects representing collaboration between research and management illustrate the diverse approaches the Forest Service is taking in the areas of Science and Education.

Applying historical ecology to land management. In February 2008, Science included the headline "Stationarity is Dead…" (Milly et al. 2008). The directionality of climate change has undermined our (already tenuous) ability to rely on static models of past climates and ecosystem response as reference conditions. The likelihood that future climates will be novel in some respects (Williams and Jackson 2007) adds to the uncertainty that assessment of past reference conditions (e.g., assessments of the "historical range of variability" [HRV]) will have much value in setting desired conditions. In April 2008, the National Forest System, in collaboration with The Nature Conservancy, held a workshop entitled "Incorporating Historical Ecology and Climate Change into Land Management." The workshop, involving managers and scientists from multiple federal agencies, three conservation organizations, and several universities, wrestled with how to effectively use history to inform management in a changing world (Safford et al. 2008). The workshop concluded that it is no longer appropriate to automatically use historical information to establish static targets for restoration, conservation, or land management. Approaches that assume "stationarity"—the theory that environments vary about some constant, long-term average—are no longer defensible. That said, historical ecology continues to represent critical context for land management planning. Past ecological responses to global change are essential to understanding changes currently occurring in the earth's natural systems, and paleoecology will always be a primary source of information for the development of mechanistic models of global change and ecosystem response. Results of the historical ecology workshop are being incorporated into agency policy and multiple teams are working to synthesize results of the workshop for publication in a variety of outlets.

Climate-conscious planning in the Greater Yellowstone region. Developing sound adaptation strategies that meet management goals requires an understanding of potential future climate at a scale relevant to the management unit, and an assessment of likely consequences for local ecological systems. Scientists from Forest Service Research are partnering with the Shoshone National Forest and neighbouring land managers to assess and manage the effects of climate change on critical public lands within the Greater Yellowstone region. This effort has resulted in down-scaled climate models to project future climate for the Greater Yellowstone region. Based on these projections, significant changes in vegetation communities are predicted (Wertz and Smith 2009).

Armed with this new information, research/management collaborators are working together to identify analysis, planning, and implementation tools that can help managers build from projections for a range of possible future conditions toward management direction to achieve multiple resource objectives. Examples of difficult issues managers face include: energy needs, the decline of white-bark pine, and beaver activity.

- Energy needs are driving massive increases in hydrocarbon extraction in the southern part of the Greater Yellowstone region. How will the Forest Service and other management agencies balance the development of oil and gas fields with fish and wildlife needs in conditions made continuously more stressful by climate change?
- Declines in white-bark pine as a result of blister rust and bark beetles will significantly reduce a major food source for grizzly bears, nutcrackers, and other species. Climate change may be increasing the rate of white-bark pine mortality. How should managers respond?
- American beaver currently occupy only a portion of suitable drainages in the Greater Yellowstone region. Through beaver "management" of water resources and riparian vegetation, beaver interact with system elements that are likely to change in response to climate. How, where, and why should managers encourage or discourage beaver activity?

This research/management collaboration will provide processes and approaches to answer these and similar questions for managers across the nation.

Managed Relocation/Assisted Migration. The current combination of habitat and climate change pose a daunting challenge for many species. Rates of global change, from human habitat alteration to modifications of the atmosphere, are so high that many species lack the capacity to "track" these changes through natural dispersal (Malcolm et al. 2002). Increasingly fragmented landscapes can sever corridors, disrupting dispersal. "Managed relocation" (MR); also known as "assisted migration" is the human-aided movement of species adversely affected by global change. Goals of MR include conservation of biodiversity, reduction of extinction risk, enhancement of evolutionary potential, and maintenance or augmentation of ecosystem services.

MR has promise as a conservation strategy, but unintended consequences could have serious costs. For example, MR may assist in rescuing a species from extinction, but may introduce a species into habitat where it becomes invasive. The Forest Service is a partner in a national effort to develop a framework for understanding the degree to which MR could achieve its objectives, the risks that it might incur, and strategies that could be used for implementation (Safford et al. 2009). Participants in the Managed Relocation working group represent federal land management agencies, academic institutions, and non-governmental organizations involved in conservation. Focus areas include: (a) basic goals of MR, (b) identifying trigger conditions for the implementation of MR, (c) genetic considerations, (d) legal, policy and ethical questions, (e) reconciling MR with existing conservation strategies, and (f) evaluating community- and ecosystem-level interactions. The working group has developed four criteria for comparing strategies for conservation of a target species: the risk of negative impact of climate change (or other anthropogenic disturbance) for the target species, the risk of collateral effects, and both the feasibility and acceptability of the strategy in question. Subgroups are currently carrying out studies that use well-known groups of plant and animal taxa to pilot test the process. Concurrently, Forest Service policy analysis specialists are examining the business mission of the agency in this important activity.

Structural Goals

Although consensus about the nature and extent of climate change impacts on ecological systems is emerging, there remains considerable equivocation as to how climate trajectories will play out (Schröter et al. 2005). Complex feedbacks between climate, the biota, land use, and land cover can foil even generalized predictions of how ecosystems may respond to some future realized climate (Hansen et al. 2001, Parmesan and Yohe 2003).

These dynamic and uncertain times suggest to some that a new conservation paradigm is needed (Winter 2009), but what form this new paradigm may take is unknown. Resource management policies that shape future wildlife and fish management under climate change will need to promote the development of decision-support tools that accommodate uncertainty and are open to the management of wildlife and fish over broad spatial and temporal scales. Interdisciplinary and multi-jurisdictional partnerships will also be required to successfully implement management actions.

Here we outline three efforts that illustrate the development of decision-support tools that inform fish and wildlife habitat management over broad scales, represent collaborative projects that developed a framework for adaptation planning, and demonstrate nation-wide assessment of wildlife management in the face of climate change.

Adaptation Planning Process. Climate change literature includes a growing number of general recommendations to conserve species and ecological systems across large geographic scales (e.g., Hannah and Hansen 2005, Scott and Lemieux 2005, Millar et al. 2007). While helpful, these recommendations have thus far failed to motivate much on-the-ground management (Cross et al. in review). Working in collaboration with the Wildlife Conservation Society, National Centre for Ecological Analysis and Synthesis, and scientists from throughout North America, the Forest Service is participating in the design of a planning framework to facilitate development of specific management actions to conserve fish and wildlife at local scales (Cross et al. in review). This effort develops a practical, participatory climate change adaptation framework to translate general recommendations into adaptation strategies for particular landscapes, species, or ecosystems. The framework addresses the uncertainty and complexity of understanding climate change impacts. It also considers the specific climate, ecological, and sociopolitical contexts that motivate management decisions. Late in 2008, a large group of state biologists in Montana used this framework to evaluate adaptation approaches for vertebrate species of conservation concern. In February 2009, this framework was introduced to nearly 40 Forest Service biologists in a workshop format. In both cases, post-workshop questioning demonstrated that biologists felt empowered to consider adaptation actions to meet a wide range of management objectives.

Assessing climate stress to terrestrial wildlife for conservation planning. State agencies that have management responsibility for wildlife incorporate vast cumulative experience in wildlife conservation. However, the dispersed nature of 50 state fish and game agencies poses problems for collaboration and integration for issues, like climate change, that transcend political boundaries. In the fall of 2006 the Forest Service initiated a study to develop a terrestrial wildlife habitat climate stress index that will seek to define areas of the country that will most likely be affected by significant changes in the climate regime, vegetation, and productivity. The study was jointly funded by the Forest Service as part of their national resource assessment responsibilities[1] and the National Council for Science and the Environment through the recently established Wildlife Habitat Policy Research Program. The Program's mission is to develop and disseminate new information and tools to accelerate the conservation of wildlife habitats by: (a) synthesizing literature on climate change impacts on terrestrial habitats; (b) quantifying the stress on terrestrial wildlife habitats from predicted changes in climate, vegetation, and productivity; and (c) reviewing management recommendations proposed in the State Wildlife Action Plans (SWAPs), which represent each state's approach to maintaining viable populations of wildlife over the long term. The SWAPs review revealed that less than half of the state plans addressed climate change as a threat to wildlife. A Forest Service-led team published a summary of the SWAPs review and recommended measures to improve treatment of climate change in state conservation planning (Joyce et al. 2008).

Development of nation-wide guidance to incorporate climate change into Forest Service resource planning. In January 2009, the Forest Service released guidance to provide the necessary level of consistency across the agency to treat climate change in land management planning (U.S. Forest Service 2009a). The guidance instructs National Forests and Grasslands to consider climate change in all relevant plan components. Moreover, the best available science should be used, including models at the finest level of resolution available, to evaluate climate change impacts on natural resources as a basis for recommending resource management strategies that address both adaptation and mitigation. The guidelines stress flexibility in crafting management that is relevant to local issues and circumstances. Agency direction specifically acknowledges the continued relevance of historical ecology in providing context within which to consider climate change. When planning projects, the agency may propose activities to increase the adaptive capacity of ecosystems, address the impacts of climate change on managed landscapes, or simply promote the sequestration of carbon. It is currently not feasible to quantify global climate effects from individual projects, but decisions can be informed by quantifying differences in carbon storage or greenhouse gas emissions among alternatives. The climate change guidelines, which direct the agency's approach to individual projects as well as Forest-wide plans, help motivate managers to carefully consider the influence of climate change on critical wildlife species, and influence management decisions on mitigation efforts. In project and forest

[1]The Forest and Ranageland Renewable Resources Planning Act of 1974 (P.L. 93-378, 88 Stat. 476, as amended; 16 U.S.C 1600[note], 1600-1614) requires the Forest Service to conduct national assessments of resource status and trends every 10 years.

planning, Regional Offices and Forest Service Research will have a substantial role in assisting in the assimilation and evaluation of scientific information relevant to the different National Forest and Grassland units.

Draft land management plans (LMPs) for the Cimarron-Comanche National Grassland, the National Forests in Mississippi and Uwharrie National Forests are the first LMPs developed under the 2008 National Forest Management Act, Planning Rule. Each draft plan includes discussion of the impact of climate change. To varying degrees, these documents address application of adaptation and mitigation. Models of future climates and ecosystem responses suggest that the Gulf Coastal Plain will be hotter and drier, will burn more frequently, and will experience increased hurricane and tornado activity in the coming years (U.S. Forest Service 2009b). In response, the National Forests in Mississippi have adopted an aggressive longleaf pine restoration program for most of their management units, because longleaf pine, which has been largely replaced by other species due to fire suppression and plantations, is significantly more resilient to fire, drought stress, and high winds than other native pines. Attention to climate change goes beyond plans developed under the 2008 Rule. For example the recent revision to the Tongass National Forest plan includes a monitoring plan that incorporates climate change considerations, and climate change on the forest is discussed at length in the Environmental Impact Statement.

Action Goals

As a land management agency, the Forest Service has the capacity to influence fish and wildlife through changes in habitat across vast portions of the United States through active programs focused on adaptation and mitigation. The agency's institutional focus is currently on foundational and structural goals, as outlined above. Developing a strong science and policy foundation is critical prior to implementing broad adaptation and mitigation programs. With some exceptions, most project planning and implementation occurs on landscapes much less than 100,000 ha in area, an area that may represent only a few grid cells in the climate, ecosystem, and biogeographical models currently used to make future predictions. Managers have limited local information on projected climate trajectories or impacts upon which they might base site-specific management decisions. As a consequence, some resource managers are taking more general action, preparing the landscapes they manage for rising temperatures and increased probabilities of extreme events, such as flooding, drought, fire, and insect outbreaks. Some of their guiding principles are "uncertainty," "resilience," "adaptation" and "mitigation" (Millar et al. 2007). The three case studies below are emblematic of the efforts being made by land and resource managers in the Forest Service to both adapt to and mitigate the tremendous— yet incompletely understood— changes in ecosystems that will likely occur over the coming century.

Aquatic species management: restoration, triage, and adaptation. The strong relationships between water temperature, oxygen, and aquatic species performance make aquatic habitats especially vulnerable to climate change. Cold-water fisheries have experienced substantial reductions in distribution over the past century and climate projections predict further declines (Rahel et al. 2008). Adaptation strategies to conserve aquatic vertebrates represent a particularly clear example of the importance of integrating science and practice to make difficult decisions to prioritize management actions. Examples from eastern and western cold-water fisheries illustrate progress the Forest Service has made in this arena.

In the east, brook trout managers are using new models of stream temperature patterns to guide restoration efforts for trout in northeastern streams (Hudy et al. 2008). Based on new understanding of fine-scale stream temperature patterns and associated models, biologists identify reaches with high potential for restoration. For instance, recovery of riparian vegetation along a 500-m reach in Virginia dropped the maximum water temperatures by 2 degrees C and created miles of additional cold water habitat (Fink 2008). Equally important, biologists can identify locales where restoration may not be helpful, resulting in significant savings through triage. On the Bighorn National Forest in Wyoming, a collaborative team of scientists and managers demonstrated the value of a more complex system of stream classification to identify restoration priorities for cutthroat trout (Wohl et al. 2007). Coupled with information on projected stream temperatures, the classification, which considers stream gradient, flow regime, and bedrock geology, can identify restoration and climate adaptation priorities for entire drainage basins.

A simple, direct application of adaptation management is motivated by the understanding that extreme precipitation events are likely to be more common and severe in the future. The active aquatic passage program in the Forest Service is asking whether road culverts are likely to fail, resulting in significant stream damage if flood events occur. As a result, new and replacement culverts are being oversized to accommodate extreme events expected in the future. In a more general sense, the aquatic passage program, which seeks to design culverts to improve connectivity, improves mobility within stream networks allowing for adaptation of aquatic organisms to changes in local conditions. On many Forests, decisions are also being made to close road segments as part of the national travel management mandate. Some of these decisions are being made with climate change impacts in mind.

Restoration of frequent-fire ecosystems: habitat, forest resilience, and carbon benefits. Many pine-dominated forest types in the United States were historically characterized by frequent, low severity fires, and relatively open stand structure dominated by mature trees. Examples include longleaf pine (*Pinus palustris*) in the Southeast, and ponderosa pine (*P. ponderosa*) and Jeffrey pine (*P. jeffreyi*) in the Southwest and California. In these forest types, a long history of timber harvest, historical grazing, land conversion, and more than 70 years of fire suppression have led to significant losses in habitat and changes in forest structure and composition (Lander et al. 1995, Allen et al. 2002). Vegetation change in these forest types has led to dramatic impacts on the biota, especially in the Southeast, where more than 30 animal and plant species associated with longleaf pine are now listed as threatened or endangered. In ponderosa and Jeffrey pine forests, highly competitive and shade tolerant conifers (often fir species [*Abies spp.*]) threaten the remaining large trees through competition for water and nutrients and increased susceptibility to high severity crown fire (Allen et al. 2002). In recent years, extensive areas of these pines have been lost to drought and insect attack, and increasingly severe wildfires (Allen and Breashears 1998, Miller et al. 2009). In longleaf forests, loblolly (*P. taeda*) and slash pine (*P. elliottii*), have largely taken the place of longleaf, and are now planted in dry, fire susceptible sites that were dominated by longleaf under the frequent-fire regime. Hurricane and fire damage to these stands is much higher than in open stands still dominated by longleaf pine (U.S. Forest Service 2009b).

In forests characterized by frequent fire, restoration efforts can serve multiple purposes. In the Southeast, replanting of longleaf pine in forest stands and reintroduction of frequent fire is commonly used to create and maintain habitat for the red-cockaded woodpecker (*Picoides borealis*). However, with greater understanding of climate change, these forest practices are recognized as producing multiple benefits. Longleaf pine is more resistant to pathogens and insect attack, it is less damaged by high winds than other pines with which it grows, and it is more tolerant of warmer, drier conditions (Burns and Honkala 1990, U.S. Forest Service 2009b). In addition, mature longleaf pine grows more rapidly than other local pine species, it has a relatively high wood specific gravity, and it may capture more carbon belowground. Taken in combination, restoration of longleaf pine-dominated forest appears to be the best bet for both wildlife habitat maintenance and carbon sequestration on these landscapes (U.S. Forest Service 2009b). Revised Forest Plans on the Uwharrie and Mississippi National Forests are noteworthy examples of restoration built on these principles.

Work in western ponderosa and Jeffrey pine forest has shown similar results. These species are highly fire and drought tolerant, and under optimal conditions they live long and attain massive size (Burns and Honkala 1990). Numerous studies have shown that ponderosa and Jeffrey pine stands that have been restored to open structure are much more likely to survive fire. Recent modeling suggests that long-term carbon sequestration is maximized where open habitats have been restored and frequent fire reintroduced (Hurteau et al. 2008). In summary, restoration efforts in forests historically characterized by frequent, low severity fires may serve multiple purposes, including the achievement of desired ecosystem and species diversity conditions, the enhancement of resilience to climate change, and maximization of the long-term potential for carbon storage.

Genetic and species strategies for reforestation. Current and projected future rates of climate change are thought to exceed the capacity of long-lived organisms like trees to evolve or disperse. Maximum documented post-glacial migration rates for trees were on the order of 100 meters per year, averaged over millennia, whereas recent modeling suggests that many species will have to average much more than 1 kilometer per year to track current rates of temperature change in the northern hemisphere (Malcolm et al. 2002). To meet evolutionary challenges, Rehfeldt et al. (2001, 2002) estimated that up to 12 generations and 1,200-1,500 years would be necessary for populations of two pine species to evolve to new optima for likely future climates. Other studies have found that in a century, regenerating conifer populations will require characteristics currently 500-1,000 meters lower in elevation or as far south in latitude as 2 to 5 degrees (St. Clair and Howe 2007). These alarming scenarios have led researchers, managers, and the public to openly advocate the managed relocation (or assisted migration) of tree species to areas that are climatically more appropriate for their long-term survival. Most active management of distributions would occur as part of reforestation efforts after stand-replacing disturbances.

The Forest Service is currently developing a policy analysis concerning managed relocation of tree taxa, but on-the-ground action is already occurring in both the science and management arms. For instance, the Pacific Northwest and Pacific Southwest Research Stations are collaborating on the development of a variety of tools for identifying the best-adapted tree populations for given climate change scenarios. Examples of these tools include guidelines for considering genetic and silvicultural options for responding to climate change (TAFCC 2008), and an internet-based tool that will allow users to characterize the current climate for a given seed zone (a “seed zone” is an area within which soil and climate are sufficiently uniform that it is expected that seed can be freely moved without problems of maladaptation). Predicted geographic locations of that seed zone’s climate are then mapped under a number of future scenarios. On the National Forests, scientific recommendations to “hedge bets” in reforestation practices were being heeded locally in the 1990s (Ledig and Kitzmiller 1992), but the increasing rapidity of climatic changes is leading to more broad application of this advice. As a business practice, many foresters now routinely (though mostly informally) mix seed sources to increase genotypic diversity, and move populations from lower to higher elevations and sometimes from south to north slopes.

Incense cedar (*Calocedrus decurrens*) represents an interesting example. In California incense cedar density is already increasing in many mixed conifer stands as a result of fire suppression, but further increases are expected under warmer climates and higher pollutant loads (Miller and Urban 2000, Arbaugh et al. 2003). Evidence suggests that this species will thrive under future climates and be a good choice for increased inclusion in planting mixes. However, certain guilds of birds consistently avoid incense cedar (e.g., Airola and Barrett 1985) and more widespread planting of the species will likely have important effects on avifaunal composition and possibly diversity. These sorts of secondary effects are likely to surprise us at every turn.

Conclusions and Recommendations

The U.S. Forest Service has embraced the management challenges posed by climate change. The agency's "Strategic Framework for Responding to Climate Change" (U.S. Forest Service 2008a) provides broad direction to guide future management and research to address climate change in all aspects of agency work. With this Framework, the agency has attempted to integrate climate change throughout its organizational structure. As a result, significant momentum is building from the individual Ranger District level up through the Washington Office to actively manage fish and wildlife habitat in a way that is mindful of climate change.

The case studies reviewed above serve two purposes. First, they provide substantive examples where the building momentum throughout the agency has manifested as successful fish and wildlife habitat management designed to address the stewardship challenges of climate change. Second, they serve to highlight features of the Forest Service that position it to be an effective partner in managing fish and wildlife resources in the 21st century. These features include: the agency's vast geographic footprint and highly diverse landbase, its strong internal ties between management and research, its considerable experience dealing with broad-scale land management, and its acquired expertise dealing with risk and uncertainty in resource management.

The Forest Service's Geographic Footprint

The vast geographic area managed by the U.S. Forest Service makes it one of only a few land stewards that can have a significant impact on how fish and wildlife respond to climate change. The ranges of many animal species are found entirely or primarily on Forest Service-managed lands, and in many cases the agency manages remnant habitats that have disappeared on adjacent private lands. The agency will play a substantial role in the development and implementation of adaptation strategies for managing fish and wildlife habitat. Nevertheless the geographic extent of the agency's reach results in numerous neighbors and the need to cultivate partners in carrying out sustainable fish and wildlife management. Strong and continuous collaboration with state and federal agencies, private landowners, and nongovernmental organizations will be necessary to successfully implement management across landscapes at scales necessary to make real impacts on populations and habitats of fish and wildlife.

The Management-Research Linkage

The strong, historical relationship between Forest Service Research and Development and its management arms (National Forest System, State and Private Forestry, and International Programs) has supported and motivated management response to the challenge of climate change. In the face of uncertainty and significant risk of unintended consequences, the agency must make an even more conscious effort to forge substantive ties between research and management. Informal approaches to field experiments or casual implementation of adaptive management (sensu Walters 1986) are unlikely to provide useful answers. New approaches, or more sophisticated implementation of existing approaches, that are based on close collaboration between scientists and managers developing well-monitored 'clinical trials' will be necessary. Furthermore, more effective communication between managers and scientists is necessary. This may demand new organizational structures, shifts in culture, and a conscious effort to bring scientists and managers together to work on important problems.

Broad-Scale Assessments

As climate change impacts manifest across broad areas, the appropriate decision-making level for various activities may shift to cover larger, more regional scales. This scope of consideration is not new to the agency. For example, the Forest Service has considerable experience developing broad-scale land management plans and associated broad-scale assessments (e.g., Sierra Nevada Framework, Northwest Forest Plan), and it has developed or contributed to dozens of species-specific conservation assessments and recovery plans that span multiple states (e.g., grizzly bears, sage grouse, Canada lynx). As demonstrated in our case study on Yellowstone (see page 9), the Forest Service is currently working to provide science assessments that include down-scaled climate scenarios and ecological threat assessments that stem from those scenarios. These examples, among others, suggest the agency is well positioned to develop the broad-scale management plans that will be a critical element of climate-change response.

Accounting for Risk and Uncertainty

Land management decisions to meet multiple resource objectives involve trade-offs (Loomis 1993: 197), where benefiting one resource or service may compromise another. As the Forest Service considers management actions that address climate change, trade-offs will continue to emerge. The Forest Service's recent experience with developing assisted migration strategies for tree species, setting priorities for cold water fishery restoration, and restoring frequent-fire ecosystems (see case studies pages 8, 9) provide some insight into the wicked problems associated with difficult risk analyses. In each case, the complex decision space that defines the climate change problem includes multiple, and often opposing, desirable outcomes supported by various stakeholder groups. For this reason, technical analyses alone will not provide an adequate decision-support framework (USDA 2004). Effective decision-making will require a functional science-management link, and a robust, two-way relationship between the public and the Forest Service. Fortunately, the Forest Service has decades of experience collaboratively developing management plans to resolve complex resource issues and we have learned that complex challenges often manifest as opportunities for the agency. The uncertainty associated with climate change and the potential risk associated with novel and untested management practices will require altogether new levels of institutional flexibility. New tools or approaches to managing for uncertainty will become essential, and their development and implementation will offer new possibilities for integration across environmental, social, and economic realms. Tools such as scenario planning, sensitivity analysis, or risk analysis will need to be commonplace and incorporated into the agency's resource planning culture if adaptive management and monitoring needs are to be retooled to address climate change.

Although the Forest Service has built considerable momentum and demonstrated a broad commitment toward addressing climate change threats to fish and wildlife, the challenge is considerable and the future uncertain. The case studies described in this paper illustrate the agency's capacity to develop knowledge and implement adaptation management to conserve fish and wildlife habitats. However, for the Forest Service to be successful, the examples we review here must, five years from now, represent the tip of an iceberg. Long-term, passionate, and focused management such as that displayed in the agency's 100-year history will be necessary if the collective stewards of fish and wildlife resources are to meet the challenge posed by one of the most significant environmental threats faced by humankind.

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