Adapting to climate change in United States national forests

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A review of climate change adaptation options in the United States offers practical information for resource managers to help them adapt their forest management goals and practices to expected climate change impacts.

Climate change is already affecting forests and other ecosystems, and additional, potentially more severe impacts are expected (IPCC, 2007; CCSP, 2008a, 2008b). As a result, forest managers are seeking practical guidance on how to adapt their current practices and, if necessary, their goals. Adaptations of forest ecosystems, which in this context refer to adjustments in management (as opposed to "natural" adaptation), ideally would reduce the negative impacts of climate change and help managers take advantage of any positive impacts.

This article summarizes key points from a review of climate change adaptation options for United States national forests (Joyce *et al.*, 2008) produced under the auspices of the United States Climate Change Science Program (CCSP) (see Box). The study sought to provide practical information on potential adaptation options for resource managers by asking:

- How will climate change affect the ability of resource managers to achieve their management goals?
- What might a resource manager do to prepare the management system for climate change impacts while maintaining current goals (and constantly evaluating if these goals need to be modified or re-prioritized)?

The Climate Change Science Program and adaptation options for national forests

The United States Climate Change Science Program (CCSP) (see www.climatescience.gov) aims to build a better understanding of how the earth's climate is changing, of humanity's role in these changes, and of how societies can mitigate and adapt to their impacts. The programme has five strategic goals:

- **to improve knowledge of past and present climate;**
- **to improve quantification of the forces bringing about climate changes;**
- **to reduce uncertainty in climate projections;**
- **to understand the sensitivity and adaptability of human systems as well as natural and managed ecosystems;**
- **to explore the uses and limits of knowledge to manage risks and opportunities related to climate change.**

To achieve these goals, CCSP commissioned 21 synthesis and assessment products (SAPs). Of these, SAP 4.4, led by the United States Environmental Protection Agency (USEPA), reviewed possible management adaptations for climate-sensitive ecosystems and resources. Recognizing that successful adaptation will be context dependent, SAP 4.4 explored options for a range of federally managed lands and waters: national parks, national forests, fish and wildlife refuges, wild and scenic rivers, marine protected areas and coastal estuaries.

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EXPECTED CLIMATE CHANGE IMPACTS ON UNITED STATES FOREST MANAGEMENT GOALS

Climate change will directly affect the ecosystem services provided by national forests and will exacerbate the impacts of current natural and anthropogenic stress factors. Wildfires, non-native and native invasive species and extreme weather events are the most critical stress factors that climate change will amplify within national forests. Reduced snowpack, earlier snowmelt and altered hydrology associated with warmer temperatures and changing precipitation patterns will complicate water management, particularly in the western states, and will affect other ecosystem services that national forests provide (e.g. winter recreational opportunities). Drought may become more difficult to manage across the United States. While elevated atmospheric carbon dioxide and warming temperatures may enhance near-term forest

Impacts of climate change on the forest management goals of the United States Forest Service

Goal	Desired or intended outcome	Possible climate change impacts	Adaptation options
Restore, sustain, and enhance national forests	Maintain forest health, productivity, diversity and resistance to severe disturbances	Longer, warmer growing seasons Altered fire regimes Shifts in seasonality of hydrological processes Intense droughts	Reduce fuel loads in forests Increase use of wildland fire use Enhance the early detection and response strategy associated with non-native invasive species
Provide and sustain benefits to the country's people	Maintain multiple socio-economic benefits to meet society's needs over the long term, including a reliable supply of forest products, energy resource needs and market-based conservation	Climate change interacting with current stress factors such as insect pests and disease, wildfire, legacy of past management and air pollution Shifts in forest species composition Increased erosion events impairing watershed condition	Increase efforts to reduce current stress factors Incorporate long-term climate change into wildland fire planning Develop silvicultural treatments to reduce drought stress Review genetic guidelines for reforestation
Conserve open space	Maintain the environmental, social and economic benefits of forests, protecting these resources from conversion to other uses, and helping private landowners and communities manage their land as sustainable forests	Large-scale forest dieback or vegetation type conversions as a result of more frequent extreme events Altered landscape and successional dynamics Increasing fragmentation of forest ecosystems and wildlife habitat	Provide technical assistance to urban foresters to sustain urban trees Develop corridors for species migration and habitat protection
Sustain and enhance outdoor recreation opportunities	Maintain high-quality outdoor recreation opportunities in national forests available to the public	Increased air and stream temperatures Reduced snowpack Altered in-stream flows	Evaluate recreational impact on ecosystems under a changing climate Expand recreational opportunities across all four seasons Redesign roads and trails to withstand increased rainfall intensity
Maintain basic management capabilities of the Forest Service	Develop administrative facilities, information systems, and landownership management strategies to support wide-ranging natural resource challenges	Poor accessibility or lack of current information on climate change projections, ecosystem impacts and socio-economic impacts on local communities Uncertainty associated with that information	Increase technical understanding by developing educational material for employees and stakeholders Incorporate climate change into planning processes Enhance research partnerships
Engage urban citizens	Provide broader access to long-term environmental, social, economic and other benefits provided by the Forest Service	Exacerbation of the stress that urban environments place on ecosystems, as a result of warming temperatures Increased wildfire and drought risks in surrounding landscapes, which may compromise ability to maintain water quality and availability	Expand conservation education programmes to include climate change Seek opportunities to educate national forest visitors on climate change
Provide science-based applications and tools for sustainable natural resource management	Ensure that the best available science-based knowledge and tools inform Forest Service management decisions	Need for management tools that incorporate climate change considerations Need to revise current management practices that are based on assumptions about ecosystems and climate that may be invalid in the future	Establish stronger relationships between scientific researchers and management to help identify resilience thresholds for key species and ecosystem processes, determine which thresholds will be exceeded, prioritize projects with a high probability of success and identify species and vegetation structures tolerant of increased disturbance

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Subalpine forest mortality in the Sierra Nevada of California – one of the "surprises" of climate change that must now be anticipated (whitebark pine,* Pinus albicaulis*)

productivity where water and nitrogen are not limiting factors, ozone and other industrial pollutants in combination with increasing climate stress are likely to decrease tree growth and severely affect watershed condition.

To fulfil its objectives of sustaining ecosystem health, diversity and productivity to meet the needs of present and future generations, the United States Forest Service has identified seven strategic goals for 2007–2012. Climate change impacts will make the achievement of all seven goals more challenging (Table). In addition, all of the goals have some relation to the current or desired ecosystem condition, which may be difficult or impossible to maintain under the future climate regime. How sensitive each goal is to climate change will depend on several factors including the temporal and spatial nature of climate change, its specific impacts on particular national forest ecosystems, the effects of human activities on these ecosystems and the extent to which current forest management approaches are based on outdated assumptions about climate.

ADAPTATION OPTIONS

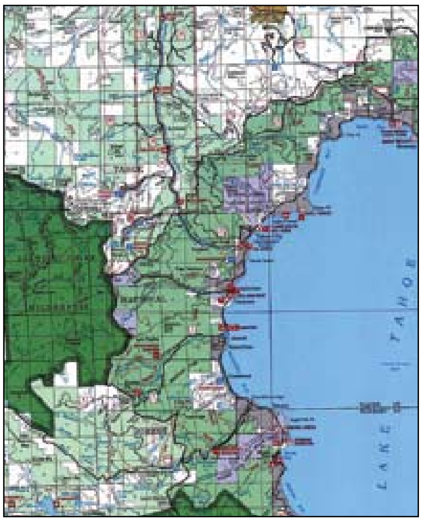
Both reactive and proactive approaches may be adopted to cope with the impacts of climate change in national forests. A reactive approach might be justified if uncertainty or costs are considered very high relative to the expected impacts and risks; or if significant cost savings and benefits would result if interventions are implemented only after a climate-related disturbance takes place (e.g. replanting an area with more fire- or drought-resistant tree species after a wildfire or drought-induced insect outbreak).

In many cases, however, proactive approaches – incorporating adaptation options into management and planning processes now, before climate-related events induce major ecosystem changes – may be less expensive and more effective for achieving current forest management goals. Key elements of a proactive approach to adaptation to climate change include:

- reviewing or identifying – and where necessary modifying – forest management goals;
- evaluating the challenges that climate change poses to achieving those goals and to implementing activities planned for that purpose;
- monitoring ecosystems and forest management responses to provide information on which to base the evaluation of vulnerability and risk;
- incorporating uncertainty about the precise impacts of climate change into forest management approaches;
- developing a portfolio or toolbox of forest management strategies.

This type of approach requires enhanced institutional and stakeholder coordination and inputs, especially because of the patchy ownership patterns in and near United States national forests (Figure), the high level of landscape fragmentation and the fact that one-quarter of all national forest lands are legally assigned other land use designations focused more narrowly on wilderness management or

Patchy ("checkerboard") landownership patterns in and near United States national forests emphasize the need to enhance stakeholder coordination in proactive approaches to climate change adaptation, for example to ensure continuous landscape for species to migrate



UNITED STATES FOREST SERVICE

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Reduced snowpack associated with warmer temperatures and changing precipitation patterns will complicate water management; conditions typical of late July or early August are seen in early June 2007 (an extremely dry year) in the upper Tuolumne drainage basin in California, the source of San Francisco's municipal water

wild and scenic river management. Further proactive approaches will need to be appraised continually as the climate continues to change and ecological systems respond; such continual changes may also necessitate a modification of the forest management goals.

A portfolio of forest management strategies is needed so that the right tool can be applied to the specific management context. A single approach to adaptation will not work across the diversity of ecosystems within the national forests. The portfolio should include both short- and long-term adaptation options, many of which are modifications of management practices and tools already used by the Forest Service.

Short-term adaptations: building resistance and resilience to climate change

Short-term adaptations are intended to build resistance and resilience so that ecosystems and natural resources are better able to withstand climate change. Increasing resistance may be the only or best option for high-value resources such as forest plantations that are near the end of their rotation or rare resources such as habitat for sensitive species (i.e. species for which population viability is a concern) in areas where future management decisions have not yet been made (Millar, Stephenson and Stephens, 2007). Practices for improving the resistance of high-value resources entail limiting their exposure to climate change impacts such as drought, fire and insects. For example, landscape-scale thinning and fuel reduction treatments can be used to reduce the risk of anomalous crown fire, drought susceptibility and insect outbreaks. Strategically placed firebreaks and other area treatments that reduce the continuity of forest floor debris will be especially important near residential areas, municipal watersheds and habitats that are designated as critical for the survival and recovery of threatened or endangered species.

Resilient ecosystems not only can accommodate gradual changes, but also return to their prior condition after disturbance (Holling, 1973, 2001). In addition to the adaptations to build resistance, resilience-enhancing adaptations emphasize management of regeneration processes. Resilience-enhancing adaptations include efforts to boost population sizes, increase the number (or diversity) of locations where individual populations, species and habitats are managed, and restore key ecosystem conditions and processes following disturbance.

Reducing current sources of stress (e.g. pollution, non-native invasive species, habitat fragmentation and the impacts of current and past extractive activities) is perhaps the most important and effective option for building ecosystem resilience. Increased effort and coordination among land management agencies and private landowners to reduce current stress factors would benefit ecosystems now and potentially reduce future impacts from climate change. An early response and rapid detection system for invasive species, for example, helps the Forest Service respond quickly when the problem is small. Such an approach might be applied to other climate change induced disturbances that have negative impacts on ecosystems, such as more intense floods and windstorms which accelerate erosion.

Another immediate adaptation option is to review existing forest management plans to identify weaknesses in measures for coping with extreme climate-related events (e.g. drought, fire, floods) as well as for managing water use, recreation and extraction of timber, forage and other natural resources before, during and after these disturbances. Such a review could also shed light on the potential impacts of more intense climate-related events in the future. Forest management plans could then be altered based on anticipated changes in rainfall patterns, fire regimes, phenology (the timing of ecological events such as budburst and the arrival of migratory species) and shifts in ecosystem composition, structure and processes. Insights gained from such a review might help managers develop plans to alter the successional trajec-

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Landscape-scale thinning and fuel reduction treatments represent a short-term adaptation for improved resistance to fire: a 70 000 ha wildfire in the Okanogan-Wenatchee National Forest in Washington State in 2006 caused 100 percent mortality in a high-density mixed conifer stand (left), whereas a stand that had been thinned and had surface fuels removed by prescribed fire sustained low scorch and minimal overstorey mortality (right)

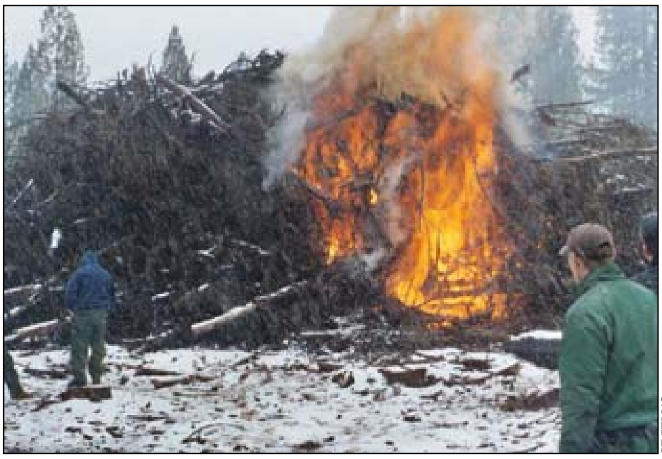
tory of ecosystems after catastrophic fire or wind events and to aim for a condition more likely to thrive under future climate.

Long-term adaptations: managing for change as resilience thresholds are crossed

Thresholds of resilience for many ecosystems are likely to be exceeded over the longer term (more than 50 years) unless greenhouse gas emissions are sharply and quickly reduced (over less than 20 years) (IPCC, 2007). Thus, longer-term adaptation options are needed that over time will help ecosystems and species to respond to climate change and that will help avoid dramatic and abrupt transitions from one ecosystem condition to another (e.g. forest to shrubland). Ensuring that landscapes are connected to permit species migration and dispersal is considered fundamental in this regard (Halpin, 1997; Holling, 2001; Noss, 2001). Likewise, boosting population sizes, protecting or restoring multiple examples of ecosystems and promoting heterogeneous, multiple-age forest stands will increase biological diversity at multiple levels of organization (from genes to landscapes), and hence the potential for natural adaptation.

Implementation of some adaptations will depend in part on the amount of certainty about the trajectory of climate change. Where there is little certainty, it may make sense to ensure that when new trees are planted, reproductive materials include ample genetic diversity. Where confidence in predicted climate changes is higher, managers might actively intervene to assist specific transitions and shifts in species ranges.

Realigning significantly disrupted ecological conditions to current and future climates may be a preferred choice when resilience thresholds are exceeded and restoration to historic pre-disturbance conditions is considered too environmentally challenging, too expensive or not politically feasible. This type of adaptation was implemented for Mono Lake, California; after court-ordered mediation among stakeholders, restoration goals were revised to take into account current climate and future climate uncertainties to determine the most appropriate lake level for present and anticipated future conditions (Millar, Stephenson and Stephens, 2007).



G. FILDES

Longer-term adaptation options are needed that over time will help ecosystems and species to respond to climate change; for example, recent changes in conditions in the Tahoe National Forest in California allow prescribed burning during winter months, a new practice that will help reduce the risk of catastrophic fires

CONCLUSIONS

As climate change continues to affect ecosystem structure, composition and processes, it will be extremely difficult to address every impact. Forest managers will need to focus on achieving realistic outcomes. Establishing a stronger relationship between scientific research and forest management will be helpful in this regard, helping to:

- identify resilience thresholds for key species and ecosystem processes;
- determine which thresholds are likely to be exceeded;
- prioritize projects with a high probability of success;
- identify species and vegetation structures tolerant of increased disturbance.

Adaptation and mitigation options are increasingly being seen as a set of strategies needed to minimize potential negative impacts and to take advantage of possible positive impacts from climate change. Mitigation options may have deleterious ecological consequences on local to regional scales, and adaptation options may elevate greenhouse gas emissions. Thus, it will be important for managers to assess trade-offs and to seek strategies that achieve synergistic benefits between mitigation and adaptation.

Managers will also have to confront what can and cannot be done given limited financial and human resources. No matter what priority setting scheme is selected, it is important to establish criteria for and participation in decision-making through a deliberative, consultative process that ensures that the concerns of all stakeholders are considered. ◆

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