3 National Forests

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Chapter Contents

3.1 Summary

The National Forest System (NFS) is composed of 155 national forests (NFs) and 20 national grasslands (NGs), which encompass a wide range of ecosystems, harbor much of the nation's biodiversity, and provide myriad goods and services. The mission of the U.S. Forest Service (USFS), which manages the NFS, has broadened from water and timber to sustaining ecosystem health, diversity, and productivity to meet the needs of present and future generations. The evolution of this mission reflects changing societal values (*e.g.*, increasing emphasis on recreation, aesthetics, and biodiversity conservation), a century of new laws, increasing involvement of the public and other agencies in NF management, and improved ecological understanding. Climate change will amplify the already difficult task of managing the NFS for multiple goals. This chapter offers potential adaptation approaches and management options that the USFS might adopt to help achieve its NFs goals and objectives in the face of climate change.

Key Findings

Climate change will affect the NFS's ability to achieve its goals and objectives. Climate change will make the achievement of all seven strategic goals more challenging because they are all likely to be sensitive to the direct effects of climate change as well as the interactions of climate change with other major stressors.

Climate change will exacerbate the impact of other major stressors on NF and NG ecosystems. Wildfires, non-native and native invasive species, extreme weather events, and air pollution are the most critical stressors that climate change will amplify within NFS ecosystems. Reduced snowpack, earlier snowmelt, and altered hydrology associated with warmer temperatures and altered precipitation patterns are expected to complicate western water management and affect other ecosystem services that NFs provide (*e.g.*, winter recreational opportunities). Drought will likely be a major management challenge across the United States. Ozone exposure and deposition of mercury, sulfur, and nitrogen already affect watershed condition, and their impacts will likely be exacerbated by climate change.

Both adaptation and mitigation strategies are needed to minimize potential negative impacts and to take advantage of possible positive impacts from climate change. Because mitigation options may have deleterious ecological consequences on local to regional scales and adaptation options may have associated carbon effects, it will be important to assess potential tradeoffs between the two approaches and to seek strategies that achieve synergistic benefits.

*Developing an adaptation strategy will involve planning for and developing a suite of management practices to achieve multiple goals, along with evaluating different types of uncertainty (*e.g., *environmental conditions, models, data, resources, planning horizons, and public support), to support decisions about the most suitable adaptations to implement.* Three different adaptation approaches are offered: no active adaptation, planned responses after a major disturbance event, and proactive steps taken in advance of a changing climate. The appropriateness of each strategy will likely vary across spatial and temporal scales of decision making; thus, selection of an approach will be influenced by specific management objectives and the adaptive capacity of the ecological, social, and economic environment. Although none of these approaches may successfully maintain extant ecosystems under a changing climate, the proactive approach is best suited to support natural adaptive processes (*e.g.*, species migration) and maintain key ecosystem services. To succeed, proactive adaptation would require greater involvement and integration of managers at many levels to appropriately monitor ecosystem changes, adjust policies, and modify specific practices.

Reducing the impact of current stressors is a "no regrets" adaptation strategy that could be taken now to help enhance ecosystem resilience to climate change, at least in the near term. Increased effort and coordination across agencies and with private landowners to reduce these stressors (especially air pollution, drought, altered fire regimes, fragmentation, and invasive species) would benefit ecosystems now, begin to incorporate climate change incrementally into management and planning, and potentially reduce future interactions of these stressors with climate change. Approaches that quickly address problems that otherwise would become large and intractable (*e.g.*, the Early Detection/Rapid Response program for invasive species) may also help managers reduce the impacts of climate-driven events such as floods, windstorms, and insect outbreaks. Consideration of post-disturbance management for short-term restoration and for long-term restoration under climate change prior to the disturbance (fire, invasives, flooding, hurricanes, ice storms) may identify opportunities and barriers. Large system-resetting disturbances offer the opportunity to influence the future structure and function of ecosystems through carefully designed management experiments in adapting to climatic change.

Incorporating climate change into the USFS planning process is an important step that could be taken now to help identify suitable management adaptations as well as ecological, social, and institutional opportunities and barriers to their implementation. Planning processes that include an evaluation of vulnerabilities (ecological, social, and economic) to climate change in the context of defining key goals and contexts (management, institutional, and environmental) might better identify suitable adaptive actions to be taken at present or in the short term, and better develop actions for the longer term. Coordination of assessments and planning efforts across the organizational levels in the USFS might better identify spatial and temporal scales for modeling and addressing uncertainty and risk linked to decision-making. Given the diversity of NFS ecosystems, a planning process that allows planners and managers to develop a toolbox of multiple adaptation options would be most suitable.

Better educating USFS employees about climate change and adaptation approaches is another step that could be implemented immediately. Developing adaptation options to climate change may require NF staff to have a more technical understanding of climate change as well as the adaptive capacity of social and economic environments. The challenge for NFs to keep up with the rapidly changing science also suggests the need to build on and strengthen current relationships between researchers (inside and outside of the USFS) and NF staff.

As climate change interacts with other stressors to alter NFS ecosystems, NFs may need to manage for change by increasing emphasis on managing for desired ecological processes by working with changes in structure and composition of NFs. The individual, disparate, and potentially surprising responses of species to climate change may preclude the preservation of current species assemblages over the long term. Under such a scenario, managing for change, despite uncertainty about its direction or magnitude, may be the most viable long-term option. Working toward the goal of desired future functions (*e.g.*, processes, ecosystem services) would involve managing current and future conditions (*e.g.*, structure, outputs), which may be dynamic through a changing climate, to sustain those future functions as climate changes.

Establishing priorities to address potential changes in population, species, and community abundances, structures, and ranges—including potential species extirpation and extinction—under climate change is an important adaptation that will require time and effort to develop. A careful examination of current prioritization methods would begin to identify opportunities and barriers to the analysis of tradeoffs and development of priorities under a changing climate. A tiered approach to priority-setting could include the “no regrets” actions mentioned above (reducing current stressors), “low regrets” actions that provide important benefits at little additional cost and risk, and “win-win” actions that reduce the impacts of climate change while also providing other benefits. Using triage to set priorities would acknowledge where limited resources might be more effective if focused on urgent, but treatable problems.

As discussed in the three case studies (Tahoe NF, Olympic NF, and Uwharrie NF; see the Case Study Summaries and Annex A1), the USFS will need to overcome various barriers to take advantage of opportunities to implement adaptation options. The collaboration and cooperation with other agencies, national networks, and the public required to manage NF lands could be an opportunity or a barrier to adaptation. The ability of the USFS to adapt will be enhanced or hindered to the extent that these other groups recognize and address climate change. Adaptive management is also both an opportunity and a barrier. While it facilitates learning about ecosystem responses to management, it may not be useful when the ability to act adaptively is constrained by policies or public opinion, or when actions must be taken quickly.

Applied research could help fill gaps in understanding and data while also providing enhanced tools for decision support. Research priorities include studies that assess the socioeconomic impacts of adaptation options, develop ways to reduce ecosystem vulnerability to disturbances that will be exacerbated by climate change (*e.g.*, insects, fire, invasives), and show how climate change can be better incorporated into long-term forest planning (including improved communication). The USFS could also take advantage of current infrastructure and coordinate with other agencies to enhance monitoring and mapping efforts with climate change in mind.

There is a clear need for the USFS as a whole to respond to the potential impacts of climate change. While this report focuses on the NFS, climate change needs to be addressed across all functional lines and program areas (including state and private forestry, international programs, and research) of the USFS. Further enhancing the relationship between NFS managers, state and private forestry staffs, and scientists in the research branch should help the USFS addresses this challenge.

3.2 Background and History

3.2.1 Historical Context and Enabling Legislation

In the mid 1800s, the rapid western expansion of European-American settlement and the associated environmental impact of deforestation, human-caused wildfire, and soil erosion raised concerns about the sustainability of public lands (Rueth, Baron, and Joyce, 2002). At a meeting of the American Association for the Advancement of Science in 1873, Franklin Benjamin Hough described the environmental harm resulting from European forest practices and proposed that the United States take action to avoid such impacts. Congress directed the U.S. Department of Agriculture (USDA) to report on forest conditions, and in 1876 Hough—as the USDA special forestry agent—completed the first assessment of U.S. forests. In 1881, the Division of Forestry within USDA was created with the mission to provide information. Three years later, research was added to the mission.

With the passage of the Forest Reserve Act of 1891, President Harrison established the first timber land reserve (Yellowstone Park Timber Land Reserve, eventually to become the Shoshone National Forest) under the control of the General Land Office (Fig. 3.1). Over the next two years, Harrison designated more than 13 million acres (5.26 million ha) within 15 forest reserves in seven western states and Alaska (Rowley, 1985). The Forest Transfer Act of 1905 established the U.S. Forest Service, in USDA, and transferred the reserves from the General Land Office to USDA. With this legislation, the policy shifted from land privatization to federal forest protection, with integrated research and scientific information as an important element in the management for sustained timber yields and watershed protection (Rowley, 1985).[1] In 1907, the forest reserves were renamed to national forests (NFs). By 1909, the NFs had expanded to 172 million acres (70 million hectares) on 150 NFs.[2]

Figure 3.1. Timeline of National Forest System formation and the legislative influences on the mission of the national forests.

3.2.2 Evolution of National Forest Mission

In the 1891 act, the mission was to "improve and protect the forest within the boundaries, or for the purposes of securing favorable conditions of water flows, and to furnish a continuous supply of timber." In 1905, Secretary of Agriculture James Wilson wrote that questions of use must be decided "from the standpoint of the greatest good for the greatest number in the long run" (USDA Forest Service, 1993). The 1936 Report of the Chief recognized a greater variety of purposes for NFs including "timber production, watershed production, forage production, and

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[1] See also **MacCleery**, D., 2006: Reinventing the U.S. Forest Service: Evolution of the national forests from custodial management, to production forestry, to ecosystem management: A case study for the Asia-Pacific Forestry Commission. In: *Proceedings of the Reinventing Forestry Agencies Workshop*. Asia-Pacific Forestry Commission, FAO Regional Office for Asia and the Pacific, Thailand. 28 February, 2006. Manila, Philippines.

[2] **USDA Forest Service**. 2007. Table 21 National Forest Lands Annual Acreage (1891 to present). Report date October 10, 2007, http://www.fs.fed.us/land/staff/lar/2007/TABLE_21.htm, accessed on 11-28-2007.

livestock grazing, wildlife production, recreational use, and whatever combination of these uses will yield the largest net total public benefits."[1] In 1960, the Multiple Use-Sustained Yield Act officially broadened the mission to give the agency "permissive and discretionary authority to administer the national forest for outdoor recreation, range, timber, watershed, and wildlife and fish purposes."[3]

Specific management goals for land within national forest boundaries were identified by legislation in the 1960s: Wilderness Act of 1964, National Trails System Act of 1968, Wild and Scenic Rivers Act of 1968.[4] As these congressional designations encompassed land from many federal agencies, coordination with other federal and in some cases state agencies became a new component of the management of these designated NF lands. By 2006, 23 percent of the National Forest System's lands were statutorily set aside in congressional designations—the national wildernesses, national monuments, national recreation areas, national game refuges and wildlife preserves, wild and scenic rivers, scenic areas, and primitive areas.

Legislation of the 1970s established oversight by agencies other than the Forest Service for the environmental effect of land management within NFs. The Clean Air Act of 1970 and the Clean Water Act of 1972 gave the Environmental Protection Agency responsibility for setting air and water quality standards, and the states responsibility for enforcing these standards. Similarly, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service were given a new responsibility through the required consultation process in the Endangered Species Act of 1973 to review proposed management on federal lands that could modify the habitat of listed species.

Additional legislation established greater public involvement in evaluating management impacts and in the forest planning process. The National Environmental Policy Act (NEPA) of 1970 required all federal agencies proposing actions that could have a significant environmental effect to evaluate the proposed action as well as a range of alternatives, and provide an opportunity for public comment. Increased public participation in the national forest planning process was provided for within the National Forest Management Act of 1976. Land management activities within the NFs were now, more than ever, in the local, regional, and national public limelight.

These laws and their associated regulations led to many changes within the organizational structure of the Forest Service, the composition of the skills within the local, regional, and national staffs, and the management philosophies used to guide natural resource management. Additionally, the public, environmental groups, internal agency sources, and the Forest Service's own research community were reporting that substantial changes were needed in natural resource management.[1] In 1992, Forest Service Chief Dale Robertson announced that "an ecological approach" would now govern the agency's management philosophy. In 1994, Chief Jack Ward Thomas issued the publication *Forest Service Ethics and Course to the Future*, which described the four components of ecosystem management: protecting ecosystems, restoring deteriorated ecosystems, providing multiple-use benefits for people within the capabilities of ecosystems, and ensuring organizational effectiveness. MacCleery[1] notes that this shift to ecosystem management occurred without explicit statutory authority, and as an administrative response to many factors such as public involvement in the planning processes, increased technical diversity within the

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[3] 16 U.S.C. § 528-531
[4] 16 U.S.C. § 1271-1287 P.L. 90-542

Forest Service staffs, increased demand for recreational opportunities, and increased understanding in the natural resource sciences.

After the active wildfire season in 2000, federal agencies drafted the National Fire Plan to reduce the risk of wildfire to communities and natural resources. The Plan has focused prevention on the reduction of woody biomass (mechanical thinning, prescribed fire, wildland fire use, removal of surface fuels) and the restoration of ecosystems where past land use had altered fire regimes. The Healthy Forest Restoration Act of 2003 included provisions to expedite NEPA and other processes to increase the rate at which fuel treatments were implemented in the wildland-urban interfaces of at-risk communities, at-risk municipal watersheds, areas where fuel treatments could reduce the risk of fire in habitat of threatened and endangered species, and where wind-throw or insect epidemics threaten ecosystem components or resource values.[5]

The 2007–2012 USDA Forest Service Strategic Plan describes the mission of the Forest Service, an agency with three branches: National Forest Systems, Research, and State and Private, as: “To sustain the health, diversity and productivity of the Nation’s forest and grasslands to meet the needs of present and future generations” (USDA Forest Service, 2007b). The mission reflects public and private interests in the protection and preservation of natural resources, a century of laws passed to inform the management of NF lands, partnerships with states for stewardship of non-federal lands, and a century of research findings.

3.2.3 Interpretation of Goals

At the national level, the USDA Forest Service Strategic Plan identifies a set of strategic priorities that are implemented over a period of time through annual agency budgets. The strategic priorities or goals are based on national assessments of natural resources and in response to social and political trends (USDA Forest Service, 2007b) (Box 3.1). Within the NFS, these goals are interpreted in each level of the organization: national, regional, and individual administrative unit (forest, grassland, and prairie) (Fig. 3.2).

Figure 3.2. Jurisdiction and organizational levels within the National Forest System.

Individual unit planning (national forest, grassland or other units) provides an inventory of resources and their present conditions on a particular management unit. This inventory, coupled with the desired future condition for ecosystem services and natural resources within each national forest, is the basis for annual work planning and budgeting (USDA Forest Service, 2007b). Annual work planning identifies the projects that all units propose for funding within a fiscal year. This level of planning involves the final application of agency strategic direction into a unit’s annual budget to move its resources toward its desired future condition. Project planning includes specific on-the-ground management for recreation, fisheries, restoration, vegetation management, and fuel treatments.

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[5] H.R. 190

Individual administrative units have worked together to develop documents that guide management across several units. For example, the Pacific Northwest Forest Plan was initiated in 1993 to end an impasse over the management of federal lands within the range of the northern spotted owl. The area encompassed 24.5 million acres (~10 million ha); 17 NFs in Washington, Oregon, and California; and public lands in Oregon and Washington managed by the Bureau of Land Management.

3.3 Current Status of Management Systems

3.3.1 Key Ecosystem Characteristics Upon Which Goals Depend

The NFS (Fig. 3.3) includes a large variety of ecosystems with diverse characteristics. National Forests include ecosystem types ranging from evergreen broadleaf tropical forests within the Caribbean NF in Puerto Rico; alpine tundra on the Medicine Bow NF in Wyoming and the Arapaho NF in Colorado; oakbrush and piñon-juniper woodlands within the Manti-LaSal NF in Utah; northern hardwood forests on the White Mountains NF in New Hampshire; mixed hardwoods on the Wayne-Hoosier NF in Indiana; oak-hickory forests on the Pisgah NF in North Carolina; and ponderosa forests in the Black Hills NF of South Dakota, the Coconino and Sitgreaves NFs of Arizona, and the Lassen NF in California (Adams, Loughry, and Plaugher, 2004). The National Grasslands (NGs) include ecosystem types ranging from shortgrass prairie on the Pawnee NG in Colorado to tallgrass prairie on the Midewin NG in Illinois, and from tallgrass prairie on the Sheyenne NG to the stark badlands found in the Little Missouri NG, both in North Dakota. The NFs also includes aquatic systems (lakes, ponds, wetlands, and waterways). Considering its extent and diversity, the NFS is an important cultural and natural heritage and, as such, is valued by a wide variety of stakeholders.

Figure 3.3. One hundred fifty-five national forests and 20 national grasslands across the United States provide a multitude of goods and ecosystems services, including biodiversity.[6]

National forests harbor much of the nation's terrestrial biodiversity. Specifically, NFs comprise three major attributes of biodiversity across multiple levels of organization (genes to landscapes) (see Noss, 1990): structural diversity (*e.g.*, genetic, population, and ecosystem structure), compositional diversity (*e.g.*, genes, species, communities, ecosystems, and landscape types), and functional diversity (*e.g.*, genetic, demographic, and ecosystem processes, life histories, and landscape-scale processes and disturbances). Biodiversity conservation has become an important goal of the USFS and is a consideration in planning.[7] National forests provide important habitat for many rare, threatened, and endangered plants and animals, ranging from charismatic species such as the grey wolf (*Canis lupus*) to lesser known species such as Ute ladies' tresses (*Spiranthes diluvialis*). Climate change will amplify the current biodiversity conservation

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[6] **USDA Forest Service Geodata Clearinghouse**, 2007: FSGeodata Clearinghouse: other forest service data sets. USDA Forest Service Geodata Clearinghouse Website, Overlay created in ArcMap 8.1, boundary files are the alp_boundaries2 file set, http://fsgeodata.fs.fed.us/clearinghouse/other_fs/other_fs.html, accessed on 7-30-2007.

[7] For example see **USDA Forest Service**, 7-11-2007: Rocky Mountain region: species conservation program. USDA Forest Service Website, http://www.fs.fed.us/r2/projects/scp/, accessed on 7-30-2007.

challenge because it is already affecting and will continue to affect the relationships between climate and the various attributes and components (*i.e.*, genes, species, ecosystems, and landscapes) of biodiversity (Hansen *et al.*, 2001; Root *et al.*, 2003; Malcolm *et al.*, 2006; Parmesan, 2006).

National forests also provide myriad goods and services—collectively called ecosystem services (Millennium Ecosystem Assessment, 2005). Historically, timber, grazing, and fresh water have been the most important goods and services provided by NFs. Although timber harvest (Fig. 3.4) and domestic livestock grazing now occur at lower than historical levels (see also Mitchell, 2000; Haynes *et al.*, 2007), NFs harvested more than 2.2 billion board feet in 2006[8] and more than 7000 ranchers relied on NFs and national grasslands for grazing their livestock.[9] About 60 million Americans (20% of the nation's population in 3,400 towns and cities) depend on water that originates in national forest watershed (USDA Forest Service, 2007b). In addition, NFs contain about 3,000 public water supplies for visitors and employees (*e.g.*, campgrounds, visitor centers, and administrative facilities) (USDA Forest Service, 2007b). Thus, the condition of the watershed affects the quality, quantity, and timing of water flowing through it.[10] Climate change will almost certainly affect all three of these historical ecosystems services of NFs (see Section 3.3.4.2) and likely complicate the USFS's already formidable task of restoring, sustaining, and enhancing NFs and NGs while providing and sustaining benefits to the American people.

Figure 3.4. Historical harvest levels across the national forests.8

Over the past few decades, the USFS and the public have come to appreciate the full range of ecosystem services that NFs provide (see Box 3.2). The Millennium Ecosystem Assessment (2005) defines ecosystem services as the benefits people derive from ecosystems, and classifies these benefits into four general categories (Box 3.2): provisioning (*i.e.*, products from ecosystems), regulating (*i.e.*, regulation of ecosystem processes), cultural (*i.e.*, nonmaterial benefits), and supporting services (*i.e.*, services required for production of all other ecosystems services). Biodiversity can be treated as an ecosystem service in its own right, or can be seen as a necessary condition underpinning the long-term provision of other services (Millennium Ecosystem Assessment, 2005; Balvanera *et al.*, 2006; Díaz *et al.*, 2006). This report treats biodiversity as an ecosystem service. The growing importance of regulating services such as pest management, and watershed and erosion management (see Goal 1); provisioning services such as providing wood and energy (see Goal 2); and cultural services such as aesthetics and especially recreation (Goal 4) are reflected in the USFS national goals (see Box 3.1).

The achievement of strategic and tactical goals set forth by the USFS depends on conservation and enhancement of ecosystems services at various scales. Maintenance and enhancement of

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[8] **USDA Forest Service**, 2006: FY1905-2006 annual national sold and harvest summary. Available from http://www.fs.fed.us/forestmanagement/reports/sold-harvest/documents/1905-2006_Natl_Sold_Harvest_Summary.pdf, USDA Forest Service Forest Management, Washington, DC.

[9] **USDA Forest Service**, 2007: *Grazing Statistical Summary 2005*. Washington, DC, pp.iii-108.

[10] **Brown**, T.C. and P. Froemke, 2006: *An Initial Ranking of the Condition of Watersheds Containing NFS Land: Approach and Methodology*. USDA Forest Service Rocky Mountain Research Station.

ecosystems services on NFs is considered within the context of all potential uses and values of individual NFs. Unlike federal lands afforded strict protection, NFs contain multiple resources to be used and managed for the benefit of current and future generations (see Multiple-Use Sustained-Yield Act of 1960). The USFS, as the steward of NFs and its resources, actively manages NFs to achieve the national goals outlined in Box 3.1 and the individual goals identified for each NF and NG.

3.3.2 Stressors of Concern on National Forests

3.3.2.1 Current Major Stressors

National forests are currently subject to many stressors that affect the ability of the USFS to achieve its goals. We define the term stressor as any physical, chemical, or biological entity that can induce an adverse response (U.S. Environmental Protection Agency, 2000). Stressors can arise from physical and biological alterations of natural disturbances within NFs, increased unmanaged demand for ecosystem services (such as recreation), alterations of the landscape mosaic surrounding NFs, chemical alterations in regional air quality, or from a legacy of past management actions (USDA Forest Service, 2007b).

Disturbances, both human-induced and natural, shape ecosystems by influencing their composition, structure, and function (Dale *et al.*, 2001). Over long timeframes, ecosystems adapt and can come to depend on natural disturbances such as fire, hurricanes, windstorms, insects, and disease. For example, sites where fire has naturally occurred include plant species with seed cones that open only in response to heat from wildfire, and thick barked trees that resist surface fire. When disturbances become functions of both natural and human conditions (*e.g.*, forest fire ignition and spread), the nature (*i.e.*, temporal and spatial characteristics) of the disturbance may change—such as when wildfire occurs outside of the recorded fire season. These altered disturbance regimes become stressors to ecosystems, and affect ecosystem services and natural resources within NF ecosystems (*e.g.*, fire, USDA Forest Service, 2007b).

Current Management Activities and the Legacy of Past Management

The legacy of past land-use can leave persistent effects on ecosystem composition, structure, and function (Dupouey *et al.*, 2002; Foster *et al.*, 2003). Depending on their scale and intensity, extractive activities such as timber harvesting, mining, and livestock grazing stress NF ecosystems, affecting their resilience and the services they provide. Current USFS management strategies emphasize mitigation of environmental impacts from these activities (see section 3.3.3). However, the legacy of extractive activities in the past (Rueth, Baron, and Joyce, 2002; Foster *et al.*, 2003) is a continuing source of stress in NFs. For example, past logging practices, in combination with fire suppression, fragmentation, and other factors, have homogenized forest species composition (including a shift from late- to early-successional species); created a unimodal age and size structure; and markedly reduced the number of large trees, snags, and coarse woody debris (Rueth, Baron, and Joyce, 2002; Foster *et al.*, 2003). The long-term ecological impacts of mining operations before the environmental regulations of the 1960s were promulgated have been similarly profound, including mortality of aquatic organisms from lethal concentrations of acid and toxic metals (*e.g.*, copper, lead, and cadmium) and alteration of aquatic and riparian food webs from bio-accumulation of these metals (Rueth, Baron, and Joyce, 2002). The uncontrolled grazing prevailing on federal lands (including areas that are now NFs) until the Taylor Grazing Act was enacted in the 1930s has left a similar environmental imprint. Overstocked rangelands contributed to widespread erosion, reduced soil productivity, and a shift in species composition, including the invasion of non-native species that have altered fire regimes (Rueth, Baron, and Joyce, 2002).

Land Use and Land Cover Change Surrounding National Forests

Changes in the land use and land cover surrounding NFs have been and continue to be associated with the loss of open space (subdivision of ranches or large timber holdings) (Birch, 1996; Sampson and DeCoster, 2000; Hawbaker *et al.*, 2006), the conversion of forestland to urban and built-up uses in the wildland-urban interface (WUI), and habitat fragmentation (related to increases in road densities and impervious surfaces). The amount of U.S. land in urban and built-up uses increased by 34% between 1982 and 1997, the result primarily of the conversion of croplands and forestland (Alig, Kline, and Lichtenstein, 2004). Subdivision of large timber holdings also results in a change in management, as private forest landowners no longer practice forest management (Sampson and DeCoster, 2000).

The WUI is defined as "the area where structures and other human developments meet or intermingle with undeveloped wildland" (Stewart, Radeloff, and Hammer, 2006). Between 1990 and 2000, 60% of all new housing units built in the United States were located in the WUI (Fig. 3.5), and currently 39% of all housing units are located in the WUI (Radeloff *et al.*, 2005). More than 80% of the total land area in the United States is within about 1 km of a road (Riitters and Wickham, 2003). "Perforated" (*i.e.*, fragmented) forests with anthropogenic edges affect about 20% of the eastern United States. (Riitters and Coulston, 2005). These changes surrounding NFs can change the effective size of wildlife habitat, change the ecological flows (*e.g.*, fire, water, and plant and animal migrations) into and out of the NFs, increase opportunities for invasive species, increase human impact at the boundaries within the borders of NFs (Hansen and DeFries, 2007), and constrain management options (*e.g.*, fire use). In addition to these land use and land cover changes surrounding the large contiguous NFs, some NFs contain large areas of checkerboard ownership where sections of USFS lands and private ownership intermingle.

Figure 3.5. Wildland Urban Interface across the United States (Radeloff *et al.*, 2005).

Invasive Species

A species is considered invasive if (1) it is non-native to the ecosystem under consideration, and (2) its introduction causes or is likely to cause economic or environmental harm, or harm to human health.[11] Invasive species have markedly altered the structure and composition of forest, woodland, shrubland, and grassland ecosystems. Non-native insects expanding their ranges nationally in 2004 include Asian longhorned beetle, hemlock woolly adelgid, the common European pine shoot beetle, and the emerald ash borer (USDA Forest Service Health Protection, 2005). Non-native diseases continuing to spread include beech bark disease, white pine blister rust, and sudden oak death. Within the Northeast, 350,000 acres (141,600 ha) of NFs are annually infested and affected by non-native species, including 165 non-native plant species of concern (USDA Forest Service, 2003). Plant species of greatest concern include purple

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[11] Executive Order 13112: Invasive Species

loosestrife, garlic mustard, Japanese barberry, kudzu, knapweed, buckthorns, olives, leafy spurge, and reed and stilt grass (USDA Forest Service, 2003). Non-native earthworms have invaded and altered soils in previously earthworm-free forests throughout the northeastern United States (Fig. 3.6) (Hendrix and Bohlen, 2002; Hale *et al.*, 2005; Frelich *et al.*, 2006).

Figure 3.6. Influence of non-native earthworms on eastern forest floor dynamics (Frelich *et al.*, 2006). Forest floor and plant community at base of trees before (a, left-hand photo) and after (b) European earthworm invasion in a sugar-maple-dominated forest on the Chippewa National Forest, Minnesota, USA. Photo credit: Dave Hansen, University of Minnesota Agricultural Experimental Station.

Non-native invasive plant species have altered fire regimes in the western United States, including Hawaii (Westbrooks, 1998; Mitchell, 2000), and consequently other important ecosystem processes (D'Antonio and Vitousek, 1992; Brooks *et al.*, 2004). Cheatgrass (*Bromus tectorum*), now a common understory species in millions of hectares of sagebrush-dominated vegetation assemblages in the Intermountain West (Mack, 1981), alters the fuel complex, increases fire frequency, and reduces habitat provided by older stands of sagebrush (Williams and Baruch, 2000; Smith *et al.*, 2000; Ziska, Faulkner, and Lydon, 2004; Ziska, Reeves, and Blank, 2005).[12] Similarly, buffelgrass (*Pennisetum ciliare*) and other African grasses are now common in much of the Sonoran Desert, providing elevated fuel levels that could threaten cactus species with increased fire frequency and severity (Williams and Baruch, 2000). Fountain grass (*Pennisetum setaceum*), introduced to the island of Hawaii, greatly increases fire susceptibility in the dry forest ecosystems where fire was not historically frequent (D'Antonio, Tunison, and Loh, 2000). Cogongrass (*Imperata cylindrica* (L.) Beauv.) invasions have similarly altered fire regimes in pine savannas in the southeastern United States (Lippincott, 2000).

Air Pollution

Ozone, sulfur dioxide, nitrogen oxides (NO_x), and mercury transported into NFs from urban and industrial areas across the United States affect resources such as vegetation, lakes, and wildlife. A combination of hot, stagnant summer air masses, expansive forest area, and high rates of NO_x emissions combine to produce high levels of ozone, especially in the western, southern, and northeastern regions of the United States (Fiore *et al.*, 2002). Current levels of ozone exposure are estimated to reduce eastern and southern forest productivity by 5–10% (Joyce *et al.*, 2001; Felzer *et al.*, 2004). Elevated nitrogen deposition downwind of large, expanding metropolitan centers or large agricultural operations has been shown to affect forests when nitrogen deposited is in excess of biological demand (nitrogen saturation). Across the southern United States it is largely confined to high elevations of the Appalachian Mountains (Johnson and Lindberg, 1992), although recent increases in both hog and chicken production operations have caused localized nitrogen saturation in the Piedmont and Coastal Plain (McNulty *et al.*, forthcoming). In the western United States, increased nitrogen deposition has altered plant communities (particularly alpine communities in the Rocky Mountains) and reduced lichen and soil mychorriza

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[12] See also **Tausch**, R.J., 1999: Transitions and thresholds: influences and implications for management in pinyon and juniper woodlands. In: *Proceedings: Ecology and Management of Pinyon-Juniper Communities Within the Interior West*, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 361-365.

(particularly in the Sierra Nevada mountains of Southern California) (Baron *et al.*, 2000; Fenn *et al.*, 2003). In Southern California, the interaction of ozone and nitrogen deposition has been shown to cause major physiological disruption in ponderosa pine trees (Fenn *et al.*, 2003). Mercury deposition negatively affects aquatic food webs as well as terrestrial wildlife, as a result of bioaccumulation, throughout the United States (Chen *et al.*, 2005; Driscoll *et al.*, 2007; Peterson *et al.*, 2007). In the Ottawa NF (Michigan), for example, 16 lakes and four streams have been contaminated by mercury that was deposited from pollution originating outside of NF borders (Ottawa National Forest, 2006).

Energy Activities

Of the estimated 99.2 million acres (40.1 million ha) of oil and gas resources on federal lands (USDA, USDI, and DOE, 2006), 24 million acres (9.7 million ha) are under USFS management. The Bureau of Land Management has the major role in issuing oil and gas leases and permits in NFs; however, the USFS determines the availability of land and the conditions of use, and regulates all surface-disturbing activities conducted under the lease (GAO, 2004). Principal causes of stress are transportation systems to access oil and gas wells, the oil and gas platforms themselves, pipelines, contamination resulting from spills or the extraction of oil and gas, and flue gas combustion and other activities in gas well and oil well productions. The extent to which these stressors affect forests depends on the history of land use and ownership rights to subsurface materials in the particular NF. For example, oil and gas development is an important concern in the Allegheny NF because 93% of the subsurface mineral rights are privately held, and because exploration and extraction have increased recently due to renewed interest in domestic oil supplies and higher crude oil prices (Allegheny National Forest, 2006).

Altered Fire Regimes

Fire is a major driver of forest dynamics in the West, South and Great Lakes region (Agee, 1998; Frelich, 2002), and fire regimes (return interval and severity) and other characteristics (season, extent, etc.) vary widely across the United States (Hardy *et al.*, 2001a; Schmidt *et al.*, 2002). Fire and insect disturbances interact, often synergistically, compounding rates of change in forest ecosystems (Veblen *et al.*, 1994). Historical fire suppression has led to an increase in wildfire activity and altered fire regimes in some forests, resulting in increased density of trees and increased build-up of fuels (Covington *et al.*, 1994; Sampson *et al.*, 2000; Minnich, 2001; Moritz, 2003; Brown, Hall, and Westerling, 2004). Lack of fire or altered fire frequency and severity are considered sources of stress in those ecosystems dependent upon fire, such as forests dominated by ponderosa pine and lodgepole pine in the West, longleaf pine in the South, and oak and pine ecosystems in the East.

Unmanaged Recreation

National forests are enjoyed by millions of outdoor enthusiasts each year, but recreation—particularly unmanaged recreation—causes a variety of ecosystem impacts.[13] Recreational activities that can damage ecosystems include cutting trees for fire, starting fires in inappropriate places, damaging soil and vegetation through the creation of roads and trails, target practice and

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[13] Reviewed in **Leung**, Y.F. and J.L. Marion, 2000: Recreation impacts and management in wilderness: a state-of-knowledge review. In: Wilderness Ecosystems, Threats, and Management [Cole, D.N. (ed.)]. *Proceedings of the Wilderness science in a time of change conference*, 23, May 1999, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

lead contamination, and pollution of waterways.[14] Impacts of these activities include vegetation and habitat loss from trampling, soil and surface litter erosion, soil compaction, air and water pollution, decreased water quality, introduction of non-native invasive species, and wildfires. The creation of unauthorized roads and trails by off-highway vehicle (OHVs) causes erosion, degrades water quality, and destroys habitat.[15]

Extreme Weather Events: Wind, Ice, Freeze-thaw events, Floods, and Drought

Severe wind is the principal cause of natural disturbance in many NFs (*e.g.*, Colorado, Veblen, Hadley, and Reid, 1991; Alaska, Nowacki and Kramer, 1998; northern temperate forests, Papaik and Canham, 2006). Wind is one of the three principal drivers (along with fire and herbivory) of forest dynamics in temperate forests of northeastern and north-central North America (for an example of a wind event, see Box 3.3) (Frelich, 2002). Turnover in northeastern forests depends on creation of gaps from individual trees falling down or being blown down by wind (Seymour, White, and deMaynadier, 2002). Winds from severe storms (*e.g.*, from tornadoes, hurricanes, derechos, and nor'easters) occurring at very infrequent intervals also replace stands at various spatial scales (0.2-3,785 ha; Seymour, White, and deMaynadier, 2002; see also McNulty, 2002). Worrall, Lee, and Harrington (2005) found that windthrow, windsnap, and chronic wind stress expand gaps initiated by insects, parasites, and disease in New Hampshire subalpine spruce-fir forests. Thus, wind, insects, and disease interact to cause chronic stress to forests, whereas extreme storms typically are stand-replacing events.

Ice storms are another important part of the natural disturbance regime (Irland, 2000; Lafon, 2006) that stress individual trees (Bruederle and Stearns, 1985), influence forest structure and composition (Rhoads *et al.*, 2002) and, when severe, can affect important ecosystem processes such as nitrogen cycling (Houlton *et al.*, 2003). The extent to which trees suffer from the stress and damage caused by ice appears to vary with species, slope, aspect, and whether severe winds accompany or follow the ice storm (Bruederle and Stearns, 1985; De Steven, Kline, and Matthiae, 1991; Rhoads *et al.*, 2002; Yorks and Adams, 2005). Growth form, canopy position, mechanical properties of the wood, and tree age and health influence the susceptibility of different species to ice damage (Bruederle and Stearns, 1985). Severe ice storms, such as the 1999 storm in New England, can shift the successional trajectory of the forest due to the interactions between the storm itself and effects of more chronic stressors, such as beech bark disease (Rhoads *et al.*, 2002).

Climate variability and extreme weather events also affect ecosystem response. Auclair, Lill, and Revenga (1996) identified the relationships between thaw-freeze and root-freeze events in winter and early spring and severe episodes of dieback in northeastern and Canadian forests. These extreme events helped trigger (and synchronize) large-scale forest dieback, because trees injured by freezing were more vulnerable to the heat and drought stress that eventually killed them. In northern hardwoods, freezing, as opposed to drought, was significantly correlated with increasing global mean annual temperatures and low values of the Pacific tropical Southern

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[14] **National Forest Foundation**, 2006: Recreation. National Forests Foundation Website, http://www.natlforests.org/consi_02_rec.html, accessed on 5-4-2007.

[15] **Foltz**, R.B., 2006: Erosion from all terrain vehicle (ATV) trails on National Forest lands. Proceedings of the 2006 ASABE Annual International Meeting, 9, July 2006, American Society of Agricultural and Biological Engineers, Portland Convention Center, Portland, OR. Available from http://asae.frymulti.com/request.asp?JID=5&AID=21056&CID=por2006&T=2.

Oscillation Index (Auclair, Lill, and Revenga, 1996). Auclair, Eglinton, and Minnemeyer (1997) identified large areas in the Northeast and Canada where this climatic phenomenon affected several hardwood species. Lack of the insulating layer of snow was shown to increase soil freezing events in northern hardwood forests (Hardy *et al.*, 2001b).

Droughts (and even less-severe water stress) weaken otherwise healthy and resistant trees and leave them more susceptible to both native and non-native insect and disease outbreaks. Protracted droughts have already contributed to large-scale dieback of species such as ponderosa pine (see Box 3.4). Vegetation in NFs with sandy or shallow soils is more susceptible to drought stress than vegetation growing in deeper or heavier soils (Hanson and Weltzin, 2000), resulting in situations where soil type and drought interact to substantially increase fire risk. The extent and severity of fire impacts is closely associated with droughts; the most widespread and severe fires occur in the driest years (Taylor and Beaty, 2005; Westerling *et al.*, 2006). The temporal and spatial distribution of droughts also affects watershed condition by affecting surface water chemistry (Inamdar *et al.*, 2006).

Floods caused by extreme precipitation events—especially those that co-occur with or contribute to snowmelt—are another important stressor in NFs. In floodplain forests, periodic floods deposit alluvium, contribute to soil development, and drive successional processes (Bayley, 1995; Yarie *et al.*, 1998). Tree damage and mortality caused by inundation depends on several factors including season, duration, water levels, temperature and oxygen, mechanical damage, and concentration of contaminants. Floods in upland forests, however, are considered large, infrequent disturbances (Turner *et al.*, 1998; Michener and Haeuber, 1998) dominated by mechanical damage that affects geophysical and ecological processes (Swanson *et al.*, 1998). The physical damage to aquatic and riparian habitat from landslides, channel erosion, and snapped and uprooted trees can be extensive and severe, or quite heterogeneous (Swanson *et al.*, 1998). Flooding facilitates biotic invasions, both by creating sites for invasive species to become established and by dispersing these species to the sites (Barden, 1987; Miller, 2003; Decruyenaere and Holt, 2005; Truscott *et al.*, 2006; Watterson and Jones, 2006; Oswalt and Oswalt, 2007).

3.3.2.2 Stress Complexes in Western Ecosystems

A warmer climate is expected to affect ecosystems in the western United States by altering *stress complexes* (Manion, 1991)—combinations of biotic and abiotic stresses that compromise the vigor of ecosystems—leading to increased extent and severity of disturbances (McKenzie, Peterson, and Littell, forthcoming). Increased water deficit will accelerate the stress complexes experienced in forests, which typically involve some combination of multi-year drought, insects, and fire. Increases in fire disturbance superimposed on ecosystems with increased stress from drought and insects may have significant effects on growth, regeneration, long-term distribution and abundance of forest species, and carbon sequestration (Fig. 3.7).

Figure 3.7. Conceptual model of the relative time scales for disturbance vs. climatic change alone to alter ecosystems. Times are approximate. Adapted from (McKenzie *et al.*, 2004).

Forests of western North America can be classified into energy-limited vs. water-limited vegetation (Milne, Gupta, and Restrepo, 2002; Littell and Peterson, 2005). Energy-related limiting factors are chiefly light (*e.g.*, productive forests where competition reduces light to most individuals) and temperature (*e.g.*, high-latitude or high-elevation forests). Energy-limited ecosystems in general appear to be responding positively to warming temperatures over the past 100 years (McKenzie, Hessl, and Peterson, 2001). In contrast, productivity in water-limited systems may decrease with warming temperatures, as negative water balances constrain photosynthesis (Hicke *et al.*, 2002), although this may be partially offset if CO_2 fertilization significantly increases water-use efficiency in plants (Neilson *et al.*, 2005b). Littell (2006) found that most montane Douglas fir (*Pseudotsuga menziesii*) forests across the northwestern United States appear to be water limited; under current climate projections these limits would increase in both area affected and magnitude.

Temperature increases are a predisposing factor causing often lethal stresses on forest ecosystems of western North America, acting both directly through increasingly negative water balances (Stephenson, 1998; Milne, Gupta, and Restrepo, 2002; Littell, 2006) and indirectly through increased frequency, severity, and extent of disturbances—chiefly fire and insect outbreaks (Logan and Powell, 2001; McKenzie *et al.*, 2004; Logan and Powell, 2005; Skinner, Shabbar, and Flanningan, 2006). Four examples of forest ecosystems whose species composition and stability are currently affected by stress complexes precipitated by a warming climate are described below. Two cases involve the loss of a single dominant species, and the other two involve two or more dominant species.

Piñon-Juniper Woodlands of the American Southwest

Piñon pine (*Pinus edulis*) and various juniper species (*Juniperus* spp.) are among the most drought-tolerant trees in western North America, and piñon-juniper ecosystems characterize lower treelines across much of the West. Piñon-juniper woodlands are clearly water-limited systems, and piñon-juniper ecotones are sensitive to feedbacks from environmental fluctuations and existing canopy structure that may buffer trees against drought (Milne *et al.*, 1996) (Box 3.4). However, severe multi-year droughts periodically cause dieback of piñon pines, overwhelming any local buffering. Interdecadal climate variability strongly affects interior dry ecosystems, causing considerable growth during wet periods. This growth increases the evaporative demand, setting up the ecosystem for dieback during the ensuing dry period (Swetnam and Betancourt, 1998). The current dieback is historically unprecedented in its combination of low precipitation and high temperatures (Breshears *et al.*, 2005). Fig. 3.8 shows the stress complex associated with piñon-juniper ecosystems. Increased drought stress via warmer climate is the predisposing factor, and piñon pine mortality and fuel accumulations are inciting factors. Ecosystem change comes from large-scale severe fires that lead to colonization of invasive species (D'Antonio, 2000), which further compromises the ability of piñon pines to re-establish.

Figure 3.8. Stress complex in piñon-juniper woodlands of the American Southwest. From McKenzie *et al*. (2004).

Mixed Conifer Forest of the Sierra Nevada and Southern California

These forests experience a Mediterranean climate with long, dry summers. Fire frequency and extent have not increased concomitantly with warmer temperatures, but instead have decreased to their lowest levels in the last 2,000 years. Stine (1996) attributed this decline to decreased fuel loads from sheep grazing, decreased ignition from the demise of Native American cultures, and fire exclusion. Continued fire exclusion has led to increased fuel loadings, and competitive stresses on individual trees as stand densities have increased (Van Mantgem *et al.*, 2004). Elevated levels of ambient ozone from combustion of fossil fuels affect plant vigor in the Sierra Nevada and the mountains of southern California (Peterson, Arbaugh, and Robinson, 1991; Miller, 1992). Sierra Nevada forests support endemic levels of a diverse group of insect defoliators and bark beetles, but bark beetles in particular have reached outbreak levels in recent years, facilitated by protracted droughts and biotic complexes that include bark beetles interacting with root diseases and mistletoes (Ferrell, 1996). Dense stands, fire suppression, and exotic pathogens such as white pine blister rust (*Cronartium ribicola*) can exacerbate biotic interactions (Van Mantgem *et al.*, 2004) and drought stress. Fig. 3.9 shows the stress complex associated with Sierra Nevada forest ecosystems, and is likely applicable to the mountain ranges east and north of the Los Angeles basin.

Figure 3.9. Stress complex in Sierra Nevada and southern Californian mixed-conifer forests. From McKenzie, Peterson, and Littell (forthcoming).

Interior Lodgepole Pine Forests

Lodgepole pine (*Pinus contorta* var. *latifolia*) is widely distributed across western North America, often forming nearly monospecific stands in some locations. It is the principal host of the mountain pine beetle (*Dendroctonus ponderosae*), and monospecific stands are particularly vulnerable to high mortality during beetle outbreaks. Recent beetle outbreaks have caused extensive mortality across millions of hectares (Logan and Powell, 2001; Logan and Powell, 2005), with large areas of mature cohorts of trees (age 70–80 yr) contributing to widespread vulnerability.[16] Warmer temperatures facilitate bark beetle outbreaks in two ways: (1) drought stress makes trees more vulnerable to attack, and (2) insect populations respond to increased temperatures by speeding up their reproductive cycles (*e.g.*, to one-year life cycles). Warming temperatures would be expected to exacerbate these outbreaks and facilitate their spread northward and eastward across the continental divide (Logan and Powell, 2005; but see Moore *et al.*, 2006). Fig. 3.10 shows the stress complex for interior lodgepole pine forests. Warmer temperatures, in combination with beetle mortality, set up some ecosystems for shifts in species dominance that will be mediated by disturbances such as fire.

Figure 3.10. Stress complex in interior (British Columbia and United States) lodgepole pine forests. From McKenzie, Peterson, and Littell (forthcoming).

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[16] **Carroll**, A., 2006: Changing the climate, changing the rules: global warming and insect disturbance in western North American forests. Proceedings of the 2006 MTNCLIM conference, Mt. Hood, Oregon. Accessed at http://www.fs.fed.us/psw/cirmount/meetings/mtnclim/2006/talks/pdf/carroll_talk_mtnclim2006.pdf.

Alaskan Spruce Forests

The state of Alaska has experienced historically unprecedented fires in the last decade, including the five largest fires in the United States. More than 2.5 million hectares burned in the interior during 2004. During the 1990s, massive outbreaks of the spruce bark beetle (*Dendroctonus rufipennis*) occurred on and near the Kenai Peninsula (including the Chugach NF) in southern Alaska (Berg *et al.*, 2006). Although periodic outbreaks have occurred throughout the historical record, these most recent ones may be unprecedented in extent and percentage mortality (over 90% in many places; Ross *et al.*, 2001; Berg *et al.*, 2006). Both these phenomena are associated with warmer temperatures in recent decades (Duffy *et al.*, 2005; Berg *et al.*, 2006; Werner *et al.*, 2006). Although fire-season length in interior Alaska is associated with the timing of onset of late-summer rains, the principal driver of annual area burned is early summer temperature (Duffy *et al.*, 2005). In the interior of Alaska, white spruce (*Picea glauca*) and black spruce (*P. mariana*) are more flammable than their sympatric deciduous species (chiefly paper birch, *Betula papyrifera*). Similarly, conifers are the target of bark beetles, so in southern Alaska they will be disadvantaged compared with deciduous species. Fig. 3.11 shows the stress complex for Alaska forest ecosystems, suggesting a significant transition to deciduous life forms via more frequent and extensive disturbance associated with climate variability and change. This transition would be unlikely without changes in disturbance regimes, even under climate change, because both empirical and modeling studies suggest that warmer temperatures alone will not favor a life-form transition (Johnstone *et al.*, 2004; Bachelet *et al.*, 2005; Boucher and Mead, 2006).

Figure 3.11. Stress complex in the interior and coastal forests of Alaska. From McKenzie, Peterson, and Littell (forthcoming).

3.3.3 Management Approaches and Methods Currently in Use to Manage Stressors

Management approaches addressing the current stressors are based on guidance from USFS manuals and handbooks, developed through planning processes that may occur after the disturbance (such as ice storms or wind events), and developed through regional scientific assessment and national planning efforts. For example, approaches for invasive species management are outlined in the National Strategy and Implementation Plan for Invasive Species Management; approaches for altered fire regimes are outlined in the National Fire Plan. Unmanaged recreation, particularly the use off-highway-vehicles, is being addressed through the new travel management plan. Management of native insects and pathogens that become problematic is the responsibility of the Forest Health Protection Program, working in cooperation with NFs. When extreme climate- or weather-related events occur, such as large wind blowdown events (see Box 3.3), management plans are developed in response to the stressor (such as after the blowdown event on the Superior National Forest).[17] Current USFS management strategies emphasize mitigation of environmental impacts from activities such as timber harvest and grazing through environmental analyses and the selection of the best management practices. Silvicultural practices are used to manipulate and modify forest stands for wildlife habitat,

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[17] **USDA Forest Service**, 5-12-2006: Superior National Forests: lowdown on the blowdown. USDA Forest Service, http://www.fs.fed.us/r9/forests/superior/storm_recovery/, accessed on 5-7-2007.

recreation, watershed management, and for fuels reductions, as well as for commercial tree harvests. Management approaches across the NFS are influenced by the local climate, physical environment (soils), plant species, ecosystem dynamics, and the landscape context (*e.g.*, WUI, proximity to large metropolitan areas for recreational use).

Adaptive management can be defined as a systematic and iterative approach for improving resource management by emphasizing learning from management outcomes (Bormann, Haynes, and Martin, 2007). An adaptive management approach was implemented through the Northwest Forest Plan to federal lands in the Pacific Northwest (Bormann, Haynes, and Martin, 2007). The Plan directed managers to experiment, monitor, and interpret as activities were applied both inside and outside adaptive management areas—and to do this as a basis for changing the Plan in the future. In that application, managers identified adaptive management areas; developed organizational strategies to apply the adaptive management process across the entire plan area (10 million acres); established a major regional monitoring program; and undertook a formal interpretive step that gathered what was learned and translated new understanding for the use of decision makers (Haynes *et al.*, 2006). The Sierra Nevada Forest Plan Amendment (see Case Study Summary 3.1) contained a Sierra-wide adaptive management and monitoring strategy. This strategy is being implemented as a pilot project on two NFs in California. This seven-year pilot project, undertaken via a Memorandum of Understanding between the USFS, the U.S. Fish and Wildlife Service, and the University of California, applies scientifically rigorous design, treatment, and analysis approaches to fire and forest health, watershed health, and wildlife. Several watersheds of Tahoe NF are involved in each of the three issue areas of the adaptive management project.

Lessening the damages caused by native insects and pathogens is the goal of the USFS Forest Health Protection (FHP) program. This program includes efforts to control the native species of southern pine beetle and western bark beetles. FHP funds southern pine beetle suppression, prevention, and restoration projects on state lands, private lands, and NFs in the South. FHP's forest health monitoring program determines the status, changes, and trends in indicators of forest condition annually. The program uses data from ground plots and surveys, aerial surveys, and other biotic and abiotic data sources, and develops analytical approaches to address forest health issues.

Reducing, minimizing, or eliminating the potential for introduction, establishment, spread and impact of invasive species across all landscapes and ownerships is the goal of the USFS National Strategy and Implementation Plan for Invasive Species Management (USDA Forest Service, 2004). The Plan encompasses four program elements: (1) prevention, (2) early detection and rapid response (EDRR), (3) control and management, and (4) rehabilitation and restoration. Activities in the Prevention element include regularly sanitizing maintenance equipment; requiring weed-free certified seed for restoration, and use of certified weed-free hay; training to identify invasive species; cooperating with other institutions and organizations to prevent the introduction of new forest pests from other countries; and providing technical assistance and funding for public education and prevention measures for invasive species on all lands, regardless of ownership. Activities in the EDRR program include the annual cooperative survey of federal, tribal, and private forestland for damage caused by forest insects and pathogens, and the establishment of the EDRR system for invasive insects in 10 ports and surrounding urban forests. Control and Management activities include treating invasive plants each year on federal, state, and private forested lands, and collaborating with biological control specialists to produce a guide to biological control of invasive plants in the eastern United States. Rehabilitation and Restoration activities highlight the importance of partnerships in such work as developing resistant planting stock for five-needle pine restoration efforts following white pine blister rust mortality, and coordinating at the national and regional levels to address the need for and supply of native plant materials (for example, seeds and seedlings) for restoration.

Reducing hazardous fuels and enhancing the restoration and post-fire recovery of fire-adapted ecosystems are two goals in the National Fire Plan. The two other goals focus on improving fire prevention and suppression, and promoting community assistance. The updated implementation plan (Western Governors' Association, 2006) emphasizes a landscape-level vision for restoration of fire-adapted ecosystems, the importance of fire as a management tool, and the need to continue to improve collaboration among governments and stakeholders at the local, state, regional, and national levels. Land managers reduce hazardous fuels through the use of prescribed fire, mechanical thinning, herbicides, grazing, or combinations of these and other methods. Treatments are increasingly being focused on the expanding WUI areas. Where fire is a major component of the ecosystem, wildland fire use—the management of naturally ignited fires—is used to achieve resource benefits. The appropriate removal and use of woody biomass, as described in the USFS Woody Biomass Strategy, has the potential to contribute to a number of the USFS's strategic goals while providing a market-based means to reduce costs.

In response to the expanded use of off-highway vehicles, the Forest Service's new travel management rule provides the framework for each national forest and grassland to designate a sustainable system of roads, trails, and areas open to motor vehicle use.[18] The rule aims to secure a wide range of recreational opportunities while ensuring the best possible care of the land. Designation includes class of vehicle and, if appropriate, time of year for motor vehicle use. Designation decisions are made locally, with public input and in coordination with state, local, and tribal governments.

The Federal Land Manager (broadly, the federal agency charged with protecting wilderness air quality; *e.g.*, the USFS or the National Park Service) has a responsibility to protect the Air Quality Related Values (AQRV) of Class I wilderness areas identified in and mandated by the Clean Air Act. Air resources managers develop monitoring plans for AQRV, such as pH and acid neutralizing capacity in high-elevation lakes. The Federal Land Manager must advise the air quality permitting agency if a new source of pollution, such as from an energy or industrial development, will cause an adverse impact to any AQRV.

3.3.4 Sensitivity of Management Goals to Climate Change

All USFS national goals (Box 3.1) are sensitive to climate change. In general, the direction and magnitude of the effect of climate change on each management goal depends on the temporal and spatial nature of the climate change features, their impact on the ecosystem, and the current status and degree of human alteration of the ecosystem (*i.e.*, whether the ecosystem has lost key

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[18] 36 CFR Parts 212, 251, 261, and 295 Travel Management; Designated Routes and Areas for Motor Vehicle Use; Final Rule, November 9, 2005.

components such as late-seral forests; free-flowing streams; or keystone species such as beaver, large predators, and native pollinators). The sensitivity of the management goals to climate change also will depend on how climate change interacts with the major stressors in each ecoregion and national forest. And finally, the sensitivity of the management goals to climate change will depend on the assumptions about climate that the management activities currently make. These assumptions range from the relationship between natural regeneration and climate to seasonal distributions of rainfall and stream flow and management tied to these distributions.

3.3.4.1 Goal 1: Restore, Sustain, and Enhance the Nation's Forests and Grasslands

The identified outcome for this goal is forests and grasslands with the capacity to maintain their health, productivity, diversity, and resistance to unnaturally severe disturbances (USDA Forest Service, 2007b). Ecosystem productivity and diversity are strongly influenced by climate. Changes in climatic variables, as well as the effects of interactions of climate change with other stressors (Noss, 2001; Thomas *et al.*, 2004; Millennium Ecosystem Assessment, 2005; Malcolm *et al.*, 2006), may affect all attributes and components of biodiversity (sensu Noss, 1990). Numerous effects of climate change on biodiversity components (*e.g.*, ecosystems, populations, and genes) and attributes (*i.e.*, structure, composition, and function of these components) have already been documented (reviewed in Parmesan, 2006). Natural disturbances such as fire regimes are tightly linked to key climate variables (*i.e.*, temperature, precipitation, and wind) (Agee, 1996; Pyne, Andrews, and Laven, 1996; McKenzie *et al.*, 2004). As a result, changes in weather and climate are quickly reflected in altered fire frequency and severity (Flannigan, Stocks, and Wotton, 2000; Dale *et al.*, 2001). Invasive species are currently contributing to a homogenization of the earth's biota (McKinney and Lockwood, 1999; Mooney and Hobbs, 2000; Rahel, 2000; Olden, 2006), increasing extinction risks for native species (Wilcove and Chen, 1998; Mooney and Cleland, 2001; Novacek and Cleland, 2001; Sax and Gaines, 2003), and harming the economy and human health (Pimentel *et al.*, 2000). Species that can shift ranges quickly and tolerate a wide range of environments, traits common to many invasive species, will benefit under a rapidly changing climate (Dukes and Mooney, 1999). Thus, this goal is sensitive to climate change.

Specific objectives related to this goal include reducing the risk to communities and natural resources from uncharacteristically severe wildfires; reducing adverse impacts from invasive non-native and native species, pests, and diseases; and restoring and maintaining healthy watersheds and diverse habitats.

Climate change and wildfire management

A continual reassessment of climate and land management assumptions may be necessary for effective wildfire management under future climate change. Future climate scenarios suggest a continued increase in fire danger across the United States (Flannigan, Stocks, and Wotton, 2000; Bachelet *et al.*, 2001; Brown, Hall, and Westerling, 2004; McKenzie *et al.*, 2004; Running, 2006) through increasing fire season length, potential size of fires, and areas vulnerable to fire, as well as by altering vegetation, which in turn will influence fuel loadings and consequently fire behavior. Future climate change may offer opportunities to conduct prescribed fire outside of traditional burn seasons, with increased accessibility in some areas in the winter (see Case Study Summary 3.1).

Since the mid-1980s, western forests have sustained more large wildfires, of longer duration, within a context of longer fire seasons, with 60% of the increase occurring at mid-elevations of the Northern Rocky Mountains (Westerling *et al.*, 2006). Land use influences do not appear to have altered fire regimes in high-elevation forests with long fire return intervals (Schoennagel, Veblen, and Romme, 2004). However, suppression of fires has led to the conversion of some lodgepole pine forests to fir and spruce. Some of these stand structures have changed significantly, which may increase their susceptibility to insect infestations (Keane *et al.*, 2002). Wildfire risk has increased in some ponderosa pine and mixed conifer forests (Schoennagel, Veblen, and Romme, 2004; Westerling *et al.*, 2006), where the exclusion of more frequent fires has led to denser stands and higher fuel loading. Future climate projections for western North America project June to August temperature increases of 2–5°C by 2040 to 2069, and precipitation decreases of up to 15% over that time period (Running, 2006). The potential for increased fire activity in high-elevation forests could be exacerbated by the increased fuel loads expected to result from enhanced winter survival of mountain pine beetles and similar pest species (Guarin and Taylor, 2005; Millar, Westfall, and Delany, forthcoming). Fires that occur in low- and mid-elevation forest types have potential for increasing fire severity (Keane *et al.*, 2002) as future burning conditions become more extreme.

Increases in the area burned or biomass burned under future climate scenarios are seen in a number of studies across the United States. Using historical data, warmer summer temperatures were shown to be significant in western state-level statistical models of area burned (McKenzie *et al.*, 2004). Using the IPCC B2 climate scenario and the Parallel Climate Model, wildfire activity was projected to increase from 1.5–4 times historical levels for all western states (except California and Nevada) by the 2070–2100 period. The highest increases were projected for Utah and New Mexico. The analysis of 19 climate models and their scenarios used in the Fourth IPCC Assessment Report (Seager *et al.*, 2007) show a consistency in the projections for increased drought in the Southwest, unlike any seen in the instrumental record. In Alaska, warmer and longer growing seasons and associated vegetation shifts under two future climate scenarios indicated an increase in the area of forests burned by a factor of two or three (Bachelet *et al.*, 2005).

The combination of extended dry periods resulting from fewer, stronger rainfall events with warmer temperatures could render northeastern forests more susceptible to fire than they have been for the past 100 years of fire suppression (Scholze *et al.*, 2006). Similarly, drought may become an increasingly important stressor in eastern forests, which in turn may increase the risk of fire in areas that have experienced low frequency fire regimes during the past century or more (Lafon, Hoss, and Grissino-Mayer, 2005).

Some climate scenarios project less and others more precipitation for the southern United States (Bachelet *et al.*, 2001). Even under the wetter scenarios, however, the South is projected to experience an increase in temperature-induced drought and an increase in fires (Lenihan *et al.*, forthcoming). On average, biomass consumed by fire is expected to increase by a factor of two or three (Bachelet *et al.*, 2001; Bachelet *et al.*, forthcoming).

Climate Change and Invasive and Native Species Management

Invasive species are already a problem in many areas of the United States (Stein *et al.*, 1996; Pimentel *et al.*, 2000; Rahel, 2000; Von Holle and Simberloff, 2005). Climate change is expected to compound this problem, due to its direct influence on native species' distributions and the effects of its interactions with other stressors (Chornesky *et al.*, 2005). A continual reassessment of management strategies for invasive species may be necessary under a changing climate.

In general, the impacts of invasive species with an expanded range are difficult to predict, in part because the interactions among changing climate, elevated CO_2 concentrations, and altered nutrient dynamics are themselves still being elucidated (Simberloff, 2000). In some cases, however, the likely impacts are better understood. For example, future warming may accelerate the northern expansion of European earthworms, which have already substantially altered the structure, composition, and competitive relationships in North American temperate and boreal forests (Frelich *et al.*, 2006). In arid and semi-arid regions of the United States, increases in annual precipitation are expected to favor non-native invasive species at the expense of native vegetation on California serpentine soils (Hobbs and Mooney, 1991) and in Colorado steppe communities (Milchunas and Lauenroth, 1995). Understanding the potential to prevent and control invasives will require research on invasive species' population and community dynamics interacting with a changing ecosystem dynamic.

Increasing concentrations of CO_2 in the atmosphere may also create a competitive advantage to some invasive species (Dukes, 2000; Smith *et al.*, 2000; Ziska, 2003; Weltzin, Belote, and Sanders, 2003). These positive responses may require a re-evaluation of current management practices. Positive responses to elevated CO_2 have been reported for red brome, an introduced non-native annual grass in the Southwest (Smith *et al.*, 2000). Increasing presence of this exotic grass, along with its potential to produce fire fuel, suggest future vegetation shifts and increased fire frequency (Smith *et al.*, 2000) where vegetation has not evolved under frequent fire. The positive response to current (from pre-industrial) levels of atmospheric CO_2 by six invasive weeds—Canada thistle (*Cirsium arvense* (L.) Scop.), field bindweed (*Convolvulus arvensis* L.), leafy spurge (*Euphorbia esula* L.), perennial sowthistle (*Sonchus* L.), spotted knapweed (*Centaurea stoebe* L.), and yellow star-thistle (*Centaurea solstitialis* L.)—suggests that 20th century increases in atmospheric CO_2 may have been a factor in the expansion of these invasives (Ziska, 2003). Because increasing CO_2 concentrations allow invasive species to allocate additional carbon to root biomass, efforts to control invasive species with some currently used herbicides may be less effective under climate change (Ziska, Faulkner, and Lydon, 2004).

Further, the combination of elevated CO_2 concentrations and warmer temperatures is expected to exacerbate the current invasive species problem in the currently cooler parts of the United States (Sasek and Strain, 1990; Simberloff, 2000; Weltzin, Belote, and Sanders, 2003). The northward expansion of the range of invasive species currently restricted by minimum temperatures (*e.g.*, kudzu and Japanese honeysuckle) is a particular concern (Sasek and Strain, 1990; Simberloff, 2000; Weltzin, Belote, and Sanders, 2003). Invasive species with a C4 photosynthetic pathway (*e.g.,* itchgrass, *Rottboellia cochinchinensis*) are particularly likely to invade more northerly regions as frost hardiness zones shift northward (Dukes and Mooney, 1999). Although C3 species (*e.g.*, lamb's quarters, *Chenopodium album*) are likely to grow faster under elevated CO_2 concentrations (Bazzaz, 1990; Drake, Gonzalez-Meler, and Long, 1997; Nowak, Ellsworth, and Smith, 2004; Ainsworth and Long, 2005; Erickson *et al.*, 2007), C4 species seem to respond better to warmer temperatures (Alberto *et al.*, 1996; Weltzin, Belote, and Sanders, 2003), probably because the optimum temperature for photosynthesis is higher in C4 species (Dukes and Mooney, 1999).

Climate change will likely facilitate the movement of some native species into the habitats of others, and thus create novel species assemblages, potentially affecting current goods and services. Some of the dispersing native species will likely become problematic invaders that place many threatened and endangered species at greater risk of local extinction due to enhanced competition, herbivory, predation, and parasitism (Neilson *et al.*, 2005a; 2005b). For example, in the Pacific Northwest, barred owls (*Strix varia*), which are rapidly migrating generalists from eastern forests of the United States, have invaded the spotted owl's range in the Pacific Northwest and are now competing with the northern spotted owl (*Strix occidentalis caurina*) for nest sites (Kelly, Forsman, and Anthony, 2003; Noon and Blakesley, 2006; Gutierrez *et al.*, 2007). An increase of 3^{o}C in minimum temperature could extend the southern pine beetle's northern distribution limit by 170 km, with insect outbreaks spreading into the mid-Atlantic states (Williams and Liebhold, 2002). Novel species assemblages may require a re-examination of management approaches for native species now acting as invasives; for threatened, endangered and rare species; and a re-evaluation of what ecosystem services can be managed within each NF.

Climate Change and Watershed Management

The hydrological regimes of NFs are closely linked to climate, as well as to the many other variables that climate change may affect. Changes in precipitation patterns, including declining snowpack, earlier snowmelt, more precipitation falling as rain vs. snow (Mote *et al.*, 2005), advances in streamflow timing (Stewart, Cayan, and Dettinger, 2004; Barnett, Adam, and Lettenmaier, 2005; Milly, Dunne, and Vecchia, 2005), and the increasing frequency and intensity of extreme precipitation events (Karl and Knight, 1998; Nearing, 2001; Groisman *et al.*, 2005) have affected the hydrology, and hence condition of watersheds and ecosystems throughout the United States (Dettinger *et al.*, 2004; Hayhoe *et al.*, 2004). Increases in flooding may occur as a result of the increased storm intensity projected by future climate models (IPCC, 2007). Changes in the distribution, form, and intensity of precipitation will make it more challenging to achieve the goal of improving watershed conditions.

Water shortages in some areas are projected, due to increasing temperatures and changing precipitation patterns, as well as to shifting demography and increased water demand (Arnell, 1999; Whiles and Garvey, 2004). National forest ecosystems in more arid parts of the country are expected to be particularly affected by projected climatic changes (Hayhoe *et al.*, 2004; Seager *et al.*, 2007). However, even in wetter regions (*e.g.*, the southeastern United States), hot temperatures and high evapotranspiration rates cause only 50% of annual precipitation to be available for streamflow (Sun *et al.*, 2005). Thus, future scenarios of climate and land-use change indicate that the water yield for this region will become increasingly variable.[19] In the Northeast, a temperature increase of 3^{o}C was projected to decrease runoff by 11–13% annually, and to a greater extent during the summer months when flow is typically lowest (Huntington, 2003). Gains in water use efficiency from elevated CO_2 may be negated or overwhelmed by

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[19] Sun, G., S.G. McNulty, E. Cohen, J.M. Myers, and D. Wear, 2005: Modeling the impacts of climate change, landuse change, and human population dynamics on water availability and demands in the Southeastern US. Paper number 052219. Proceedings of the 2005 ASAE Annual Meeting, St. Joseph, MI.

changes in the hydrological variables described above, leading to increased water stress for vegetation in NFs (Baron *et al.*, 2000; but see Huntington, 2003).

Climate Change and Biodiversity Management

Climate change affects biodiversity directly by altering the physical conditions to which many species are adapted. Although species with large geographic ranges have a wide range of physiological tolerance, species that are rare, threatened, endangered, narrowly distributed, and endemic, as well as those with limited dispersal ability, will be particularly at risk under climate change (Pounds *et al.*, 2006) because they may not be able to adapt *in situ* or migrate rapidly enough to keep pace with changes in temperature (Hansen *et al.*, 2001; Wilmking *et al.*, 2004; Neilson *et al.*, 2005b). Changes in precipitation patterns may disrupt animal movements and influence recruitment and mortality rates (Inouye *et al.*, 2000). The projected changes in fish habitat associated with increases in temperature and changes in hydrology (Preston, 2006) would cause shifts in the distributions of fish and other aquatic species (Kling *et al.*, 2003). Projected declines in suitable bird habitat of 62–89% would increase the extinction risk for Hawaiian honeycreepers (Benning *et al.*, 2002). Similar projected losses of suitable habitat in U.S. forests would decrease Neotropical migratory bird species richness by 30–57% (Price and Root, 2005). Interactions among species may also amplify or reverse the direct impacts of climate change on biodiversity (Suttle, Thompsen, and Power, 2007).

Tree species richness is projected to increase in the eastern United States as temperatures warm, but with dramatic changes in forest composition (Iverson and Prasad, 2001). Projections indicate that spruce-fir forests in New England could be extirpated and maple-beech-birch forests greatly reduced in area, whereas oak-hickory and oak-pine forest types would increase in area (Bachelet *et al.*, 2001; Iverson and Prasad, 2001). Projected changes in temperature and precipitation suggest that southern ecosystems may shift dramatically. Depiction of the northern shift of the jet stream and the consequent drying of the Southeast (Fu *et al.*, 2006) varies among future climate scenarios, with some showing significant drying while others show increased precipitation (Bachelet *et al.*, 2001). However, even under many of the somewhat wetter future scenarios, closed-canopy forests the Southeast may revert, or in some areas, be converted to savanna, woodland, or grassland under temperature-induced drought stress and a significant increase in fire disturbance (Bachelet *et al.*, 2001; Scholze *et al.*, 2006).

Ecosystems at high latitudes and elevations (including many coniferous forests), as well as savannas, ecosystems with Mediterranean (*e.g.*, California) climates, and other water-limited ecosystems, are expected to be particularly vulnerable to climate change (Thomas *et al.*, 2004; Millennium Ecosystem Assessment, 2005; Malcolm *et al.*, 2006). Temperature-induced droughts in these ecosystems are expected to contribute to forest diebacks (Bugmann, Zierl, and Schumacher, 2005; Millar, Westfall, and Delany, forthcoming). Alpine ecosystems are also projected to decrease in area as temperatures increase (Bachelet *et al.*, 2001). Specifically, as treelines move upward in elevation, many species could be locally extirpated as they get “pushed” off the top of the mountains (Bachelet *et al.*, 2001). Also, given the strong species-area relationship that has been shown for the “island” habitats on the tops of western mountains, species diversity could be significantly reduced as these habitats become smaller or even disappear (McDonald and Brown, 1992).

Simulations of future vegetation distribution in the Interior West show a significant increase in woody vegetation as a result of enhanced water-use efficiency from elevated CO_2, moderate increases in precipitation, and a strengthening of the Arizona Monsoon (Neilson *et al.*, 2005a), with the greatest expansion of woody vegetation projected in the northern parts of the interior West (Lenihan *et al.*, forthcoming). The drier interior vegetation shows a large increase in savanna/woodland types, suggesting possibly juniper and yellow pine species range expansions. However, this region is also projected to be very susceptible to fire and drought-induced dieback, mediated by insect outbreaks (Neilson *et al.*, 2005a). Such outbreaks have already altered the species composition of much of this region (Breshears *et al.*, 2005).

A key predicted effect of climate change is the expansion of native species' ranges into biogeographic areas in which they previously could not survive (Simberloff, 2000; Dale *et al.*, 2001). This prediction is supported by the observed northward shift in the ranges of several species, both native and introduced, due to the reduction of cold temperature restrictions (Parmesan, 2006). In general, climate change would facilitate the movement of some species into the habitats of others, which would create novel species assemblages, especially during post-disturbance succession. An entire flora of frost-sensitive species from the Southwest may invade ecosystems from which they have been hitherto restricted, and in the process displace many extant native species over the course of decades to centuries (Neilson *et al.*, 2005b) as winter temperatures warm (Kim *et al.*, 2002; Coquard *et al.*, 2004) and hard frosts occur less frequently in the interior West (Meehl, Tebaldi, and Nychka, 2004; Tebaldi *et al.*, 2006). Similar migrations of frost-sensitive flora and fauna occurred during the middle-Holocene thermal maximum, which was comparable to the minimum projected temperature increases for the 21st century (Neilson and Wullstein, 1983).

Similarly increases in warm temperate/subtropical mixed forest are projected in the coastal mountains of both Oregon and Washington, with an increase in broadleaved species such as various oak species, tanoak, and madrone under many scenarios (Bachelet *et al.*, 2001; Lenihan *et al.*, forthcoming). However, slow migratory rates of southerly (California) species would likely limit their presence in Oregon through the 21st century (Neilson *et al.*, 2005b).

These potential shifts in species may or may not enhance the biodiversity of the areas into which they migrate. This shift will potentially confound management goals based on the uniqueness of species for which there are no longer habitats.

3.3.4.2 Goal 2: Provide and Sustain Benefits to the American People

The outcome for this goal is forests and grassland with sufficient long-term multiple socioeconomic benefits to meet the needs of society. Specific objectives are focused on providing a reliable supply of forest products and rangeland, with productivity that is consistent with achieving desired conditions on NFS lands and helps support local communities, meets energy resource needs, and promotes market-based conservation and stewardship of ecosystem services.

Co-benefits of joint carbon sequestration and biofuel production, along with other potential synergies, are certainly possible via forest management (Birdsey, Alig, and Adams, 2000; Richards, Sampson, and Brown, 2006), and would enable contribution to both the country's energy needs and its carbon sequestration and greenhouse gas mitigation goals. Forest management practices designed to achieve goals of removing and storing CO_2 are diverse, and the forestry sector has the potential for large contributions on the global to regional scales (Malhi, Meir, and Brown, 2002; Krankina and Harmon, 2006). Along with preventing deforestation, key activities include afforestation, reforestation, forest management, and post-harvest wood-product development (Harmon and Marks, 2002; Von Hagen and Burnett, 2006). Reducing deforestation (Walker and Kasting, 1992) and promoting afforestation provide important terrestrial sequestration opportunities (Nilsson and Schopfhauser, 1995),[20] as do many forest plantation and forest ecosystem management practices (*e.g.*, Briceno-Elizondo *et al.*, 2006). Many suggested approaches duplicate long-recognized best forest management practices, where goals are to maintain healthy, vigorous growing stock, and keep sites as fully occupied as possible while still maintaining resistance to uncharacteristically severe fire, insects, and disease (Gottschalk, 1995). Projects planned to delay return of CO_2 to the atmosphere (*e.g.*, by lengthening rotations; Richards, Sampson, and Brown, 2006), both *in situ* (in the forest or plantation) and post-harvest, are most successful.

Climate change is expected to alter forest and rangeland productivity (Joyce and Nungesser, 2000; Aber *et al.*, 2001; Hanson *et al.*, 2005; Norby, Joyce, and Wullschleger, 2005; Scholze *et al.*, 2006). This alteration in forest productivity, in turn, will influence biomass available for wood products or for energy (Richards, Sampson, and Brown, 2006), whether as a direct energy source or for conversion to a biofuel. The interactions of climate change (*e.g.*, warming temperatures, droughts) and other stressors—including altered fire regimes, insects, invasive species, and severe storms—may affect the productivity of forests and rangelands. This alteration in forest productivity in turn would affect the volume of material that could be harvested for wood products or for energy, or the rate at which a forest would sequester carbon on site. The interactions of climate change with other stressors such as insects (Volney and Fleming, 2000; Logan, Regniere, and Powell, 2003), disease (Pounds *et al.*, 2006), and fire (Flannigan, Stocks, and Wotton, 2000; Whitlock, Shafer, and Marlon, 2003) will challenge the management of ecosystem services and biodiversity conservation in NF ecosystems. Indeed, Flannigan, Stocks, and Wotton (2000) noted that “the change in fire regime has the potential to overshadow the direct effects of climate change on species distribution and migration.” Thus, this goal is sensitive to a changing climate.

Climate Change and Ecosystem Services

The distinctive structure and composition of individual NFs are key characteristics on which forest and rangeland products and ecosystem services depend, and that national forest managers seek to sustain using current management approaches. For example, efforts to achieve a particular desired forest structure, composition, and function have been based on an understanding of ecosystem dynamics as captured in historical references or baselines (*i.e.*, observed range of variation), and the now outdated theory that communities and ecosystems are at equilibrium with their environment (Millar and Woolfenden, 1999). Under a changing climate

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[20] See also **Kadyszewski**, J., S. Brown, N. Martin, and A. Dushku, 2005: Opportunities for terrestrial carbon sequestration in the west. Winrock International. Presented at the Second Annual Climate Change Research Conference, From Climate to Economics and Back: Mitigation and Adaptation Options for California and the Western United States, 15, September 2005. Accessed at http://www.climatechange.ca.gov/events/2005_conference/presentations/2005-09-15/2005-09-15_KADYSZEWSKI.PDF.

(increased temperatures; changes in rainfall intensity; and greater occurrence of extreme events, such as drought, flooding, etc.), such an approach may no longer be sensible. Ecosystem composition, structure, and function will change as species respond to these changes in climate. Thus, as climate change interacts with other stressors to alter NF ecosystems, it will be important to focus as much on maintaining and enhancing ecosystem processes as on achieving a particular composition. For these reasons, it will be increasingly important for the USFS to consider evaluating current management practices, their underlying climatic and ecological assumptions, and to consider managing ecosystems for change (discussed further in Sections 3.4–3.5).

Although forests are projected to be more productive under elevated CO_2 (Joyce and Birdsey, 2000; Hanson *et al.*, 2005; Norby, Joyce, and Wullschleger, 2005), productivity increases are expected to peak by 2030. Declines thereafter are likely to be associated with temperature increases, changes in precipitation, ozone effects, and other climate change stressors (Scholze *et al.*, 2006; Sitch *et al.*, 2007). Productivity increases may be offset especially where water and/or nutrients are limiting and increases in summer temperature further increase water stress (Angert *et al.*, 2005; Boisvenue and Running, 2006), and where ozone exposure reduces the capacity of forests to increase their productivity in response to elevated CO_2 (Karnosky, Zak, and Pregitzer, 2003; Hanson *et al.*, 2005; Karnosky *et al.*, 2005; King *et al.*, 2005). In cooler regions where water will not be a limiting resource, and where other stressors do not offset potential productivity increases, opportunities may increase for the production of biofuels and biomass energy. The feasibility of taking advantage of these opportunities may hinge on whether economic, political, and logistical barriers can be overcome (Richards, Sampson, and Brown, 2006). If, as projected, climate change enhances woody expansion and productivity for the near term in the intermountain West (Bachelet *et al.*, 2003), then forests and woodlands in that region could provide a source of fuel while mitigating the use of fossil fuels (Bachelet *et al.*, 2001).

Interactions of Climate Change with Other Stressors

Insect and disease outbreaks may become more frequent as the climate changes, because warmer temperatures may accelerate their life cycles (*e.g.*, Logan and Powell, 2001). As hardiness zones shift north[21] and frost-free days and other climatic extremes increase (Tebaldi *et al.*, 2006), the hard freezes that in the past slowed the spread of insect and disease outbreaks may become less effective, especially if the natural enemies (*e.g.*, parasitoids) of insects are less tolerant of the climate changes than are their hosts or prey (Hance *et al.*, 2007). In addition, previously confined southern insects and pathogens may move northward as temperatures warm (see Box 3.5) (Ungerer, Ayres, and Lombardero, 1999; Volney and Fleming, 2000; Logan, Regniere, and Powell, 2003; Parmesan, 2006), especially in the absence of predatory controls. While the expectation is for increased wildfire activity associated with increased fuel loads (*e.g.*, Fleming, Candau, and McAlpine, 2002), in some ecosystems (*e.g.*, subalpine forests in Colorado), insect outbreaks may decrease susceptibility to severe fires (*e.g.*, Kulakowski, Veblen, and Bebi, 2003).

Species, whether or not they are indigenous to the United States, may act invasively and increase the stress on ecosystems and on other native species. The rapid advance of the mountain pine beetle beyond its historic range (Logan and Powell, 2005) is a case in which a native species,

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[21] **National Arbor Day Foundation**, 2006: Differences between 1990 USDA hardiness zones and 2006 arborday.org hardiness zones reflect warmer climate. Available at http://www.arborday.org/treeinfo/zonelookup.cfm.

indigenous to the American West, has begun to spread across large areas like an invasive species (as reflected by faster dispersal rates and greater range extension) because longer and warmer growing seasons allow it to more rapidly complete its lifecycle, and because warmer winters allow winter survival (Logan and Powell, 2001; Carroll *et al.*, 2004; Millar, Westfall, and Delany, forthcoming).

3.3.4.3 Goal 3: Conserve Open Space

The outcome for this goal is the maintenance of the environmental, social, and economic benefits of the Nation's forests and grasslands, protecting those forest and grasslands from conversion to other uses, and helping private landowners and communities maintain and manage their land as sustainable forests and grasslands. As described under Goals 1 and 2 above, the environmental benefits of forests and grasslands are influenced strongly by climate and changes in climate. Additionally, fragmentation and urbanization facilitate the spread of invasive species, and are key drivers contributing to biotic homogenization in the United States in general (Olden, 2006) Under a changing climate, landscape fragmentation may exacerbate or cause unexpected changes in species and ecosystems (Iverson and Prasad, 2001; Price and Root, 2005). Thus this goal will be sensitive to a changing climate.

Climate Change and Open Space

The loss of open space and land-use changes that are already problematic may be worsened under climate change, due to shifts in species' behaviors and changed habitat requirements. The loss of open space is of particular concern because it may impede species' migration and exacerbate edge effects (*e.g.*, windthrow, drought, and non-native invasive species) during extreme climatic events, and possibly result in increased population extirpation (Ewers and Didham, 2006). Fragmentation may result in the loss of larger management unit sizes, broad habitat corridors, and continuity of habitat. In this regard, enhancing coordination among the multiple agencies that manage adjacent lands to ensure habitat continuity will be essential (Malcolm *et al.*, 2006). Land-use change and invasive species are expected to exacerbate the effects of climate change, and hence make the goal of maintaining environmental benefits on forests and grasslands more challenging to achieve.

3.3.4.4 Goal 4: Sustain and Enhance Outdoor Recreation Opportunities

The outcome identified for this goal is high-quality outdoor recreational opportunities on the Nation's forests and grassland available to the public. Specific objectives include improving the quality and availability of outdoor recreation experiences, securing legal entry to NF lands and water, and improving the management of off-highway vehicle use. National forests across the United States are managed for a variety of outdoor recreational opportunities, capitalizing on the natural resources and ecosystem services available within each NF (Cordell *et al.*, 1999). The demands on NFs for recreation have diversified with population growth (local, regional, and national), preferences for different types of recreation, and technological influences on recreation (off-road motorized vehicles, mountain biking, snowboarding). Along with camping, hunting, and fishing, recreational activities now include skiing (downhill, cross-country), snowboarding, mountain biking, hiking, kayaking, rafting, and bird watching.

Climate Change and Recreation Management

Because individual recreational opportunities are often a function of climate (cold-water fisheries or winter snow), climate change may affect both the opportunity to recreate and the quality of recreation (Irland *et al.*, 2001), curtailing some recreational opportunities and expanding others.

Winter outdoor recreation—such as alpine and Nordic skiing, snowmobiling, skating, ice fishing, and other opportunities—may decrease and/or shift in location due to fewer cold days and reduced snowpack (National Assessment Synthesis Team, US Global Change Research Program, 2001). The costs of providing these opportunities (*e.g.*, increased snowmaking) are likely to rise (Irland *et al.*, 2001) or may result in potential conflicts with other uses (*e.g.*, water) (Aspen Global Change Institute, 2006). Other winter recreational activities (*e.g.*, ice skating, ice fishing, and ice climbing) may also become more restricted (both geographically and seasonally) as winter temperatures warm (National Assessment Synthesis Team, US Global Change Research Program, 2001), with limited opportunities for management to sustain these opportunities.

Altered streamflow patterns and warmer stream temperatures, observed trends that are projected to continue with future climate change (Regier and Meisner, 1990; Eaton and Scheller, 1996; Rahel, Keleher, and Anderson, 1996; Stewart, Cayan, and Dettinger, 2004; Barnett, Adam, and Lettenmaier, 2005; Milly, Dunne, and Vecchia, 2005), may change fishing opportunities from salmonids and other cold-water species to species that are less sensitive to warm temperatures (Keleher and Rahel, 1996; Melack *et al.*, 1997; Ebersole, Liss, and Frissell, 2001; Mohseni, Stefan, and Eaton, 2003) and altered streamflow (Marchetti and Moyle, 2001). One estimate indicates that cold-water fish habitat may decrease by 30% nationally and by 50% in the Rocky Mountains by 2100 (Preston, 2006). More precise estimates of the climate change impacts on fish populations will depend on the ability of modelers to consider other factors (*e.g.*, land use change, fire, invasive species, and disease) in addition to temperature and streamflow regimes (Clark *et al.*, 2001). The projected reductions in volume of free-flowing streams during summer months, due to advances in the timing of flow in these streams (Stewart, Cayan, and Dettinger, 2004; Barnett, Adam, and Lettenmaier, 2005; Milly, Dunne, and Vecchia, 2005), may also restrict canoeing, rafting, and kayaking opportunities (Irland *et al.*, 2001).

Climate change may also increase recreational opportunities, depending on the preferences of users, the specific climatic changes that occur, and the differential responses of individual species to those changes. Fewer cold days, for example, may encourage more hiking, biking, off-road vehicle use, photography, swimming, and other warm-weather activities. The different growth responses of closely related fish species to increases in temperature and streamflow (Guyette and Rabeni, 1995) may enhance opportunities for species favored by some anglers.

Interactions of Climate Change with Other Stressors

An increase in the frequency, extent, and severity of disturbances such as fire and severe storms also may affect the quality of recreation experienced by visitors to NFs during and after disturbances. Recreational opportunities may be curtailed if forest managers decide (for public safety or resource conservation reasons) to reduce access during and in the wake of major disturbances such as fire, droughts, insect outbreaks, blowdowns, and floods, all of which are projected to increase in frequency and severity during the coming decades (IPCC, 2007). Unlike smoke from prescribed fires, which is subject to NAAQS (national ambient air quality standards),[22] wildfire smoke is considered a temporary "natural" source by EPA and the departments of environmental quality in Montana, Idaho, and Wyoming, and is therefore not directly regulated. Within the Greater Yellowstone Ecosystem, prescribed fire smoke is managed to minimize smoke encroachment on sensitive areas (communities, Class 1 wilderness areas, high use recreation areas, scenic vistas) during sensitive periods.[22] After wildfire, the quality of the recreational experience has been shown to be affected by the need to travel through a historical fire area (Englin *et al.*, 1996) and by the past severity of fire (Vaux, Gardner, and Thomas, 1984). Groups experiencing different types of recreation (hiking versus mountain biking) react differently to wildfire, and reactions vary across geographic areas (Hesseln *et al.*, 2003). Changes in vegetation and other ecosystem components (*e.g.*, freshwater availability and quality) caused by droughts, insect and disease outbreaks (Rouault *et al.*, 2006), fires, and storms may alter the aesthetics, sense of place, and other cultural services that the public values.

The projected increases of pests and vector-borne diseases may also affect the quality of recreational experiences in NFs. Hard freezes in winter have been shown to kill more than 99% of pathogen populations annually (Burdon and Elmqvist, 1996; as cited in Harvell *et al.*, 2002). The hard freezes necessary to slow the spread of insect and disease outbreaks may become less effective (Gutierrez *et al.*, 2007). In particular, warmer temperatures are expected to increase the development, survival, rates of disease transmission, and susceptibility of both human and non-human hosts (Harvell *et al.*, 2002; Stenseth *et al.*, 2006). Land-use change leading to conversion of forests adjacent to NFs may compound the effect of climate change on disease, because increases in disease vectors have been associated with loss of forests (Sutherst, 2004). Conversely, where climate change contributes to a decline in the impacts of pathogens—or in cases where species have demonstrated an ability to adapt to changes in disease prevalence (*e.g.*, Woodworth *et al.*, 2005)—the goal may become easier to achieve because visitors may have a positive experience.

3.3.4.5 Goal 5: Maintain Basic Management Capabilities of the Forest Service

The outcome identified for this goal is administrative facilities, information systems, and landownership management with the capacity to support a wide range of natural resources challenges. The means and strategies identified for accomplishing this goal include (and are not limited to) recruiting and training personnel to develop and maintain strong technical and leadership skills in Forest Service program areas to meet current and future challenges. Resource management is challenging in today's environment, and climate change will heighten that challenge. Maintaining technical skills associated with resource management will require the most current information on climate change and its potential impacts to ecosystems within the NFS, as well as its impacts on the ecological and socioeconomic systems surrounding the NFs. The depth of this technical understanding will influence policy development across all levels of the agency. Under a changing climate, ecosystem services will likely be altered within the NFs, resulting in the need to evaluate national policy as well as local land management objectives, relationships with current partnerships, and the need to develop new partnerships. Line officers

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[22] **Story**, M., J. Shea, T. Svalberg, M. Hektner, G. Ingersoll, and D. Potter, 2005: *Greater Yellowstone Area Air Quality Assessment Update*. Greater Yellowstone Clean Air Partnership. Available at http://www.nps.gov/yell/planyourvisit/upload/GYA_AirQuality_Nov_2005.pdf.

and resource staff are faced with—and will continue to be faced with—the challenge of making decisions in an uncertain environment. This goal is sensitive to climate change.

Climate Change and Management Capabilities of the Forest Service

The capacity of the USFS to address climate change may require the staff within NFs to have a technical understanding of climate change impacts on ecological systems, to be able to share technical information and experiences (successes as well as failures) about managing under climate change efficiently and effectively, to be able to apply new knowledge to the development of management approaches, and to be able to develop and use planning tools with climate information. Current understanding about the relationships among climate and disturbances, ecosystem services, and forest and grassland products may no longer be appropriate under a changing climate. The climate sensitivity of best management practices, genetic diversity guidelines, restoration treatments, and regeneration guidelines may need to be revisited. Many forest managers are awaiting information from quantitative models about future climates and environments to guide climate-related planning, but adequate training and user-friendly interfaces will be needed before these can be implemented. Limited staff capacities within NFs, combined with the scope of current on-the-ground management needs, could slow the attainment of this goal.

3.3.4.6 Goal 6: Engage Urban America with Forest Service Programs

The outcome identified for this goal is broader access by Americans to the long-term environmental, social, economic, and other types of benefits provided by the USFS. The climate change impacts associated with ecosystem services from NFs would suggest that this goal will be sensitive to climate change.

Climate Change and Urban America

Two objectives were identified for this goal: (1) promote conservation education and (2) improve the management of urban and community forests to provide a wide range of public benefits. The current goal of the conservation education program in the USFS is to “ensure that educational programs and materials developed or certified by the Forest Service incorporate the best scientific knowledge; are interdisciplinary and unbiased; support the Forest Service mission; and are correlated with appropriate national, State, and agency guidelines” (USDA Forest Service, 2007a). Incorporating the best scientific knowledge will require information on climate change and the potential impacts of climate change, necessitating a strong tie to and need for ongoing research on climate change and natural resource management.

Means and strategies identified for this goal include continuing urban forest inventory and analysis, to monitor the health and benefits of ecological and social services of urban forests and more effectively manage these complex landscapes; developing and disseminating strategies and options such as “green infrastructure,” to effectively manage resources to maintain environmental quality and services in urban and urbanizing landscapes; helping communities increase professional urban forestry staffing, ordinances, management plans, and local advisory and advocacy groups for managing forest resources in cities, suburbs, and towns; developing and disseminating tools to ensure that urban trees and forests are strategically planned and managed to maximize ecosystem services and benefits; engaging partners and educators in conservation education and interpretive programs; developing methods to measure environmental literacy and techniques to engage urban residents in the management of urban forests; improving access by urban Americans to USFS resources and information; and developing partnerships with nontraditional partners to engage urban and underserved audiences.

The rapid and continuing growth of the WUI in both the eastern and western states is dramatically altering the strategic and tactical approaches to fire and forest management. Urban and urbanizing communities may need information on the changing dynamics of the surrounding wildland and urbanizing environment, as well as the need to manage the surrounding landscapes to reduce the risks from uncharacteristically severe wildfires, which are often related to drought and pest infestations. Urban and urbanizing communities' sense of place may have an important role in developing adaptation strategies for those environments.

3.3.4.7 Goal 7: Provide Science-based Applications and Tools for Sustainable Natural Resources Management

The outcome identified for this goal is that management decisions are informed by the best available science-based knowledge and tools. Means and strategies include developing and making available cost-effective methods for transferring scientific information, technologies, methods, and applications; providing information and science-based tools that are used by managers and policymakers; developing and implementing effective processes for engaging users in all phases of R&D study development; developing and deploying analysis and decision-support systems; developing tools for evaluating the efficiency and effectiveness of alternative management practices; and ensuring that current resource information is available to address the strategic, tactical, and operational business requirements of the USFS.

Under a changing climate, the need will arise for quantitative tools to address complex issues facing each forest and region, such as linkages between ecosystems; water resources; disturbances, including drought, fire, infestation and disease; regional migration patterns, including invasions of both native and exotic species; and local to regional carbon storage and carbon management, such as for biofuels. This goal will be sensitive to the impacts of a changing climate on ecosystems and the needs of resource managers.

Climate Change and Science-based Applications and Tools

As with any natural resource management issue, resource managers need access to current scientific information, qualitative/quantitative tools to use in decision support analyses at forest and project planning levels, and management strategies to guide on-the-ground management. Scientific information is scattered across websites, scientific journals, regional assessments, government documents, and international reports, challenging attempts by resource managers to compile the best available information. At present, most established planning and operational tools within NFs, such as the Forest Vegetation Simulator, assume that climate will continue to reflect the historical climate. No climate information or dynamics are included in many of the currently available planning tools. Recognition that climate is an important element in natural resource management is beginning to occur in some of the natural resource management communities such as water resource planning. However, few analytical tools are available to incorporate uncertainty analyses into resource planning.

3.4 Adapting to Climate Change

3.4.1 The Need for Anticipatory Adaptation

Climate is constantly changing at a variety of time scales, prompting natural and managed ecosystems to adjust to these changes. As a natural process, without human intervention, adaptation typically refers to the autonomous and reactive changes that species and ecosystems make in response to environmental change such as a climate forcing (Kareiva, Kingsolver, and Huey, 1993; Smit *et al.*, 2000; Davis and Shaw, 2001; Schneider and Root, 2002). Organisms respond to environmental change (including climate change) in one of three ways: adaptation, migration, or extinction. Adaptation typically refers to genetic changes, but also includes *in situ* acclimation (physiological adaptation to the changing environment while remaining in place) as well as phenological (*e.g.*, breeding, flowering, migration) and behavioral changes. This natural adaptation in the ecosystem is important to understand, so that the influence of management on these natural processes can be assessed. Space for evolutionary development under climate change may be important to incorporate into conservation and restoration programs under a changing climate (Rice and Emery, 2003).

We focus on adaptation as interventions and adjustments made by humans in ecological, social, or economic systems in response to climate stimuli and their effects, such as fire, wind damage, and so on. More specifically, in the social-science literature, the term adaptation refers to "a process, action, or outcome in a system (household, community, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity" (Smit and Wandel, 2006).

Human adaptation to climate change impacts is increasingly viewed as a necessary complementary strategy to mitigation—reducing greenhouse gas emissions from energy use and land use changes in order to minimize the pace and extent of climate change (Klein *et al.*, 2007). Because adaptive strategies undertaken will have associated effects on carbon dynamics, it is important to consider carbon impacts of any proposed adaptive strategy. Forest management practices designed to achieve mitigation goals of reducing greenhouse gases (CO_2 in particular) are diverse, and have large potential mitigation contributions on the global to regional scales (Malhi, Meir, and Brown, 2002; Krankina and Harmon, 2006). Options for minimizing return of carbon to the atmosphere include storing carbon in wood products (Wilson, 2006), or using biomass as bioenergy, both electrical and alcohol-based. While many positive opportunities for carbon sequestration using forests appear to exist, evaluating specific choices is hampered by considerable difficulty in quantifying net carbon balance from forest projects (Cathcart and Delaney, 2006), in particular unintentional emissions such as wildfire and extensive forest mortality from insects and disease (Westerling *et al.*, 2003; Westerling and Bryant, 2005; Westerling *et al.*, 2006; Lenihan *et al.*, 2006). Adaptation and mitigation can have positive and negative influences on each other's effectiveness (Klein *et al.*, 2007). Management practices that lower vulnerabilities to uncharacteristically severe wildfire and non-fire mortality could meet multiple goals of mitigation and adaptation if such practices also reflected goals for other ecosystem services. Both strategies—adaptation and mitigation—are needed to minimize the potential negative impacts, and to take advantage of any possible positive impacts from climate variability and change (Burton, 1996; Smit *et al.*, 2001; Moser *et al.*, forthcoming).

Several concepts related to adaptation are important to fully appreciate the need for successful anticipatory adaptation to climate-related stresses, as well as the opportunities and barriers to adaptation. The first of these is *vulnerability*. Vulnerability is typically viewed as the propensity of a system or community to experience harm from some stressor as a result of (a) being *exposed* to the stress, (b) its *sensitivity* to it, and (c) its potential or *ability to cope* with and/or *recover* from the impact (see review of the literature by Adger, 2006). Key vulnerabilities can be assessed by exploring the magnitude of the potential impacts, the timing (now or later) of impacts, the persistence and reversibility (or irreversibility) 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 (Schneider *et al.*, 2007). Of particular importance here is a system's *adaptive capacity*: the ability of a system or region to adapt to the effects of climate variability and change. How feasible and/or effective this adaptation will be depends on a range of characteristics of the ecological system, such as topography and micro-refugia, soil characteristics, biodiversity; pre-existing stresses, such as the presence of invasive species or loss of foundation species or fragmentation of the landscape; the status of the local ecosystem, *e.g.*, early to late successional and its intrinsic "inertia" or responsiveness; and on characteristics of the social system interacting with, or dependent on, the ecosystem (Blaikie *et al.*, 1994; Wilbanks and Kates, 1999; Kasperson and Kasperson, 2001; Walker *et al.*, 2002; Adger, 2003).

As Smit and Wandel (2006) state in their recent review, "Local adaptive capacity is reflective of broader conditions (Yohe and Tol, 2002; Smit and Pilifosova, 2003). At the local level, the ability to undertake adaptations can be influenced by such factors as managerial ability; access to financial, technological, and information resources; infrastructure; the institutional environment within which adaptations occur; political influence, etc. (Blaikie, Brookfield, and Allen, 1987; Watts and Bohle, 1993; Adger, 1999; Handmer, Dovers, and Downing, 1999; Toth, 1999; Adger and Kelly, 2001; Smit *et al.*, 2001; Wisner *et al.*, 2004)." Adaptive capacity is determined mainly by local factors (*e.g.*, local forest managers' training in ecological processes, available staffing with appropriate skills, available financial resources, local stakeholder support) while other factors reflect more general socioeconomic and political systems (*e.g.*, federal laws, federal forest policies and regulations, state air quality standards, development pressures along the forest/urban interface, commodity market (timber, grazing) conditions, stakeholder support).

While the literature varies in the use of these and related concepts such as *resilience* and *sustainability*, adaptation in the context of NF management would be viewed as successful if stated management goals (see Section 3.3) were continued to be achieved under a changing climate regime while maintaining the ecological integrity of the nation's forests at various scales. For example, Section 3.3 identified the close relationship between ecosystem services and management goals, and their sensitivity to climate change. While these stated management goals are periodically updated or modified, this re-examination entails a risk of setting goals lower (*e.g.,* lower quality, quantity, or production) as environmental and climatic conditions deteriorate. For the purposes of this report it is assumed that the larger tenets of the cumulative laws directing NF management remain intact: "the greatest good of the greatest number in the long run…without impairment of the productivity of the land…[and] secure for the American people of present and future generations."

Below, we distinguish different adjustments of NF management approaches by reference to timing and intention. By “timing” we mean *when* the managing agency thinks about a management intervention: after a climate-driven, management-relevant event, or in advance of such an event. By “intention” we mean whether the managing agency acknowledges that a change is likely, anticipates possible impacts, and begins planning for a response prior to it occurring—for example, developing a monitoring or early warning system to detect changes as they occur (see Fig. 3.12). We distinguish three different adaptation scenarios: no active adaptation; planned management responses to disturbances associated with changing climate regimes; and management responses in anticipation of future climate change, and in preparation for climate change now.

Figure 3.12. Anticipatory and reactive adaptation for natural and human systems (IPCC, 2001b).

3.4.1.1 No Active Adaptation

An approach of “no active adaptation” could describe two decision-making pathways. The event- or crisis-driven approach reacts to a climate or related environmental stimulus, without foresight and planning. No active adaptation could also result from the approach where consideration of the potential effects of climate change and management investment result in a conscious decision not to manage for climate change. The first approach would be without anticipatory planning, whereas the second, appearing as no active adaptation, would involve consideration of vulnerabilities and impacts. These reactions could be at any level of policy- or decision-making—national, regional, forest planning level, or project level.

The extent and severity of an extreme weather or climate event vis-à-vis the ecosystem’s ability to naturally adjust to or recover from it, as well as the management agency’s ability to quickly marshal the necessary response resources (money, staff, equipment, etc.) when the event occurs, will determine the ultimate impacts on the ecosystem and the cost to the managing agency. Depending on the extent of the impacts on the ecosystem and on the managing agency, future attainment of management goals may also be affected. While unforeseen opportunities may emerge, the cost of such unplanned reactive management is typically larger than if management tools can be put in place in a timely and efficient manner (a common experience with reactive vs. proactive resource or hazard management, *e.g.,* Tol, 2002; Multihazard Mitigation Council, 2006).

This reactive approach, which does not take into account changing climate conditions, is sometimes used when scientific uncertainty is considered too great to plan well for the future. There is a strong temptation to not plan ahead, because it avoids the costs and staff time needed to prepare for an event that is uncertain to occur. The risk to the agency of initiating expensive and politically challenging management strategies is large in the absence of a strong scientific consensus on vulnerabilities and climate change effects. However, not planning ahead also can mean incurring greater cost, and may bring with it great risk later on—risk that results from inefficiencies in the response when it is needed, wasted investments made in ignorance of future conditions, or potentially even greater damages because precautionary actions were not taken.

The reactive approach would also reflect a management philosophy that does not consider the likelihood of climate-driven changes and impacts. Most past forest planning documents typically described a multi-decadal future without climate variability or change. While the development of the National Fire Plan is an example of planning for increasingly challenging wildfires in a cost-efficient manner, the influence of climate change on wildfire is not considered. Addressing climate change in wildland fire management could include setting up pathways for information-sharing and coordination of climate change adaptation strategies of wildland fire agencies; considering climate change and variability when developing long-range wildland fire management plans and strategies; and incorporating the likelihood of more severe fire weather, lengthened wildfire seasons, and larger-sized fires when planning and allocating budgets.[23] Most management strategies or practices (*e.g.*, natural regeneration or cold-water fisheries restoration) assume a relatively constant climate or weather pattern. A careful study of the historical range of natural variability provides a wealth of information on ecological process—how diverse and variable past plant community dynamics have been (Harris *et al.*, 2006). However, pre-settlement patterns of vegetation dynamics (*e.g.*, a point in time such as the mid-1800s, the end of the so-called Little Ice Age) are associated with a climate that was much cooler, and may not adequately reflect the current climate or an increasingly warmer future climate and the associated vegetation dynamics. Many quantitative tools currently used do not include climate or weather in their dynamics. Growth and yield models, unmodified by growth and density control functions (Dixon, 2003), project forest growth without climate information. The past climate may not be an adequate guide to future climate (Williams, Jackson, and Kutzbach, 2007), and our understanding of the ecological assumptions underlying restoration management practices may also need to be revisited (Harris *et al.*, 2006).

An approach of no active adaptation could also result from consideration of the potential for climate change, and a conscious decision to not prepare for or adapt to it. Examples could include low-sensitivity ecosystems, short-term projects, or a decision to triage. For low-sensitivity ecosystems, vulnerability is low or the likely impacts of climate change are very low probability, or the effects of climate change are not undesired. Existing projects nearing completion, such as high-value short-rotation timber that is about to be harvested, could be considered not critical to prepare for climate change, assuming that the harvest will occur before any major threat of climate change or indirect effects of climate change emerge. The risk is deemed low enough to continue with current management. And finally, the decision to not manage for a particular species would reflect a strategy of no active adaptation. Most prioritizing methods rank all options with varying priorities. In contrast, proper and systematic triage planning includes the necessary option of *not* treating something that could/should be treated if more resources (time, money, staff, technology) were available. Issues needing treatment are relegated untreatable in triage planning when greater gain will ensue by allocating scarce resources elsewhere; *i.e.*, in emergency situations where resources for treatment are limited, one cannot treat everything. Thus, conscious decisions are made for no action or no management.

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[23] **National Association of State Foresters,** 2007: NASF Resolution No. 2007-1. Issue of Concern: The role that climate change plays in the severity and size of wildland fires is not explicitly recognized in the “National Fire Plan” and the Implementation Plan for its 120-year Strategy. htt://www.stateforesters.org/resolution/2007-01.pdf.

Major institutional obstacles or alternative policy priorities can also lead to inattention to changing climatic and environmental conditions that affect land and resource management. Moreover, sometimes this approach is chosen unintentionally or inadvertently when climatic conditions change in ways that no one could have anticipated. Or, even if a “no action” plan is taken for the short run—say in anticipation of an impending harvest—the post-harvest plan may also inadvertently not take rapidly changing climate conditions into account for the “regeneration” of the next ecosystem.

3.4.1.2 Planned Management Responses to Changing Climate Regimes, Including Disturbances and Extreme Events

This approach to adaptation assumes that adjustments to historical management approaches are needed eventually, and are best made during or after a major climatic event. In this case, the managing agency would identify climate-change-cognizant management approaches that are to be implemented at the time of a disturbance, as it occurs, such as a historically unprecedented fire, insect infestation, or extreme windfall event, hurricanes, droughts and other extreme climatic events. A choice is made to not act now to prepare for climate change, but rather to react once the problem is evident. The rationale, again, could be that the climate change impacts are too uncertain to enact or even identify appropriate anticipatory management activities, or even that the best time for action from a scientific as well as organizational efficiency standpoint may be post-disturbance (*e.g.,* from the standpoint of managing successional processes within ecosystems and across the landscape).

For example, forest managers may see large disturbances (fire, flooding, insects, hurricanes) as opportunities to react to climate change. Those disturbances could be windows of opportunity for implementing adaptive practices, such as adjusting the size of management units to capture whole watersheds or landscapes, developing a prescribed fire plan for the post-fire treated landscape, addressing road and culvert needs to handle changes in erosion under climate change, revisiting objectives for even-age versus uneven-age management, reforesting with species tolerant to low soil moisture and high temperature, using a variety of genotypes in the nursery stock, and moving plant genotypes and species into the disturbed area from other seed zones. For example, where ecosystems move toward being more water-limited under climate change, populations from drier and warmer locations will be more resistant to such changing conditions. In practice, this typically means using trees from provenances that are farther south or at lower elevation than what is currently indicated for a particular geographic location (Ying and Yanchuk, 2006). Because local climate trends and variability will always be uncertain, managers can hedge their bets by managing for a variety of species and genotypes with a range of tolerances to low soil moisture and higher temperatures. In general, genetic diversity provides resilience to a variety of environmental stressors (Moritz, 2002; Reed and Frankham, 2003; Reusch *et al.*, 2005).

Furthermore, disturbed landscapes could be used as experiments in an adaptive management context that provide data for evaluating and improving approaches to adapt ecosystems to a warmer climate. An example may be to reforest an area after a fire or windfall event with a type of tree species that is better adjusted to the new or unfolding regional climate. This may be difficult to achieve, because the climate that exists during the early years of tree growth will be different from those that will persist during the later stages of tree growth.

Significant cost efficiencies, relative to the unplanned approach, may be achieved in this approach, as management responses are anticipated—at least generically—well in advance of an event, yet are implemented only when "windows of opportunity" open. Future constraints to implementing such changes will need to be anticipated and planned for, and, if possible removed in advance for timely adaptation to be able to occur when the opportunity arises. For example, managers could ensure that the genetic nursery stock is available for wider areas, or they could re-examine regulations restricting practices so that, immediately after a disturbance, management can act rapidly to re-vegetate and manage the site. Such an approach may be difficult to implement, however, as crises often engender political and social conditions that favor "returning to the status quo" that existed prior to the crisis rather than doing something new (*e.g.*, Moser, 2005).

3.4.1.3 Management Responses in Anticipation of Future Climate Change and in Preparation for Climate Change Now

The management approach that is most forward-looking is one that uses current information about future climate, future environmental conditions, and the future societal context of NF management to begin making changes to policy and on-the-ground management now and when future windows of opportunity open. Opportunities for such policy and management changes would include any planning or project analysis process in which a description of the changing ecosystem/disturbance regime as climate changes would be used to identify a proactive management strategy.

Relevant information for forest managers may include projections of regional or even local climates, including changes in average temperature, precipitation, changes in patterns of climatic extremes and disturbance patterns (*e.g.*, fire, drought, flooding), shifts in seasonally important dates (*e.g.*, growing degree-days, length of fire season), expected future distribution of key plant species, and changes in hydrological patterns. The ability of climate science to provide such information at higher spatial and temporal resolution has been improving steadily over recent years, and is likely to improve further in coming years (IPCC, 2007). Current model predictions have large uncertainties, which must be considered in making management adaptation decisions (see Sections 3.4.2.1 and 3.4.2.2 for other treatments of uncertainty). Other relevant information may be species-specific, such as the climatic conditions favored by certain plant or animal species over others, or the ways in which changed climatic conditions and the resultant habitats may become more or less favorable to particular species (*e.g.*, for threatened or endangered species). The overall goals of planned anticipatory management would be to facilitate adaptation in the face of the changing climate.

For example, based on the available information, large-scale thinnings might be implemented to reduce stand densities in order to minimize drought effects, avoid large wildfire events in areas where these are not typical, and manage the potential for increased insect and disease outbreaks under a changing climate. Widely spaced stands in dry forests are generally less stressed by low soil moisture during summer months (*e.g.*, Oliver and Larson, 1996). Disease and insect concerns are at least partially mitigated by widely spaced trees, because trees have less competition and higher vigor. Low canopy bulk densities in thinned stands, with concurrent treatments to abate surface fuels, can substantially mitigate wildfire risk (Peterson *et al.*, 2005).

However, not all forest landscapes and stands are amenable to thinning, nor is it ecologically appropriate in some upper-elevation forest types. In these situations, shelterwood cutting that mitigates extreme temperatures at the soil surface can facilitate continued cover by forest tree species while mitigating risks of uncharacteristically severe fire, insects, and disease (Graham *et al.*, 1999). Again, it will be important to assess the tradeoffs between these silvicultural benefits and potential for genetic erosion resulting from the shelterwood treatment (Ledig and Kitzmiller, 1992). This approach is economically feasible in locations where wood removed through thinnings and shelterwood cuttings can be marketed as small-dimensional wood products or biomass (Kelkar *et al.*, 2006). To identify and provide the most relevant information to support such an anticipatory approach to adaptation, it is critical that scientists and managers work together to form a growing mutual understanding of information needs and research capabilities in the context of ongoing, trusted relationships (Slovic, 1993; Earle and Cvetkovich, 1995; Cash, 2001; Cash *et al.*, 2003; Cash and Borck, 2006; Vogel *et al.*, forthcoming).[24] Further examples of such information needs are described in the next section and in the case studies (see Case Study Summaries and Annex A1).

Again, significant cost efficiencies and maybe even financial gains may be achieved in this approach, as management responses are anticipated well in advance and implemented at the appropriate time. If climatic changes unfold largely consistent with the scientific projections, this approach to adaptation may turn out to be the most cost-effective and ecologically effective (referred to as the "perfect foresight" situation by economists; see e.g., Sohngen and Mendelsohn, 1998; Mastrandrea and Schneider, 2001; Yohe, Andronova, and Schlesinger, 2004). For example, analyses using forest sector economic models that assume “perfect foresight” have shown that when a diverse set of management options are available to managers under conditions of extensive mortality events from climate change, the economic impacts on the wood product sector, even with large-scale mortality events, are less costly than otherwise (Sohngen and Mendelsohn, 1998; Joyce, 2007).

This approach may not be able to maintain ecosystems that currently exist (as those are better adapted to current climate regimes), but it may be best suited to support natural adaptive processes—such as planning corridor development to facilitate species migration to more appropriate climates, or managing for protection of viable habitats for threatened and endangered species to enhance or extend opportunities for adaptation (see Section 3.4.3.3). Under such a management approach, the specific management targets—such as outputs of particular rangeland and forest products, or maintenance of a particular species habitat—may themselves be adjusted over time, as the opportunities for those ecosystem services diminish under a changing climate and new opportunities for other services may have a greater chance of being met. The inability to maintain ecosystems that currently exist may suggest activities such as long-term seed bank storage with future options for re-establishing populations in new and more appropriate locations. Assessing the potential for this type of change will draw on ecological, economic, and social information. Importantly, such an approach would need to involve managers at various levels to monitor changes in the ecosystem (*i.e.*, observed on the ground); coordinate and make appropriate changes in policies, regulations, plans, and programs at all relevant scales; and modify the on-the-ground practices needed to implement these higher-level policies. This degree

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[24] See also **Tribbia**, J. and S.C. Moser, in press: More than information: what California coastal managers need to prepare for climate change. *Environmental Science & Policy*.

of cross-scale integration is not typically achieved at present, and would need to occur in the future to effectively support such an approach to adaptation. Additionally, such considerations would need to involve the public, as well as stakeholders dependent upon the ecosystem services from NFs. On the local scale, the importance of establishing relationships with existing community organizations early on in a wildfire incident was identified in order to incorporate local knowledge into firefighting and rehabilitation efforts (Graham, 2003). This coordination was also important to establish a recovery base that continues once emergency personnel and resources have left the community. These partnerships should be developed as early as possible during the fire, and perhaps might best be developed before any fire in order to systematize actions, increase efficiency, and decrease potential contentions between locals and federal agencies by building trust (Graham, 2003). Lessons learned in integrating fire management across local to state to federal agencies may help in similar considerations of cross-scale integration of resource managers to address current and future resource management under a changing climate.

3.4.2 Approaches for Planning in the Context of Climate Change

3.4.2.1 Use of Models and Forecasting Information

Many forest managers are awaiting information from quantitative models about future climates and environments to guide climate-related planning. Increasingly sophisticated models are being developed at regional and finer spatial scales. In general, while model information will be important for planning, the best use of this information at local and regional scales currently is to help organize thinking, attain insight into the nature of potential processes, and understand qualitatively the range of magnitudes and likely direction and trends of possible future changes. Focusing on results that are similar across diverse models may indicate results of greater likelihood.

While science is progressing, uncertainty about climate projections are much greater at the local and regional scales important to land managers, because uncertainties amplify as data and model output are downscaled. Some climate parameters, such as changes in average annual temperature, may be more robust than others, such as changes in annual precipitation, which have higher uncertainties associated with them. Augmenting this uncertainty in physical conditions is the difficulty of modeling biological responses. Ecological response to climate-related changes is highly likely to be more difficult than climate to model accurately at local scales, because threshold and non-linear responses, lags and reversals, individualistic behaviors, and stochastic (involving probability) events are common (Webb, III, 1986; Davis, 1989). Models typically rely on directional shifts following equilibrium dynamics of entire plant communities (or, physiognomic community types), whereas especially in heterogeneous and mountainous regions, patchy environments increase the likelihood of complex, individualistic responses.

At the global scale, this uncertainty is dealt with through simultaneous analysis of multiple scenarios (IPCC, 2007), which yields a wide range of potential future climate conditions. Similarly, approaches at finer spatial scales could be developed to use scenario analysis (Peterson, Cumming, and Carpenter, 2003; Bennett *et al.*, 2003) (alternative future climate scenarios can be used to drive ecosystem and other natural resource models), thus examining the possible range of future conditions. Scenario analysis can help to identify potential management options that could be useful to minimize negative impacts and enhance the likelihood of positive impacts, within the range of uncertainty.

Uncertainty does not imply a complete lack of understanding of the future or a basis for a no action decision. Managing in the face of uncertainty will best involve a suite of approaches, including planning analyses that incorporate modeling with uncertainty, and short-term and long-term strategies that focus on enhancing ecosystem resistance and resilience, as well as actions taken that help ecosystems and resources move in synchrony with the ongoing changes that result as climates and environments vary.

3.4.2.2 Planning Analyses for Climate Change

RPA Assessment

The only legislatively required analysis with respect to climate change and USFS planning was identified in the 1990 Food Protection Act, which amended the 1974 Resources Planning Act (RPA). The 1990 Act required the USFS to assess the impact of climate change on renewable resources in forests and rangelands, and to identify the rural and urban forestry opportunities to mitigate the buildup of atmospheric CO_2. Since 1990, the RPA Assessments (e.g., USDA Forest Service, 1993; USDA Forest Service, 2000; USDA Forest Service, forthcoming) have included an analysis of the vulnerability of U.S. forests to climate change, and the impact of climate change on ecosystem productivity, timber supply and demand, and carbon storage (Joyce, Fosberg, and Comandor, 1990; Joyce, 1995; Joyce and Birdsey, 2000; Haynes *et al.*, 2007). These analyses have identified several important aspects of the analysis of climate change impacts on the forest sector. Transient analyses, where annual dynamics are followed throughout the projection period, allow interactions between ecosystem responses to climate change and market responses to identify adaptation options to the changing climate. The forest sector trade at the global scale can influence the forest sector responses (price as well as products) within countries. National level analyses aggregate impacts across regions, and it remains important to identify the regional response, which may be greater, because that is where management decisions will be made (Joyce, 2007). Most critically, all of these analyses have stressed the importance of evaluating the ecological and the economic response in an integrated fashion

Adaptation strategies may vary based on the spatial and temporal scales of decision making. Planning at regional or national scales may involve acceptance of different levels of uncertainty and risk than appropriate at local (*e.g.*, NF or watershed) scales. National analyses associated with RPA offer the opportunity to develop potential approaches to link assessments at the national, regional, multi-forest, and NF scales. Such an approach could involve key questions, methods of assessment, approaches to uncertainty and risk, needed expertise and resources, responsibilities and timelines, and identification of spatial and temporal scales for modeling linked to decision making. The assessment would consider how vulnerabilities and sensitivities within these systems might be identified, given the available information, as well as identifying situations of high resilience to climate change or situations where the climate change effects might be locally buffered. Significant involvement by scientists, managers, policymakers, and stakeholders from local to national levels would be critical. Such a linked assessment could guide NFs and their partners in terms of a process to assess the impacts of climate change on natural resources and ecosystem services within their boundaries, across their boundaries, and at larger spatial scales such as regional and national.

Forest Planning and Project Analyses

The following planning steps have been suggested as appropriate in a climate-change context when beginning a project (Spittlehouse and Stewart, 2003; see examples therein):

1. Define the issue (management situation, goals, and environmental and institutional contexts);
2. Evaluate vulnerabilities under changing conditions;
3. Identify suitable adaptive actions that can be taken at present or in the short term; and
4. Develop suitable adaptive actions that could be taken in the longer term.

In a survey of the forest plans available online in December 2006, 15 plans from a total of 121 individual forests had included references to climate change (terms “climate change,” “climate variability,” or “global warming”) in the sections of the plan describing trends affecting management or performance risks, or, in earlier plans, as a concern in the environmental impact statement; both of these types of references are similar to Step 2 above (evaluating vulnerabilities).

Given the challenges of the uncertainty in climate scenarios at fine spatial scale (Section 3.4.2.1), a set of assumptions to be considered in planning has been proposed.[25] Specifically, the recommendations make use of an adaptive management approach to make adjustments in the use of historical conditions as a reference point. Flexibility to address the inherent uncertainty about local effects of climate change could be achieved through enhancing the resiliency of forests, and specific aspects of forest structure and function are mentioned (Box 3.6). These assumptions would allow the plan components to be designed in a way that allows for adaptability to climate change, even though the magnitude and direction of that change is uncertain. The assumptions to be examined (listed in Box 3.6) explore underlying premises about climate and climate change in the management processes.

One information-gathering option to help define the underlying assumptions and vulnerabilities to climate change might be to consider convening a science-based (*e.g.*, USFS research team) rapid assessment or “audit” of existing forest planning documents (*e.g.*, the Forest Land Management Plan, or larger plans such as the Sierra Nevada Forest Plan amendment or the Northwest Forest Plan, and project plans). The purpose of the audit would be to determine the level of climate adaptedness, pitfalls, and areas for improvement in current forest plans and operations. Such an audit could focus on current management direction (written policy); current management practices (implementation); and priorities of species (*e.g.*, specific targeted species) and processes (fire, insects/disease). The audit would highlight concrete areas of the plans and projects that are poorly adapted to potential changes in climate, as well as those that are already climate-proactive. Audit recommendations would identify specific areas where changes are needed, and where improvements in forest planning or project-level planning and management could be made.

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[25] **West**, 2005: *Letter and Attachments*. File Code 4070, letter dated July 26, 2005. Pacific Northwest Station.

Information and tools needed to assist adaptation form the basis for a long-term, management-science partnership continually refining scientific information for resource management decisions. A wide suite of modeling approaches that project climate change impacts on ecosystems are available (for example, Melillo *et al.*, 1993; Joyce and Birdsey, 2000; Bachelet *et al.*, 2001; Iverson and Prasad, 2001; Currie, 2001; Felzer *et al.*, 2004; McKenzie *et al.*, 2004; Logan and Powell, 2005; Scholze *et al.*, 2006; Rehfeldt *et al.*, 2006; Joyce, 2007; Lenihan *et al.*, forthcoming; Bachelet *et al.*, forthcoming).[19] These modeling approaches contain different underlying assumptions about ecological process, mathematical and statistical descriptions of ecosystems, the effect of climate, and may or may not include the ability to explore the effect of management on the ecosystem under a changing climate. For example, some statistical models are based on the assumption of equilibrium relationships between vegetation and climate, a concept that is no longer considered a valid description of ecosystem dynamics and biogeography. In addition, the recent literature on non-analog future climates and 30 years of literature on paleoecology demonstrate that species respond individualistically and uniquely in time and space, and models must take into account competition and ecological disturbance, not just gradual temperature change. Understanding the strengths and weaknesses of the available models and where these models can contribute to planning and analysis needs, as well as the development of pathways to add climate to existing planning and analysis tools used by NFs, are critical research needs.

In the short-term, natural resource managers could benefit from a manager's guide with current state-of-the art scientific concepts and techniques. Critical gaps in scientific understanding of the impacts of climate change, and of management on ecosystem services, hinder adaptation by limiting assessment of risks, efficacy, and sustainability of actions. Assistance and consultation on interpreting climate and ecosystem model output would provide the context and relevance of model predictions to be reconciled with managers' priorities for adaptation.

3.4.3 Approaches for Management in the Context of Climate Change

3.4.3.1 Toolbox of Management Approaches

A primary premise for adaptive approaches is that change, novelty, uncertainty, and uniqueness of individual situations are expected to define the planning backdrop of the future. Rapid changes that are expected in physical conditions and ecological responses suggest that management goals and approaches will be most successful when they emphasize ecological processes, rather than focusing primarily on structure and composition. Information needs (*e.g.*, projections of future climates, anticipated ecological responses) will vary in availability and accuracy at local spatial and temporal scales. Thus, strategic flexibility and willingness to work in a context of varying uncertainty will improve success at every level (Anderson *et al.*, 2003). Learning from experience and iteratively incorporating lessons into future plans—adaptive management in its broadest sense—is an appropriate lens through which natural-resource management is conducted (Holling, 2001; Noss, 2001; Spittlehouse and Stewart, 2003). Dynamism in natural conditions is appropriately matched by dynamic approaches to management and adaptive mindsets.

Given the nature of climate and environmental variability, the inevitability of novelty and surprise, and the range of management objectives and situations, a central dictum is that *no* *single approach will fit all situations* (Spittlehouse and Stewart, 2003; Hobbs *et al.*, 2006). From a toolbox of options such as those proposed below, appropriate elements (and modifications) should be selected and combined to fit the situation. Some applications will involve existing management approaches used in new locations, seasons, or contexts. Other options may involve experimenting with new practices.

A toolbox approach recognizes that strategies may vary based on the spatial and temporal scales of decision making. Planning at regional scales may involve acceptance of different levels of uncertainty and risk than appropriate at local (*e.g.*, NF or watershed) scales. The options summarized below fall under adaptation, mitigation, and conservation practices (Dale *et al.*, 2001; IPCC, 2001a). Based on the toolbox approach, an overall adaptive strategy will usually involve integrating practices that have different individual goals. An important consideration in building an integrative strategy is to first evaluate the various types of uncertainty: for example, uncertainty in present environmental and ecological conditions, including the sensitivity of resources; uncertainty in models and information sources about the future; uncertainty in support resources (staff, time, funds available); uncertainty in planning horizon (short- vs. long-term); and uncertainty in public and societal support. This evaluation would lead to a decision on whether it is best to develop reactive responses to changing disturbances and extreme events, or proactive responses anticipating climate change (see Section 3.4.1). The following options provide a framework for building management strategies in the face of climate change. Some examples of specific, on-the-ground, adaptation options are presented in Box 3.7 and are elaborated upon further in the sections that follow. Examples of institutional and planning adaptations, given in Box 3.8, are also elaborated upon further in the sections that follow.

3.4.3.2 Reducing Existing Stresses

The USFS implements a variety of management approaches to reduce the impact of existing stressors on NFs (see Section 3.3.3), and an increased emphasis on these efforts represents an important “no regrets” strategy. It is likely that the direct impacts of climate change on ecosystems and the effects of interactions of climate change with other major stressors may render NFs increasingly prone to more frequent, extensive, and severe disturbances, especially drought (Breshears *et al.*, 2005; Seager *et al.*, 2007), insect and disease outbreaks (Logan and Powell, 2001; Carroll *et al.*, 2004), invasive species, and wildfire (Logan and Powell, 2001; Brown, Hall, and Westerling, 2004; McKenzie *et al.*, 2004; Logan and Powell, 2005; Skinner, Shabbar, and Flanningan, 2006) (see also Section 3.3.2). The elevated water stress resulting from warmer temperatures in combination with greater variability in precipitation patterns and altered hydrology (*e.g.*, from less snowpack and earlier snowmelt, Mote *et al.*, 2005) would increase the frequency and severity of both droughts and floods (IPCC, 2001a). Air pollution can negatively affect the health and productivity of NFs, and the fragmented landscape in which many NFs are situated impedes important ecosystem processes, including migration. Efforts to address the existing stressors would address current management needs, and potentially reduce the future interactions of these stressors with climate change.

Drought has occurred across the United States in recent years, resulting most notably in large areas of forest mortality in the Southwest (see Section 3.3.2). Federal, state, and local governments, as well as private institutions, have drought management plans, but the National Drought Policy Commission Report (2000) stated that the current approach is patchy and uncoordinated. Climate change is likely to result in increased drought, with potential interactions with air quality and fire. Exposure to ozone may further exacerbate the effects of drought on both forest growth and stream health (McLaughlin *et al.*, 2007a; 2007b). Preparedness is an important element in reducing the potential impacts of drought on individuals, communities, and the environment. The development or refinement of drought plans that incorporate preparedness, mitigation, and response efforts would address the current stresses of drought, as well as begin to address potential adaptations to likely future droughts. Increased coordination among local, state, and federal government agencies on drought planning and drought-related policies (fire closures, recreation uses, and grazing management) would help in this regard. Coordination with the Bureau of Land Management, whose lands intermingle extensively with NF land, would be particularly beneficial. Enhancing the effectiveness of observation networks and current drought monitoring efforts would provide information on which to make management decisions, particularly in response to the impacts of drought on aquatic ecosystems, wildlife, threatened and endangered species, and forest health. Increased collaboration among scientists and managers would enhance the effectiveness of prediction, information delivery, and applied research, and would help develop public understanding of and preparedness for drought.

Invasive species are currently a problem throughout NFs, and disturbances such as fire, insects, hurricanes, ice storms, and floods create opportunities for invasive species to become established on areas ranging from multiple stands to landscapes. In turn, invasive plants alter the nature of fire regimes (Williams and Baruch, 2000; Lippincott, 2000; Pimentel *et al.*, 2000; Ziska, Reeves, and Blank, 2005)[12] as well as hydrological patterns (Pimentel *et al.*, 2000), in some cases increasing runoff, erosion, and sediment loads (*e.g.*, Lacey, Marlow, and Lane, 1989). Potential increases in these disturbances under climate change will heighten the challenges of managing invasive species. Early detection/rapid response (EDRR, see Section 3.3.3) focuses on solving small problems before they become large, unsolvable problems, and recognizes that proactive management is more effective than long delays in implementation. The Olympic Land Management Plan, for example, recognizes that invasive species often become established in small, treatable patches, and are best addressed at early stages of invasion. Although designed for invasives, this EDRR approach may also be appropriate for other types of disturbances, because it could allow managers to respond quickly to the impacts of extreme events (disturbances, floods, windstorms, insect outbreaks), with an eye toward adaptation.

The USFS allocates considerable resources toward wildfire management (see Section 3.3.3). The projected increase in frequency, severity, and extent of fire under climate change is also likely to affect watershed condition, soil quality, erosional processes, and water quantity and quality in NFs (Wagle and Kitchen, Jr., 1972; Neary *et al.*, 1999; Spencer, Gabel, and Hauer, 2003; Certini, 2005; Guarin and Taylor, 2005; Neff, Harden, and Gleixner, 2005; Neary, Ryan, and DeBano, 2005; Murphy *et al.*, 2006; Deluca and Sala, 2006; Hauer, Stanford, and Lorang, 2007).
The National Fire Plan describes a wide variety of approaches to manage wildfire, the most prominent of which is hazardous fuels reduction. Fuel abatement approaches include prescribed fire, wildland fire use (see Section 3.3.3), and various mechanical methods such as crushing, tractor and hand piling, tree removal (to produce commercial or pre-commercial products), and

pruning. Incorporation of additional climate information into fire management and planning may enhance current efforts to address wildfires.[26]

Air pollution from a variety of sources decreases forest productivity, diminishes watershed condition, and deleteriously affects aquatic and terrestrial food webs in NFs (see Section 3.3.2). Although droughts and fires within NFs affect air quality, the USFS actively seeks to directly reduce these stressors and their impacts. In contrast, reducing the deposition of pollutants originating from outside NFs is beyond the agency's control, and thus the USFS mainly works to mitigate the impacts of these stressors. To directly reduce these stressors, the USFS would need to increase coordination with other agencies (federal, state, and local) and the private sector. Efforts to reduce fragmentation and land use change near NFs by creating habitat corridors, increasing the size of management units, and identifying high-value conservation lands outside of NFs that could be managed in a coordinated way with the USFS will yield ecological benefits regardless of climate change. Large, connected landscapes will be even more critical as native species attempt to migrate or otherwise adapt to climate change. As is the case with air pollution, reducing these stressors with this approach will require increased coordination across federal, state, and local agencies as well as with private landowners.

One of the legacies of past management in NFs (see Section 3.3.2.1) is the presence of large landscapes consisting of even-aged stands, which are vulnerable to large-scale change by fire, insects, disease, and extreme weather events and their interactions. Management that emphasizes diverse, uneven age stands will benefit many NF ecosystems regardless of climate change. This approach would also likely enhance ecosystem resilience to climate change.

3.4.3.3 Adaptation Options

Forestalling Ecosystem Change

Create Resistance to Change

Notwithstanding the importance of dynamic approaches to change and uncertainty, one set of adaptive options is to manage ecosystems and resources so that they are better able to resist the influence of climate change (Parker *et al.*, 2000; Suffling and Scott, 2002). From rare species with limited available habitat to high-value forest plantation investments near rotation, maintaining the status quo for a limited period of time may be the only or best option in some cases. Creating resistance includes improving ecosystem defenses against climate effects *per se,* but also creating resistance against climate-exacerbated disturbance impacts. Conditions with low sensitivity to climate will be those most likely to accommodate resistance treatments, and high-sensitivity conditions will require the most intensive efforts to maintain current species and ecological functions.

For conditions with low sensitivity to climate, maintaining ecosystem health and biodiversity is an important adaptation approach, building on current understanding and management practices. Healthy forest stands recover more quickly from insect disturbances than do stressed stands, and conservation of biodiversity would aid in successful species migrations (Lemmen and Warren,

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[26] **National Association of State Foresters**, 2007: NASF Resolution No. 2007-1.Issue of Concern: The role that climate change plays in the severity and size of wildland fires is not explicitly recognized in the "National Fire Plan" and the Implementation Plan for its 120-year Strategy. http://www.stateforesters.org/resolution/2007-01.pdf.

2004). Maintaining key processes, such as hydrological processes and natural disturbances, would be important. Management for resistance might require ensuring reasonable use of water from forests, and appropriate road closures to minimize invasive species transport (Christen and Matlack, 2006).

Fragmentation and land-use changes that are already problematic may be worsened under climate change due to shifts in species behaviors and changed habitat requirements. Anticipating these impacts for high-risk, high-value, and sensitive resources may require adopting landscape management practices that enable species movements. Creating larger management unit sizes, broad habitat corridors, and continuity of habitat would increase resistance of animal species to climate change by improving their ability to migrate. In this regard, enhancing coordination among the multiple agencies that manage adjacent lands to ensure habitat continuity will be essential (Malcolm *et al.*, 2006).

In the arid West, aggressive prophylactic actions may be needed to increase resistance of ecosystems from risks of climate-exacerbated disturbances such as drought, insect outbreak, and uncharacteristically severe wildfire. Resistance practices include thinning and fuels abatement treatments at the landscape scale to reduce crown fire potential and risk of insect epidemic, maintaining existing fuelbreaks, strategically placed area treatments that will reduce fuel continuity and drought susceptibility of forests, creating defensible fuel profile zones around high-value areas (such as WUI, critical habitat, or municipal watersheds), and similar treatments. Intensive and aggressive fuelbreaks may be necessary around highest-risk or highest-value areas, such as WUI or at-risk species, while mixed approaches may best protect habitat for biodiversity and general forest zones (Wheaton, 2001).

With respect to climate-related insect and disease outbreaks, traditional silvicultural methods may be applied creatively. These may involve intensive treatments, such as those used in high-value agricultural situations: resistance breeding, novel pheromone applications (such as sprayable micro-encapsulated methods), complex pesticide treatments, and aggressive fuelbreaks. Abrupt invasions, changes in behavior and population dynamics, and long-distance movements of native and non-native species may occur in response to changing climates. Monitoring non-native species, and taking aggressive early and proactive actions at key migration points to remove and block invasions, are important steps to increase resistance. However, monitoring species range distributions may indicate that native species, considered non-native to a particular area, may be migrating. Evaluating the original objectives and the changing local assemblages of species may be necessary before taking aggressive action. Conditions could be cumulatively adjusting to a changing climate, and maintenance of the status quo may not be feasible.

Efforts to increase resistance may be called for in other high-value situations. Building resistance to exacerbated effects of air pollution from climate change may require that aggressive thinning and age-control silvicultural methods are applied at broad landscape scales, that mixed species plantations be developed, that broader genetic parameters be used in plantations, or that plantations are switched to resistant species entirely (Papadopol, 2000).

Resisting climate change influences on natural forests and vegetation over time will almost always require increasingly aggressive treatments, accelerating efforts and investments over time, and a recognition that eventually these efforts may fail as conditions cumulatively change. Critical understanding of the changing environmental, social, and economic impacts of climate change will be needed to evaluate the success of management approaches to resist the influence of climate change. Creating resistance in most forest and rangeland situations to directional change is akin to "paddling upstream," and eventually conditions may change so much that resistance is no longer possible. For instance, climate change in some places will drive environments to change so much that site capacities shift from favoring one species to another, and a type conversion occurs.

Maintaining prior species may require significant extra and repeated efforts to supply needed nutrients and water, remove competing understory, fertilize young plantations, develop a cover species, thin, and prune. More seriously, forest conditions that have been treated to resist climate-related changes may cross thresholds and convert (*i.e.*, be lost) through extreme events such as wildfire, ice storm, tornado, insect epidemic, or drought, resulting in significant resource damage and loss. For this reason, in some situations, resistance options may best be applied in the short term and for projects with short planning horizons and high value, such as short-rotation biomass or biofuels plantings. Alternative approaches that work with processes of change, rather than against the direction of climate-related change, may enable inevitable changes to happen more gradually over time, and with less likelihood of cumulative, rapid, and catastrophic impact. For example, widely spaced thinning or shelterwood cuttings that create many niches for planted or naturally established seedlings may facilitate adaptation to change on some sites. In selecting these alternative approaches, a holistic analysis may be required to identify the break point beyond which intervention to natural selection and adaptation to climate changes may not be possible or cannot be managed at reasonable cost.

Promote Resilience to Climate Change

Resilient ecosystems are those that not only accommodate gradual changes related to climate, but resile (return to a prior condition of that ecosystem) after disturbance. Promoting resilience is the most commonly suggested adaptive option discussed in a climate-change context (*e.g.*, Dale *et al.*, 2001; Spittlehouse and Stewart, 2003; Price and Neville, 2003), but has its drawbacks as climate continues to change. Resilience can be increased through management practices similar to those described for resisting change, but applied more broadly, and specifically aimed at coping with disturbance (Dale *et al.*, 2001; Wheaton, 2001). As with any adaptation approach, land manager objectives will vary—*e.g.*, protection; management for endangered species, commodities, or low fire vulnerability—and these choices may or may not result in a decision to resile the system to a former state. An understanding of the ecological consequences of the changing climate is a critical component of identifying adaptation strategies.

An example of promoting resilience in forest ecosystems is a strategy that combines practices to reduce fire or insect and disease outbreaks (resistance) with deliberate and immediate plans to encourage return of the site, post-disturbance, to species reflective of its prior condition (resilience). Given that the plant establishment phases tend to be most sensitive to climate-induced changes in site potential, intensive management dedicated to the revegetation period through the early years of establishment may enable retention of the site by desired species, even if the site is no longer optimal for those species (Spittlehouse and Stewart, 2003). Practices could include widely spaced thinnings or shelterwood cuttings to promote resilience with living stands, and rapid treatment of forests killed by fire or insects. In forests killed by fire or other disturbance, resilience could be promoted by maintaining some degree of shade as appropriate for the forest type; intensive site preparation to remove competing vegetation; replanting with high-quality, genetically appropriate, and diverse stock; diligent stand-improvement practices; and minimizing invasion of non-native species (Dale *et al.*, 2001; Spittlehouse and Stewart, 2003). Many of these intensive forestry practices may have undesired effects on other elements of ecosystem health, and thus have often come under dispute. However, if the intent is to return a forest stand to its prior condition after disturbance under changing climate (*i.e.*, to promote resilience), then deliberate, aggressive, intensive, and immediate actions may be necessary.

Similar to the situation with regard to resistance options, the capacity to maintain and improve resilience will, for many contexts, become more difficult as changes in climate accumulate and accelerate over time. These options may best be exercised in projects that are short-term, have high value (*e.g.*, commercial plantations), or under ecosystem conditions that are relatively insensitive to the potential climate change effects (*e.g.*, warming temperatures). Climate change has the potential to significantly influence the practice and outcomes of ecological restoration (Harris *et al.*, 2006), where the focus is on tying assemblages to one place. A strategy that combines practices to restore vigor and redundancy (Markham, 1996; Noss, 2001) and ecological processes (Rice and Emery, 2003), so that after a disturbance these ecosystems have the necessary keystone species and functional processes to recover to a healthy state even if species composition changes, would be the goal of managing for ecosystem change.

Managing for Ecosystem Change

Enable Forests to Respond to Change

This suite of adaptation options intentionally plans for change rather than resisting it, with a goal of enabling forest ecosystems to naturally adapt as environmental changes accrue. Given that many ecological conditions will be moving naturally toward significant change in an attempt to adapt (*e.g.*, species migration, stand mortality and colonization events, changes in community composition, insect and disease outbreaks, and fire events), these options seek to work with the natural adaptive processes. In so doing, options encourage gradual adaptation over time, thus hoping to avoid sudden thresholds, extreme loss, or conversion that may occur if natural change is cumulatively resisted.

Depending on the environmental context, management goals, and availability and adequacy of modeling information (climate and otherwise), different approaches may be taken. In this context, change is assumed to happen—either in known directions, with goals planned for a specific future, or in unknown directions, with goals planned directly for uncertainty. Examples of potential practices include the following:

1. Assist transitions, population adjustments, range shifts, and other natural adaptations. Use coupled and downscaled climate and vegetation models to anticipate future regional conditions, and project future ecosystems into new habitat and climate space. With such information, managers might plan for transitions to new conditions and habitats, and assist the transition—*e.g.*, as appropriate, move species uphill, plan for higher-elevation insect and disease outbreaks, reduce existing anthropogenic stresses such as air quality or land cover changes, anticipate species mortality events and altered fire regimes, or consider loss of species' populations on warm range margins and do not attempt restoration there (Ledig and Kitzmiller, 1992; Parker *et al.*, 2000; Spittlehouse and Stewart, 2003). Further examples might be to modify rotation lengths and harvest schedules, alter thinning prescriptions and other silvicultural treatments, consider replanting with different species, shift desired species to new plantation or forest locations, or take precautions to mitigate likely increases in stress on plantation and forest trees.

A nascent literature is developing on the advantages and disadvantages of "assisted migration," the intentional movement of propagules or juvenile and adult individuals into areas assumed to become their future habitats (Halpin, 1997; Collingham and Huntley, 2000; McLachlan, Hellmann, and Schwartz, 2007).

It is important to not generalize assumptions about habitat and climate change in specific areas. Local climate trajectories may be far different from state or regional trends, and local topography and microclimatology interact in ways that may yield very different climate conditions than those given by broad-scale models. In mountainous terrain especially, the climate landscape is patchy and highly variable, with local inversions, wind patterns, aspect differences, soil relations, storm tracks, and hydrology influencing the weather that a site experiences. Sometimes lower elevations may be refugial during warming conditions, as in inversion-prone basins, deep and narrow canyons, riparian zones, and north slopes. Such patterns, and occupation of them by plants during transitional climate periods, are corroborated in the paleoecological record (Millar and Woolfenden, 1999; Millar *et al.*, 2006). Additionally, land use change and agricultural practices can alter local and regional precipitation and climate patterns (Foley *et al.*, 2005; Pielke, Sr. *et al.*, 2006).

Despite the challenges in mountainous terrain, anticipating where climate and local species habitats will move will become increasingly important. On-the-ground monitoring of native species gives insight into what plants themselves are experiencing, and can suggest the directions of change and appropriate natural response at local scales. This can allow management strategies that mimic emerging natural adaptive responses. For instance, new species mixes (mimicking what is regenerating naturally), altered genotype selections, modified age structures, and novel silvicultural contexts (*e.g.*, selection harvest versus clearcut) may be considered.

2. Increase Redundancy and Buffers. This set of practices intentionally manages for an uncertain but changing future, rather than a specific climate future. Practices that involve spreading risks in diverse opportunities rather than concentrating them in a few are favored; using redundancy and creating diversity are key. Forest managers can facilitate natural selection and evolution by managing the natural regeneration process to enhance disturbances that initiate increased seedling development and genetic mixing, as has been suggested for white pines and white pine blister rust (Schoettle and Sniezko, forthcoming). Managers might also consider shortening generation times by increasing the frequency of regeneration, and increasing the effectiveness of natural selection by managing for high levels of intraspecific competition; in other words, by ensuring that lots of seedlings get established when stands are regenerated. This diversification of risk with respect to plantations can be achieved, for instance, by spreading plantations over a range of environments rather than within the historic distribution or within a modeled future location. Options that include using diverse environments and even species margins will provide additional flexibility. A benefit of redundant plantings across a range of environments is that they can provide monitoring information if survival and performance are measured and analyzed. Further, plantations originating as genetic provenance tests and established over the past several decades could be re-examined for current adaptations. This diversification of risk could also be achieved using natural regeneration and successional processes on NFs. A range of sites representing the diversity of conditions on a NF could be set aside after disturbance events to allow natural regeneration and successional processes to identify the most resistant species and populations. Other examples include planting with mixed species and age classes, as in agroforestry (Lindner, Lasch, and Erhard, 2000); increasing locations, sizes, and range of habitats for landscape-scale vegetation treatments; assuring that fuels are appropriately abated where vegetation is treated; and increasing the number of rare plant populations targeted for restoration, as well as increasing population levels within them (Millar and Woolfenden, 1999). In the same way, opportunistic monitoring, such as horticultural plantings of native species in landscaping, gardens, or parks, may provide insight into how species respond in different sites as climate changes, as well as engaging the public in such information gathering.

3. Expand Genetic Diversity Guidelines. Existing guidelines for genetic management of forest plantations and restoration projects dictate maintenance of and planting with local germplasm. In the past, small seed zones, used for collecting seed for reforestation or restoration, have been delineated to ensure that local gene pools are used and to avoid contamination of populations with genotypes not adapted to the local site. These guidelines were developed assuming that neither environments nor climate were changing—*i.e.*, a static background. Relaxing these guidelines may be appropriate under assumptions of changing climate (Ledig and Kitzmiller, 1992; Spittlehouse and Stewart, 2003; Millar and Brubaker, 2006; Ying and Yanchuk, 2006). In this case, options could be chosen based on the degree of certainty known about likely future climate changes and likely environmental changes (*e.g.*, air quality). If sufficient information is available, germplasm could be moved in the anticipated adaptive direction; for instance, rather than using local seed, seed from a warmer (often, downhill) current population would be used. By contrast, if an uncertain future is accepted, expanding seed zone sizes in all directions and requiring that seed collections be well distributed within these zones would be appropriate, as would relaxing seed transfer guidelines to accommodate multiple habitat moves, or introducing long-distance germplasm into seed mixes. Adaptive management of this nature is experimental by design, and will require careful documentation of treatments, seed sources, and outplanting locations in a corporate data structure to learn from both failures and successes of such mixes.

Traditional best genetic management practices will become even more important to implement under changing climates. Paying attention not only to the source but the balance of genetic diversity within seedlots and outplanting collections (*i.e.*, maintaining high effective population sizes) is prudent: approaches include maximizing the number of parents, optimizing equal representation by parents (*e.g.*, striving for equal numbers of seeds/seedlings per family), and thinning plantations such that existing genetic diversity is not greatly reduced. Genotypes known or selected for broad adaptations could also be favored. By contrast, although economic incentives may override, using a single or few genotypes (*e.g.*, a select clone or small clonal mix) is a riskier choice in a climate change context.

4. Manage for Asynchrony and Use Establishment Phase to Reset Succession to Current Conditions. Changing climates over paleoecologic timescales have repeatedly reset ecological community structure (species diversity) and composition (relative abundances) as plants and animals have adapted to natural changes in their environments. To the extent that climate acts as a region- and hemispheric-wide driver of change, the resulting shifts in biota often occur as synchronous changes across the landscape (Swetnam and Betancourt, 1998). At decadal and century scales, for instance, recurring droughts in the West and windstorms in the East have synchronized forest species, age composition, and stand structure across broad landscape. These then become further vulnerable to rapid shifts in climate, such as is occurring at present, which appear to be synchronizing forests through massive drought-insect-related diebacks. An opportunity exists to proactively manage the early successional stages that follow widespread mortality, by deliberately reducing synchrony.[27] Asynchrony can be achieved through a mix of activities that promotes diverse age classes, species mixes, stand diversities, genetic diversity, etc., at landscape scales. Early successional stages are likely the most successful (and practical) opportunities for resetting ecological trajectories that are adaptive to present rather than past climates, because this is the best chance for widespread replacement of plants. Such ecological resetting is evidenced in patterns of natural adaptation to historic climate shifts (Davis and Shaw, 2001).

5. Establish "Neo-Native" Plantations and Restoration Sites. Information from historic species ranges and responses to climate change can provide unique insight about species behaviors, ecological tolerances, and potential new habitats. For instance, areas that supported species in the past under similar conditions to those projected for the future might be considered sites for new plantations or "neo-native" stands of the species. These may be well outside the current species range, in locations where the species would otherwise be considered exotic. For instance, Monterey pine (*Pinus radiata*), endangered throughout its small native range, has naturalized along the north coast of California far disjunct from its present native distribution. Much of this area was paleohistoric range for the pine, extant during climate conditions that have been interpreted to be similar to expected futures in California (Millar, 1999). Using these locations specifically for "neo-native" conservation stands, rather than planning for the elimination of the trees as undesired exotics (which is the current management goal), is an example of how management thinking could accommodate a climate-change context (Millar, 1998). This option is relevant to both forest plantation and ecological restoration contexts.

6. Promote Connected Landscapes. Capacity to move (migrate) in response to changing climates is key to adaptation and long-term survival of plants and animals in natural ecosystems (Gates, 1993). Plants migrate, or "shift ranges" by dying in unfavorable sites and colonizing favorable edges, including internal species' margins. Capacity to do this is aided by managing for porous landscapes; that is, landscapes that contain continuous habitat with few physical or biotic restrictions, and through which species can move readily (recruit, establish, forage) (Halpin, 1997; Noss, 2001). Promoting large forested landscape units, with flexible management goals that can be modified as conditions change, will encourage species to respond naturally to changing climates (Holling, 2001). This enables managers to work with, rather than against, the flow of change. Evaluating and reducing fragmentation, and planning cumulative landscape

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[27] **Mulholland**, P., J. Betancourt, and D.D. Breshears, 2004: *Ecological Impacts of Climate Change: Report From a NEON Science Workshop*. American Institute of Biological Sciences, Tucson, AZ.

treatments to encourage defined corridors as well as widespread habitat availability, is a proactive approach.

7. Realign Significantly Disrupted Conditions. Restoration treatments are often prescribed for forest species or ecosystems that have been significantly or cumulatively disturbed and are far outside natural ranges of current variation. Because historical targets, traditionally used as references for restoration, are often inappropriate in the face of changing climates, re-alignment with current process rather than restoration to historic pre-disturbance condition may be a preferred choice (Millar and Brubaker, 2006; Harris *et al.*, 2006; Willis and Birks, 2006). In this case, management goals seek to bring processes of the disturbed landscape into the range of current or anticipated future environments (Halpin, 1997). An example comes from the Mono Lake ecosystem in the western Great Basin of California (National Research Council, 1987; Millar and Woolfenden, 1999). A basin lake with no outlet, Mono Lake is highly saline, thus is naturally fishless but rich in invertebrate endemism and productivity, provides critical habitat for migratory waterfowl, and supports rich communities of dependent aquatic and adjacent terrestrial animal species. In 1941, the Los Angeles Department of Water and Power diverted freshwater from Mono Lake's tributaries; the streams rapidly dried and Mono Lake's level declined precipitously. Salinity increased, groundwater springs disappeared, and ecological thresholds were crossed as a series of unexpected consequences unfolded, threatening Mono Lake's aquatic and terrestrial ecosystems. An innovative solution involved a 1990 court-mediated re-alignment process. Rather than setting pre-1941 lake levels as a restoration goal, a water-balance model approach, considering current climates as well as future climatic uncertainties, was used to determine the most appropriate lake level for present and anticipated future conditions.[28]

Options Applicable to Both Forestalling Change and Managing for Change

Anticipate and Plan for Surprise and Threshold Effects

Evaluate potential for indirect and surprise effects that may result from cumulative climate changes or changes in extreme weather events. This may involve thinking outside the range of events that have occurred in recent history. For example, reductions in mountain snowpacks lead to more bare ground in spring, so that "average" rain events run off immediately rather than being buffered by snowpacks, and produce extreme unseasonal floods (*e.g.*, Yosemite Valley, May 2005[29]). Similarly, without decreases in annual precipitation, and even with increasing precipitation, warming minimum temperatures are projected to translate to longer dry growing-season durations. In many parts of the West, especially Mediterranean climate regions, additional stresses of longer summers and extended evapotranspiration are highly likely to push plant populations over thresholds of mortality, as occurred in the recent multi-year droughts throughout much of the West (Breshears *et al.*, 2005). Evidence is accumulating to indicate that species interactions and competitive responses under changing climates are complex and unexpected (Suttle, Thompsen, and Power, 2007). Much has been learned from paleo-historic

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[28] **State of California**, 1994: *Decision and Order Amending Water Right Licenses to Establish Fisher Protection Flows in Streams Tributary to Mono Lake and to Protect Public Trust Resources at Mono Lake and in the Mono Lake Basin*. State Water Resources Board Decision 1631, pp.1-212.

[29] **Dettinger**, M., J. Lundquist, D. Cayan, and J. Meyer, 2006: The 16 May 2005 Flood in Yosemite National Park--A Glimpse into High-Country Flood Generation in the Sierra Nevada. Presentation at the American Geophysical Union annual meeting, San Francisco. http://www.fs.fed.us/psw/cirmount/meetings/agu/pdf2006/dettinger_etal_poster_AGU2006.pdf

studies about likely surprises and rapid events as a result of climate change. Anticipating these events in the future means planning for more extreme ranges than in recent decades, and arming management systems accordingly (Millar and Woolfenden, 1999; Harris *et al.*, 2006; Willis and Birks, 2006).

Experiment with Refugia

Plant ecologists and paleoecologists recognize that some environments appear more buffered against climate and short-term disturbances, while others are sensitive. If such "buffered" environments can be identified locally, they could be considered sites for long-term retention of plants, or for new plantations (commercial or conservation). For instance, mountainous regions are highly heterogeneous environmentally; this patchiness comprises a wide range of micro-climates within the sites. Further, unusual and nutritionally extreme soil types (*e.g.*, acid podsols, limestones, etc.) have been noted for their long persistence of species and genetic diversity, resistance to invasive species, and long-lasting community physiognomy compared with adjacent fertile soils (Millar, 1989). During historic periods of rapid climate change and widespread population extirpation, refugial populations persisted on sites that avoided the regional climate impacts and the effects of large disturbance. For example, Camp (1995) reported that topographic and site characteristics of old-growth refugia in the Swauk Pass area of the Wenatchee National Forest were uniquely identifiable. These populations provided both adapted germplasm and local seed sources for advance colonization as climates naturally changed toward favoring the species. In similar fashion, a management goal might focus specific attention to protect populations that currently exist in environmentally and climatically buffered, cooler, or unusually mesic environments.

3.4.4 Prioritizing Management Responses in Situations of Resource Scarcity

Species, plant communities, regional vegetation, and forest plantations will respond to changing climates individualistically. Some species and situations will be sensitive and vulnerable, while others will be naturally buffered and resilient to climate-influenced disturbances (Holling, 2001; Noss, 2001). Management goals for species and ecosystems across the spectrum of NFs also vary for many reasons. As a result, proactive climate planning will reflect a range of management intensities. Some species and ecosystems may require aggressive treatment to maintain viability or resilience, others may require reduction of current stressors, and others less intensive management, at least in the near future.

While evaluating priorities has always been important in resource management, the magnitude and scope of anticipated needs, combined with diminishing availability of human resources, dictate that priorities be evaluated swiftly, strictly, and definitively. A useful set of guidelines for certain high-demand situations comes from the medical practice of triage (Cameron *et al.*, 2000). Coming from the French *triare*, to sort, triage approaches were developed from the need to prioritize the care of injured soldiers in battlefield settings where time is short, needs are great, and capacity to respond is limited. Well-established emergency and disaster triage steps can be modified to fit resource needs when conditions cannot be handled with traditional planning or institutional capacity. Triage in a natural-resource context sorts management situations ("patients") into categories according to urgency, sensitivity, and capacity of available resources to achieve desired goals ("survival"). Cases are rapidly assessed and sorted into three to five major categories ("color tags") that determine further action:

1. *Red*: Significant ongoing emergency; immediate attention required. Cases in this category are extremely urgent, but may be successfully treated with immediate attention given available resources. Without attention, they will rapidly fail; in the medical sense, the patient will die soon if untreated. These cases receive the highest priority for treatment and use of available resources. Depending on available resources, some of these cases may be assigned black rather than red.

2. *Yellow*: Strong to medium potential for emergency. Cases in this category are sensitive to disruption, vulnerable due to history or disturbance (degree and extent of trauma), have the capacity with small additional disturbance to become rapidly worse, but are marginally stable at the time of assessment. These cases have medium priority.

3. *Green*: Low likelihood for emergency conditions. Cases in this category may have some problems but overall are relatively resistant to disturbance, have low stress or high capacity to deal with stress, a history of low vulnerability, and show signs of retaining stability at least in the short term with little need for intervention. These cases receive low priority, but conditions are monitored regularly for change.

4. *Black*: Conditions altered beyond hope of treatment. Cases in this category are so disrupted, altered, and weakened that chances of successfully treating them with available resources are nil. In medical context, patients are either dead or unable to be kept alive with existing capacity. These cases have the lowest priority in the short term, and alternative resolutions have to be developed.

While triage is valuable to practice under conditions of scarce resources or apparently overwhelming choice, it is not viable as a long-term or sole-use approach to priority-setting. Other approaches may be used for quick prioritizing of traditional management plans and practices. An example would be rapid assessments of current national forest land management plans, performed by teams of climate experts that visit NFs. Teams would rapidly review planning documents, interview staff, and visit representative field sites; they would conclude their visits with a set of recommendations on what aspects of the overall local forest management practices and plans are in (1) immediate need of significant revision, (2) need of revision in a longer timeframe, and (3) no need of revision; already climate-savvy. Similar integrated threat assessment tools are being developed that help managers and decision-makers grasp categories of urgency.

In situations where available resources can be augmented, where time is not a critical factor, and where more information can be obtained, traditional evaluations and priority-setting will be most appropriate. Triage may be used, however, at any time and at any scale where urgency arises, and when demands become greater than normally managed. The common alternative under these conditions, reacting to crises chaotically and without rules of assessment, will achieve far less success in the long run than triage-based approaches.

3.4.5 Barriers to Adaptation Approaches

The USFS will need to overcome various barriers to take advantage of opportunities to implement adaptations to climate change. Insufficient resources, various uncertainties, checkerboard ownership patterns, lengthy planning processes, agency targets and reward systems, and air quality standards that restrict the use of prescribed fire are examples of such barriers. The need to coordinate with other agencies, the private sector, and the general public may either enhance or impede the ability of the USFS to implement management adaptations. How these other stakeholders perceive climate change and react to USFS management proposals will strongly influence how the USFS can ultimately adapt.

Developing innovative adaptations to climate change will require creative thinking, coupled with improved scientific understanding of proposed new approaches. The USFS may need to encourage planners and managers to relax perceptions about rules and other constraints that may, in reality, afford enough flexibility to try something new. Scientists would then need to be given the resources and support to test new approaches that are developed through this innovative process.

3.5 Conclusions and Recommendations

3.5.1 Climate Change and National Forests

The mission of the NFs has broadened over time, from protecting water and producing timber to managing for multiple resources and now, to sustaining the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations. Increasingly ecosystem management, ecological integrity, resilience, and sustainability have become important concepts and goals of NF management.

The management of NF lands has broadened to include involvement by several other federal agencies, including EPA, the Fish and Wildlife Service, the National Marine Fisheries Service, and the Bureau of Land Management, as well as coordination on management of lands within NFs for national systems such as the Wilderness Preservation System, National Trails, National Monuments, and Wild and Scenic Rivers. The checkerboard ownership patterns of many of the western forests, the scattered private in-holdings of many NFs, and the scattered land parcels of the eastern forests result in the important need to coordinate with other federal and state agencies and with private land owners. Public involvement has increased. This broader level of participation—by the public and other federal and state agencies, as well as the assortment of different management units—is an asset, but also can be a challenge for coordinating and responding to novel situations such as climate change.

One of the challenges to the USFS will be the diversity of climatic changes experienced by NFs. Not only will each NF experience regional and site-specific changes in temperature and precipitation, but the forests are likely to experience changes in frequency, intensity, timing, and locations of extreme weather events such as the occurrence of ice storms; wind events such as derechos, tornados, and hurricanes; and flooding associated with high-intensity rainfall events or with shifts between rain and snow events. Local land management goals differ greatly by NF and grassland, and by management units within NFs (*e.g.*, wilderness, matrix working forests associated with the Northwest Forest Plan, ski areas, campgrounds, etc). Thus, no single approach to adaptation to climate change will fit all NFs. This diversity of climatic changes and impacts will interact with the diversity of stressors, the diversity of ecosystems, and the diversity of management goals across the NFs—in short, responses to climate change will need to reflect local and regional differences in climate, ecosystems, and the social and economic settings.

The NFs have, in many aspects, begun to address many of the challenges of climate variability and change—changes to historic disturbance regimes, historically unprecedented epidemics of native insects, large-scale forest mortality, extreme and unseasonal weather events, spread of non-native invasive species, drought, fuels accumulation, and ecosystem fragmentation. Current management approaches include landscape-scale planning and coordinated agency planning for fire suppression, regional water management, and coordinated agency efforts for invasive species, among others.

Adaptation options for climate-sensitive ecosystems encompass three approaches: no active planning for a changing environment, reaction to a changing disturbance regime, and anticipatory adaptation actions. The rationale for each adaptation approach involves consideration of the costs and benefits associated with the ecological, social, and economic components under the changing climate, the available information on future climatic conditions, and other technical and institutional concerns. In some cases, the choice of no active planning could reflect short-term goals on landscapes where the risk of climate change impacts may be minimal in the short term, for ecosystems with low sensitivity to climate change, where the uncertainty is great (climate variability large, potential impacts low), or where the resources to manage a particular ecosystem service jeopardized by climate change would be better used to manage other ecosystem resources. Responding to a climate-induced changing disturbance (*i.e.*, implementing adaptations after disturbances occur) might be justified in situations where managers determine that adjustments to historical management approaches are needed eventually, but are best made during or after a major climatic or disturbance event. In this instance, adaptive actions are incorporated after the disturbance occurs. The third option involves anticipating and specifically preparing for climate change opportunities and impacts. The choice involves using the best available information about future climate and environmental conditions, and the best available information about the societal context of forest management, to begin making changes to policy and on-the-ground management now, as well as when future windows of opportunity open. Each response may be appropriate in some circumstances and not in others.

3.5.2 Management Response Recommendations

3.5.2.1 Integrate Consideration of Climate Change across All Agency Planning Levels

Adaptation strategies may vary based on the spatial and temporal scales of decision making within the USFS. The integration of climate change and climate change impacts on ecosystem services into policy development and planning across all levels of the agency—USFS strategic goals, Resource Planning Act (RPA) Assessment, NF plans, multi-forest plans, project planning—could facilitate a cohesive identification of opportunities and barriers (institutional, ecological, social). Planning at regional or national scales may involve acceptance of different levels of uncertainty and risk than appropriate at local (*e.g.*, NF or watershed) scales. The current approach responds to the legislative requirement to address climate change analyses within the strategic national level through the RPA Assessment. National analyses associated with RPA offer the opportunity to develop potential approaches to link assessments at the scale of the national level, regional, multi-forest and NF. More quantitative approaches may be available at the national/regional scales, providing strategic guidance for broad consideration of climate change opportunities and impacts to management activities at finer scales.

3.5.2.2 Reframe the Role of Uncertainty in Land Management: Manage for Change

Current ecological conditions of NFs are projected to change under a changing climate, along with social and economic changes. The challenge for the USFS will be to determine which ecosystem services and which attributes and components of biodiversity can be sustained or achieved through management under a changing climate. There will be a need to anticipate and plan for surprise and threshold effects that are at once difficult to predict with certainty yet certain to result from the interaction of climate change and other stressors. Rather than targeting a single desired future condition, avoiding a range of undesirable future conditions may be more effective

There may also be a need to shift focus to managing for change, setting a goal of desired future function (processes, ecosystem services), and managing current and future conditions (structure, outputs), which may be quite dynamic because of a changing climate. Rapid changes that are expected in physical conditions and ecological responses suggest that management goals and approaches will be most successful when they emphasize ecological processes rather than focus on structure and composition. Under a changing climate, embracing uncertainty will necessitate a careful examination of various underlying assumptions about climate, climate change, ecological processes, and disturbances. Specifically, the USFS will need to re-evaluate (1) the dynamics of ecosystems under disturbances influenced by climate; (2) current management options as influenced by climate; and (3) important assumptions and premises about the nature of disturbances (*e.g.*, fire, insect outbreaks, diseases, extreme climate-related events, and the interactions among these disturbances) that influence management philosophy and approaches. Our assumptions about the climate sensitivity of best management practices, genetic diversity guidelines, restoration treatments, and regeneration guidelines may need to be revisited. Opportunities to test these assumptions through management activities and research experiments will be valuable. Current management approaches offer a good platform to reframe these strategies to address uncertain and varying climates and environments of the future.

3.5.2.3 Nurture and Cultivate Human Capital within the Agency

The USFS has a long tradition of attracting and retaining highly qualified employees. The capacity of the agency to address climate change may require the staff within NFs to have a more technical understanding of climate change, as well as building the adaptive capacity of the social and economic environments in which they work. Specifically, the USFS could provide opportunities to develop a better technical understanding of climate and its ecological and socioeconomic impacts, as well as options for adaptation and mitigation in NFs through the many training opportunities that currently exist within the USFS, including the silvicultural certification program, regional integrated resource training workshops, and regional training sessions for resource staff. New opportunities to share training of resource managers with other natural resource agencies could also enhance the ability of the USFS to address climate change in resource management. Additionally, increased awareness and knowledge of climate change could be transferred through the development of managers' guides, climate primers, management toolkits, a Web clearinghouse, and video presentations. Opportunities for managers to share information on the success or failure of different adaptation approaches will be critical.

The skill set necessary to address the challenge of managing natural resources under a changing climate may need to be examined. Staffing in areas such as silviculture, forest genetics and tree breeding, entomology (including taxonomy), and insect control has declined. Access to this knowledge will be critical; the challenge will be how to staff internally, or to develop relationships with experts in other federal or state agencies, universities, or the private sector.

Resource management is challenging in today's environment, and climate change will increase that challenge. Line officers and resource staff are faced with—and will continue to be faced with—the challenge of making decisions in an uncertain environment. Facilitation of a learning environment, where novel approaches to addressing climate change impacts and ecosystem adaptation are supported by the agency, will support USFS employees as they attempt to achieve management goals in the face of climate uncertainty and change. Scientists and managers will sometimes be called upon to sift through apparently conflicting approaches to understanding climate impacts on ecosystems. What may appear as "mistakes" are, in fact, opportunities to learn the technical issues and conditions for assessing and using such approaches.

It may be that NF staff will not be able to keep up with the rapidly changing science. Thus, it is critical to build ongoing relationships between researchers (within and outside the USFS) and the NF staff. An example of such a partnership is the Regional Integrated Sciences and Assessments (RISA) program, which supports research that addresses complex climate-sensitive issues of concern to decision-makers and policy planners at a regional level. The RISA research team members are primarily based at universities, though some of the team members are based at government research facilities, non-profit organizations, or private sector entities. Traditionally the research has focused on the fisheries, water, wildfire, and agriculture sectors.

3.5.2.4 Develop Partnerships to Enhance Natural Resource Management under a Changing Climate

There is an urgent need for policy makers, managers, scientists, stakeholders, and the broader public to share the specific evidence of global climate change and its projected consequences on ecosystems, as well as their understanding of the choices, future opportunities, and risks. The dialogue on adaptation and mitigation might begin with the USFS and current partners. Changes in ecosystems service and biodiversity (*e.g.*, a loss of cold-water fisheries in some areas and the development of warm water fisheries) under a changing climate will likely reveal a need to develop new partnerships.

Education and outreach on the scale necessary will require new funding and educational initiatives. Effective efforts, informed by cutting-edge social science insights on effective communication, will involve diverse suites of educational media, including information delivery on multiple and evolving platforms. There will also be a need to educate landowners in the WUI about the potential for increased disturbances or changing patterns of disturbances in these areas, as well as the challenges of land ownership and protection of valued resources within this environment.

3.5.2.5 Increase Effective Collaboration Across Federally Managed Landscapes

Where federally managed land encompasses large landscapes, increasing collaboration will facilitate the accomplishment of common goals (*e.g.*, the conservation of threatened and endangered species), as well as adaptation and mitigation, that can only be attained on larger connected (or contiguous) landscapes. Common goals might include protection of threatened and endangered species habitats, integrated treatment of fuels or insect and disease conditions that place adjacent ownerships at risk, and developing effective strategies to minimize loss of life and property at the WUI.

While collaboration logically makes sense, and seems conceptually like the only way to manage complex ownerships, large landscapes, and across multiple jurisdictions, there are many challenges to such an approach. Attempting to collaborate multi-institutionally across large landscape scales can bring into focus unexpected institutional barrier and focus unanticipated societal responses. For example, large multi-forest landscapes have high investment stakes—with resulting political pressure from many different directions. Further, if collaboration is taken to mean equal participation and that each collaborator has an effective voice, then potential mismatches among laws, regulations, resources and staffing capacities can lead to situations in which collaboration by different groups is uneven and possibly unsuccessful. For example, the USFS, EPA, and the U.S. Fish and Wildlife Service each must obey its particular governing laws, and thus agency oversight can overrule attempts at equal participation and collaboration. Careful consideration of the challenges and expert facilitation may be necessary to successfully manage adaptation across large landscapes.

3.5.2.6 Establish Priorities for Addressing Potential Changes in Populations, Species, and Community Abundances, Structures, Compositions, and Ranges, Including Potential Species Extirpation and Extinction under Climate Change

A primary premise for adaptive approaches is that change, novelty, uncertainty, and uniqueness of individual situations are expected to define the planning backdrop of the future. Management goals for species and ecosystems across the spectrum of NFs also vary for many reasons. As a result, proactive climate planning will reflect a range of management intensities. Some species and ecosystems (already affected in the near-term) may require aggressive treatment to maintain viability or resilience; others may require reduction of current stressors, and others less intensive management, at least in the near future. While evaluating priorities has always been important in resource management, the magnitude and scope of anticipated needs, combined with diminishing availability of human resources, dictate that priorities may need to be evaluated swiftly, strictly, and definitively. Consideration of methods to establish these priorities before the crisis appears would facilitate decision-making. The medical metaphor of triage is appropriate here. Other approaches include developing strategies that establish options that are “win-win” or “no regrets,” or those that gradually add options as resources and the need for change become apparent. These approaches are best developed jointly by neighboring land resource managers and private land owners, or regionally, to guide the management of currently rare or threatened and endangered species as well as of populations, species, communities, and ecosystems that expand and retreat across the larger landscape. These approaches could capitalize on the respective strengths of the various local, state, and federal land management agencies.

3.5.2.7 Reduce Current Stressors

The USFS implements a variety of management approaches to reduce the impact of existing stressors on NFs (see Section 3.3.3), and an increased emphasis on these efforts represents an important "no regrets" strategy. It is likely that the direct impacts of climate change on ecosystems, and the effects of interactions of climate change with other major stressors, may render NFs increasingly prone to more frequent, extensive, and severe disturbances, especially drought, insect and disease outbreaks, invasive species, and wildfire. Increased flooding is a likely possibility. Air pollution can negatively affect the health and productivity of NFs, and the fragmented landscape in which many NFs are situated impedes important ecosystem processes, including migration. Efforts to address the existing stressors would address current management needs, allow an incremental approach that begins to incorporate climate into management and planning, and potentially reduce the future interactions of these stressors with climate change.

3.5.2.8 Develop Early Detection and Rapid Response Systems for Post-Disturbance Management

Early detection and rapid response systems are a component in the current invasive species strategy of the USFS. Such an approach may have value for a broader suite of climate-induced stressors, for example using the current network of experimental forests and sites in an early detection and response system. Consideration of post-disturbance management for short-term restoration and for long-term restoration under climate change prior to the disturbance (fire, invasives, flooding, hurricanes, ice storms) may identify opportunities and barriers. Large system-resetting disturbances offer the opportunity to influence the future structure and function of ecosystems through carefully designed management experiments in adapting to climatic change. Current limitations (barriers) may need to be revisited so that restricted management practices are permitted.

3.5.3 Research Priorities

3.5.3.1 Conceptual (Research Gaps)

Global climate change will continually alter the dynamics of ecosystems, local climate, disturbances, and management, challenging not only the management options but also the current understanding of these dynamics within the scientific community. To address the long-term challenges, it will be valuable to establish strong management-research partnerships now to collaboratively explore the information and research needed to manage ecosystem services under a changing climate. These research-management partnerships could identify research studies on how forest planning can better adapt to climate change in the long-term, as well as in near-term project-level analyses. Further adaptation approaches could be tested, including improved communication of knowledge and research.

Climate change will interact with current stressors—air quality, native insects and diseases, non-native invasives, and fragmentation—in potentially surprising ways. Greater understanding of the potential interactions of multiple stressors and climate change is needed through field experiments, modeling exercises, and data mining and analysis of past forest history or even recent geological records. Such approaches could promote syntheses of disciplinary research related to climate and other stressors, and integrate the efforts of the research communities at universities, non-governmental organizations, state agencies, tribal organizations, and other federal agencies.

Climate change may also challenge current theories on ecosystem restoration. Current protocols about restoration may need further experimentation to determine the role and assumptions of climate in the current techniques, and how a changing climate might alter the application of these techniques.

Determining the baseline for monitoring, determining what to monitor, and evaluating whether current monitoring approaches will be adequate under a changing climate are critical research needs. These needs may be approached collaboratively with research institutions and other federal land management agencies.

Understanding ecosystem restoration practices—and what metrics to use for monitoring—will raise in importance the need for paleo-ecological research. Little of the current understanding of paleo-ecology is brought into current thinking about the dynamics of species, communities and landscapes. This knowledge, relevant to the present and future, provides a greater understanding of lessons about change, dynamism, thresholds, novelty, reversibility, individualistic responses, and non-analog conditions. Whether to manage for process or structure may be learned from studying past responses to historic climate change. A paleo approach places managers in the stream of change. Thus: what is a baseline? What are native species range distributions? What is natural?

The adaptive capacity of NFs and the surrounding social and economic systems is not well-understood. There is great need for social scientific research into the factors and processes that enhance NFs' adaptive capacity, as well as into the barriers and limits to potentially hinder effective and efficient adaptation. In addition, socioeconomic research and monitoring are needed on how social and economic variables and systems are changing, and are likely to change further, as climate change influences the opportunities and impacts within and surrounding NFs. The expansion of the urban and suburban environment into remote areas will likely be influenced by climate change—potentially shifting this expansion to higher elevations or to more northerly regions where winters may historically not have been as severe. Recreational choices are also likely to be influenced by climate changes, shifting outdoor activities across a spectrum of options from land-based to water-based, from lower/warmer regions to higher/cooler regions.

The need currently exists to develop tradeoff analyses for situations in which management actions taken now potentially could alter more serious impacts later, such as the tradeoffs of planned prescribed fire/air quality versus unplanned wildfire/smoke/air quality. Habitat restoration for threatened and endangered species under a changing climate might involve social, economic, and ecological impacts and opportunities on NF land, adjacent ownerships, or private land. Tradeoffs involve ecological benefits and consequences, as well as social and economic benefits and consequences. Similarly, the tradeoffs between mitigation and adaptation at present cannot be addressed in the available suite of decision-making and management tools.

These research priorities will be most useful to managers if they explicitly incorporate evaluations of uncertainty. Toward that end, new approaches for assessing (or evaluating) uncertainty with quantitative and qualitative management methods are needed.

3.5.3.2 Data Gaps (Monitoring/Mapping)

Information on the status of ecosystem services as climate changes will be important in ascertaining whether management goals are being attained under the changing climate. The Forest Inventory and Analysis data have informed historical analyses of productivity shifts as affected by recent climate variability and change at large spatial scales, and contributed to national accounting analyses of carbon in U.S. forests. Other potential analyses with these inventory data could include exploring the response of ecosystems to changing fire regimes and insect outbreaks. Opportunities exist to link the existing inventory networks within the USFS (Forest Inventory Analysis) with other existing and planned networks, such as the National Science Foundation’s Long-term Ecological Research networks, the National Ecological Observation Network (NEON), and other monitoring programs within USGS and NASA. Increasingly, data are needed in a spatial format.

The Montreal Process Criteria and Indicators for Boreal and Temperate Forests have been used to describe sustainability of forests and rangelands by managers at several spatial scales. The use of Montreal Process Criteria and Indicators may also have value in assessing the opportunities and impacts on sustainability under a changing climate.

3.5.3.3 Tool Gaps (Models and Decision Support Tools)

There is a need to develop techniques, methods, and information to assess the consequences of climate change and variability on physical, biological, and socioeconomic systems at varying spatial scales, including regional, multi-forest, and NF scales. The analyses at the national scale in the RPA Assessment, particularly if extended beyond forest dynamics, could provide national-level information and set a larger context for the forest opportunities and impacts under climate change. Fine-scale analyses of the ecological and economic impacts of climate change will soon be available and could offer projections at the spatial scale of importance to managers.

There is a need to develop a toolbox for resource managers that can be used to quantify effects of climate change on natural resources, as a component of land management planning. This toolbox would have a suite of science-based products that deliver state-of-the-art information derived from data, qualitative models, and quantitative models in accessible formats, including a Web-based portal on climate-change science. Technology transfer through training packages on climate change that can be delivered through workshops and online tutorials would be valuable to internal staff and potentially to stakeholders.

Forest-scale decision support applications that incorporate the dynamics of climate, climate variability, and climate change into natural resource management planning would enhance the information about climate used in management analyses. At present, most established planning and operational tools do not directly incorporate climate variability and change. These tools need to be informed by recent scientific data on climate trends and the relationship between climate and the resource of interest. Research can contribute immediately to the revision of popular tools such as the Forest Vegetation Simulator, thereby improving their accuracy for a variety of applications. A Web-based portal on climate change, customized for the needs of USFS users, will be an important component of the toolbox, providing one-stop shopping for scientific information, key publications, and climate-smart models. A training curriculum and tutorials will ensure that Forest Service managers receive current, consistent information on climate change issues.

It can not be overstated however, that effective decision support involves more than providing the right information and tools and the right time. Importantly, for climate change information to meet the needs of NF land managers at various scales of decision-making, and for that information to be used properly and effectively, it is highly advisable that ongoing relationships be built between those producing the relevant information (researchers) and those eventually using it (managers). Thus tools, Web-based tutorials, reports, and other written materials should always be viewed as decision-support products that must be embedded in an ongoing decision-support process.

3.5.3.4 Management Adjustments or Realignments

The development of management alternatives for adapting to and mitigating the effects of an uncertain and variable climate, and other stressors on natural resource outputs and ecosystem services, will require experimentation under the changing climate. Many proposed management alternatives may need to be established as small-scale pilot efforts, to determine the efficacy of such proactive approaches to adapting to climate change in various ecosystems and climates. Protocols for “assisted migration” of species need to be tested and established before approaches are implemented more broadly.

Assumptions about the dynamics of ecosystems under climate change and alternative treatments may need to be revisited in field experiments. Regeneration and seedling establishment studies using a variety of vegetation management treatments under the changing climate may suggest that new approaches are needed to ensure ecosystem establishment and restoration.

New or innovative management options may need experiments or demonstration projects to explore their impact. For example, research is needed to increase our understanding of the impacts of active management on ecosystems—such as the effects of reintroducing species to disturbed ecosystems, or transferring species to areas outside of the current distribution but within areas of compatible climate. The potential for *ex situ* gene conservation techniques to remedy the impact of global change might be explored. These techniques (seed banks, common garden studies) conserve genetic diversity outside the environment where it exists at this time. Putting seed from diverse parents in diverse populations into long term storage will not prevent existing forest ecosystems from being disrupted, but it provides an opportunity to reestablish populations in new and more appropriate locations if needed. Establishing common garden studies with diverse materials at multiple locations can serve several purposes. Assuming the material planted in these plots survives, it can serve as a source of propagules for establishing new populations. The tests can also provide evidence of what sources of plant material are most adapted for the new conditions.

Research is needed to explore options to reduce both the short- and long-term vulnerability of ecosystems to disturbance altered by climate (insects, fire, disease, etc.). Many natural resource values can be enhanced by allowing fire to play its natural role where private property and social values can be protected. Research on new opportunities for ecosystem services within NFs is needed. Testing and developing a range of science-based management alternatives for adapting to and mitigating the effects of climate change on major resource values (water, vegetation, wildlife, recreation, etc.) may facilitate the attainment of these goals under a changing climate.

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3.8 Boxes

Box 3.1. Strategic Plan Goals of the Forest Service, 2007–2012

1. Restore, Sustain, and Enhance the Nation’s Forests and Grasslands.
2. Provide and Sustain Benefits to the American People.
3. Conserve Open Space.
4. Sustain and Enhance Outdoor Recreation Opportunities.
5. Maintain Basic Management Capabilities of the Forest Service.
6. Engage Urban America with Forest Service Programs.
7. Provide Science-Based Applications and Tools for Sustainable Natural Resources Management.

Box 3.2. Ecosystem Services Described by the Millennium Ecosystem Assessment (2005)

Provisioning services—fiber, fuel, food, other non-wood products, fresh water, and genetic resources

Regulating services—air quality, climate regulation, water regulation, erosion regulation, water purification and waste treatment, disease regulation, pest regulation, pollination, and natural hazard regulation

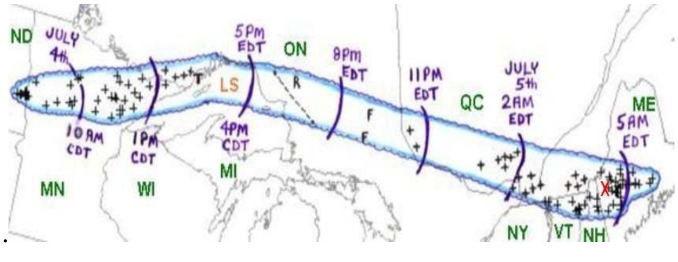
Cultural services—cultural diversity, spiritual/religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, recreation and ecotourism

Supporting services—primary production, soil formation, pollination, nutrient cycling, water cycling

Box 3.3. The “Boundary Waters-Canadian Derecho,” a Straight-Line Wind Event in the Central United States and Canada

During the pre-dawn hours on Sunday, July 4, 1999, thunderstorms were occurring over portions of the Dakotas. By 6 AM CDT, some of the storms formed into a bow echo and began moving into the Fargo, North Dakota area, with damaging winds. Thus would begin the “Boundary Waters-Canadian Derecho,” which would last for more than 22 hours, travel more than 2,080 kilometers at an average speed almost 96 kph, and result in widespread devastation and many casualties in both Canada and the United States

In the Boundary Waters Canoe Area (BWCA), winds estimated at 128-160 kph moved rapidly, causing serious damage to 1560 square kilometers of forest in the area. Tens of millions of trees were blown down. Sixty people in the BWCA were injured by falling trees, some seriously. Twenty of those injured were rescued by floatplanes flying to lakes within the forest.



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Area affected by the July 4–5, 1999 derecho event (outlined in blue). Curved purple lines represent the approximate locations of the “gust front” at three hourly intervals. “+” symbols indicate the locations of wind damage or estimated wind gusts above severe limits (58 mph or greater)[30].

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[30] **NOAA's National Weather Service**, 2007: The boundary waters-canadian derechos. NOAA Website, http://www.spc.noaa.gov/misc/AbtDerechos/casepages/jul4-51999page.htm, accessed on 7-30-2007.

Box 3.4. Insects and Drought in Piñon-Juniper Woodlands in the Southwest United States

Between 2002 and 2003, the southwestern United States experienced a sub-continental scale dieback of piñon pines (*Pinus edulis)*, Ponderosa pines (*P. ponderosa*), and juniper (*Juniperus monosperma*), the dominant tree species in the region (Breshears *et al.*, 2005). Piñon pines were hit hardest, and suffered 40–80% mortality across an area spanning 12,000 km^2 of Colorado, Utah, Arizona, and New Mexico. Beetles (*Ips confuses* LeConte) were the proximate cause of death of the piñons, but the beetle infestation was triggered by a major "global-change type drought" that depleted soil water content for at least 15 months (Breshears *et al.*, 2005). Although a major drought occurred in the same region in the 1950s, mortality was less extensive—mostly Ponderosa pine stems older than 100 years and on the driest sites died (Allen and Breshears, 1998). In contrast, the more recent drought killed piñons across all size classes and elevations. It also killed 2–26% of the more drought-tolerant junipers, and reduced by about half the live basal cover of *Boutelua gracilis*, a dominant grass in the piñon-juniper woodlands (Breshears *et al.*, 2005). The more recent drought also was characterized by warmer temperatures, which increased the water stress on the trees. This increased water stress was probably exacerbated by the increased densities of piñons that resulted from anomalously high precipitation in the region from about 1978–1995 (Breshears *et al.*, 2005).

The scale of this dieback will greatly affect carbon stores and dynamics, runoff and erosion, and other ecosystem processes, and may also lead to an ecosystem type conversion (Breshears *et al.*, 2005). The possibility that vegetation diebacks at the scale observed in this example may become more common under climate change presents a major management challenge.

These photos—taken from similar vantages near Los Alamos, NM—show the large-scale dieback of piñon pines in 2002–2003 that resulted from a protracted drought and associated beetle infestation. In 2002, the pines had already turned brown from water stress, and by 2004, they had lost all their needles.

Photo credit: CD Allen, USGS

Box 3.5. Bark Beetles in Western North American Forests

Bark beetles are native insects and important disturbance agents in western North American forests (Carroll *et al.*, 2004). Beetle outbreaks occur periodically when otherwise healthy trees are weakened from drought, injury, fire damage, and other stresses. Since 1996, bark beetles have infested and killed millions of pine, spruce, and fir trees over vast areas from Arizona to British Columbia. This outbreak, which is considered to be more extensive and damaging than any previously recorded in the West, is expected to continue without active management.[31]

The most "aggressive, persistent, and destructive bark beetle in the United States and western Canada" is the mountain pine beetle (*Dendroctonus ponderosae* Hopkins),[32] which will attack and kill most western pine species. The mountain pine beetle (MPB) infested 425,000 acres of Colorado's lodgepole pine (LP) forests in 2005 (Colorado Department of Natural Resources, 2005) and 660,000 acres (~40% of Colorado's LP forests) by 2006. The unprecedented scale of this outbreak in Colorado is attributable to a combination of factors, including large areas with even-age, monospecific stands (a result of fire suppression and other management practices), drought, and climate change (Colorado State Forest Service cited in Paulson, 2007).

Warmer winters have spurred extensive mountain pine beetle damage in the U.S. and Canadian Rockies. Left from Fox (2007); photo below is reprinted with permission from Colorado State University Extension, fact sheet no. 5.528, Mountain Pine Beetle, by D.A. Leatherman. and I. Aguayo.

[33]

Despite the historic scale of the recent MPB outbreak in Colorado's lodgepole pine forests, periodic outbreaks, albeit on a smaller spatial scale, are considered normative (Logan and Powell, 2001). Lodgepole pine and MPB are co-evolved, and lodgepole pine is the MPB's most important host (Logan and Powell, 2001). Lodgepole pine has serotinous cones and is maintained by stand replacing fires that are facilitated by MPB-induced mortality. Dead needles from outbreaks are an important fuel, standing dead trees serve as fire ladders, and falling limbs and stems provide high fuel loads for high-intensity crown fires. Without such fires, more shade-tolerant species would eventually replace lodgepole pine in much of its range (Logan and Powell, 2001).

Other western pines, especially those growing at higher elevations such as whitebark pine, are not similarly co-evolved with MPB. Until recently, high elevation and high latitude habitats typically have been too harsh for MPB to complete its life cycle in one season. Because the ability to complete its life cycle in one season is central to the MPB's success (Amman, 1973),[34] MPB activity has historically been restricted to lower elevation pines, which are separated from high-elevation (3,000 m or 10,000 ft in Colorado) pines by non-host species.

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[31] **Western Forestry Leadership Coalition**, 2007: Western bark beetle assessment: a framework for cooperative forest stewardship. Western Forestry Leadership Coalition Website, http://www.wflccenter.org/news_pdf/222_pdf.pdf, accessed on 7-31-2007.

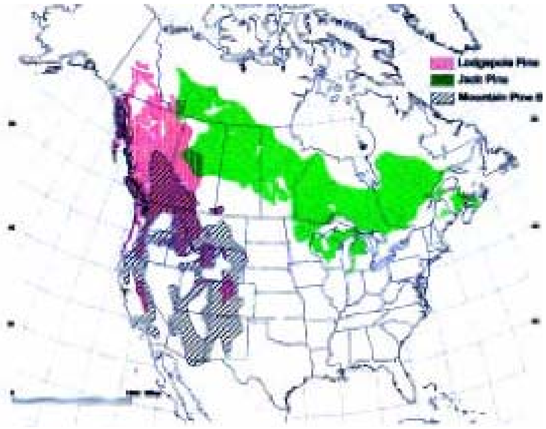
[32] **The Bugwood Network**, 2007: Mountain Pine Beetle - Dendroctonus ponderosae (Hopkins). Bark and Boring Beetles of the World Website, http://www.barkbeetles.org/mountain/mpb.html, accessed on 7-30-2007.

[33] **Leatherman**, D.A. and I. Aguayo, 2007: Mountain Pine Beetle. Colorado State University Extension Website, http://www.ext.colostate.edu/pubs/insect/05528.html, accessed on 7-31-0007.

[34] See also **Safranyik**, L., 1978: Effects of climate and weather on mountain pine beetle populations. In: *Proceedings, Symposium: Theory and Practice of Mountain Pine Beetle Management in Lodgepole Pine Forests* [Berryman, A.A., G.D. Amman, and R.W. Stark (eds.)]University of Idaho Forest, Wildlife and Range Experiment Station, pp. 77-84.

Climate change will not only spur further MPB outbreaks, but will also likely facilitate the invasion of species currently restricted to more benign environments into whitebark pine and other high-elevation pine stands in the wake of MPB infestations (Logan and Powell, 2001). The fact that all aspects of the MPB’s seasonality are controlled by seasonal temperature patterns (Logan and Bentz, 1999) supports this forecast. It is further supported by the finding that both the timing and synchrony of the beetle’s life cycle are responsive to climate change (Logan and Powell, 2001). Specifically, Logan and Powell (2001) showed that a 2°C increase in annual average temperature allows MPB populations to synchronously complete their life cycle in a single season. Such a shift from a two season, asynchronous life cycle confers the greatest chance for population success. Because the response of the MPB’s life cycle to temperature is nonlinear, climate change-induced MPB outbreaks are likely to occur in high elevation pine ecosystems without warning.

In addition to creating ideal conditions for populations of MPB to reach epidemic levels, climate change has allowed the MPB to expand its range northward and eastward in recent decades (Carroll *et al.*, 2004). The current MPB range extends from northern Mexico through the American Rockies west and into British Columbia, Alberta, and Saskatchewan (Carroll *et al.*, 2004). The range of the MPB is constrained principally by climate rather than the availability of suitable hosts; lodgepole pine exists beyond the range of MPB (Logan and Powell, 2001; Carroll *et al.*, 2004). Evidence for the range expansion of MPB includes accelerating rates of infestation since 1970 into previously unsuitable habitats. Further range expansion is likely with additional warming (Carroll *et al.*, 2004). Logan and Powell (2001) predict a 7° northward shift in the range of MPB with a doubling of CO_2 and an associated temperature increase of 2.5°C. Such a shift would allow MPB to occupy previously unoccupied lodgepole pine habitat, and allow an invasion into jack pine ecosystems in both the United States and Canada, which have not been previously attacked by MPB (see map at right). The continuous habitat provided by lodgepole pine will facilitate this range shift. Although cold snaps and depletion of hosts caused previous large-scale MPB outbreaks to collapse, the current outbreak may not collapse because there is no shortage of host trees, and temperatures are expected to continue warming (Carroll *et al.*, 2004).



Geographic ranges of lodgepole pine (pink), mountain pine beetle (hatched), and jack pine (green). Source Logan and Powell (2001).

Box 3.6. Forest Planning Assumptions to Consider Regarding Climate Change.[25]

Historic Conditions: We assume that historical conditions are a useful reference or point of comparison for current or future trends, in accord with the Healthy Forest Restoration Act, the 2005 planning rule, and LANDFIRE (and other national fire-related projects). However, we recognize that this assumption is likely to face substantial challenges as the effects of climate change on vegetation and disturbance regimes play out over the next several decades. Accordingly, an adaptive management approach can be used to test this assumption, make adjustments in the desired future condition, and plan goals and objectives as the local effects of climate change become apparent.

Flexibility and Considerations: Although climate and ecosystem forecast models have improved significantly, they cannot produce highly accurate local projections. Flexibility to address the inherent uncertainty about local effects of climate change could be achieved through enhancing the resiliency of forests by considering that:

- Diverse plantings will likely be more adaptable to changing conditions than will single species stands.
- Prescribed fire and thinning could be used to keep tree densities low to improve resistance to drought and pest infestations.
- Nitrogen-fixing species, intermixed in a stand, may facilitate regrowth after disturbance in a rapidly changing environment, although they may compete for water on droughty sites.
- Encouraging local industries that can adapt to or cope with variable kinds of forest products because of the uncertainty in which tree species will prosper under changed climate.
- Some vegetation types in vulnerable environments (*e.g.*, ecotonal, narrow distribution, reliant on specific climate combinations, situations sensitive to insect/pathogens) will be highly sensitive to changes in climate and may undergo type conversions despite attempts at maintaining them (meadow to forest, treeline shifts, wetland loss). Some of these changes are likely to be inevitable.
- Reforestation after wildfire may require different species (*i.e.*, diverse plantings, as mentioned above) than were present on the site pre-fire to better match site-type changes due to climate effects.
- Genetic diversity of planting stock may require different mixes than traditionally prescribed by seed zone guidelines.
- Massive forest diebacks may be clues to site transition issues.
- Behavior of invasive species is likely to be different as climates shift.
- Increasing interannual climate variability (*e.g.*, dry periods followed by wet, as in alternating ENSO patterns) may set up increasingly severe fuels situations.
- Non-linear, non-equilibrium, abrupt changes in vegetation types and wildlife behavior may be more likely than linear, equilibrium, and gradual changes.
- Water supply and water quality issues might become critical, particularly if increased or prolonged drought or water quality changes are the local consequences of climate change.
- Carbon storage to reduce greenhouse gas and other effects might be important.

Adaptive Management: Effects due to climate change (*e.g.*, wildfire severity/acreage trends, vegetation trends, insect and disease trends) may become more apparent as new information becomes available to NFs through regional or sub-regional inventories, data collection, and research. This information may be useful for adjusting desired conditions and guidelines as plans are implemented. Information of interest might include:

- The frequency, severity, and area trends of wildfire and insect/disease disturbances, stratified by environment
- The distribution of major forest types. For example, the lower and upper elevational limits of forests and woodlands might change as precipitation, temperature, and other factors change. These trends might be detected through a combination of permanent plots (*e.g.*, Forest Inventory and Analysis plots) and remotely sensed vegetation data (*e.g.*, gradient nearest neighbor analyses).
- Stream flow and other indicators of the forests' ability to produce water of particular quality and quantity.

Box 3.7. National Forest Adaptation Options

- Facilitate natural (evolutionary) adaptation through management practices (e.g., prescribed fire and other silvicultural treatments) that shorten regeneration times and promote interspecific competition.
- Promote connected landscapes to facilitate species movements and gene flow, sustain key ecosystem processes (e.g., pollination and dispersal), and protect critical habitats for threatened and endangered species.
- Reduce the impact of current anthropogenic stressors such as fragmentation (e.g., by creating larger management units and migration corridors) and uncharacteristically severe wildfires and insect outbreaks (e.g., by reducing stand densities and abating fuels).
- Identify and take early proactive action against non-native invasive species (e.g., by using early detection and rapid response approaches).
- Modify genetic diversity guidelines to increase the range of species, maintain high effective population sizes, and favor genotypes known for broad tolerance ranges.
- Where ecosystems will very likely become more water limited, manage for drought- and heat-tolerant species and populations, and where climate trends are less certain, manage for a variety of species and genotypes with a range of tolerances to low soil moisture and higher temperatures.
- Spread risks by increasing ecosystem redundancy and buffers in both natural environments and plantations.
- Use the paleological record and historical ecological studies to revise and update restoration goals so that selected species will be tolerant of anticipated climate.
- Where appropriate after large-scale disturbances, reset succession and manage for asynchrony at the landscape scale by promoting diverse age classes and species mixes, a variety of successional stages, and spatially complex and heterogeneous vegetation structure.
- Use the paleological record and historical ecological studies to identify environments buffered against climate change, which would be good candidates for long-term conservation.
- Establish or strengthen long-term seed banks to create the option of re-establishing extirpated populations in new/more appropriate locations.

Box 3.8. Examples of institutional and planning adaptations to improve the readiness of the USFS to cope with climate change

- Rapidly assess existing USFS forest plans to determine the level of preparedness to climate change, examine underlying assumptions about climate, suggest improvements, and forge a long-term management-science partnership to continually refine information for resource management decisions.

- Anticipate and plan for more extreme events (*e.g.*, incorporate likelihood of more severe fire weather and lengthened wildfire seasons in long-range fire management plans) that may lead to surprises and threshold responses and remove (if possible) future constraints to timely adaptive responses.

- Use climate and ecological models to organize thinking and understand potential changes in ecosystem processes, as well as the likely direction and magnitude of future climate trends and impacts, to explore adaptation options for climate change.

- Adjust management goals based on updated baseline conditions for species and ecosystems that have been significantly/cumulatively disturbed and are far outside of the historical range of variation.

- Use the federally mandated Resource Planning Assessment process to link assessments at the national, regional, and NF scales, and to provide guidance on assessing climate change impacts, uncertainty, vulnerability, and adaptation options.

- Coordinate with other agencies, as well as the private sector and other stakeholders, to reduce pollution and other landscape-scale anthropogenic stressors.

3.9 Case Study Summaries

The summaries below provide overviews of the case studies prepared for this chapter. The case studies are available in Annex A1.

Case Study Summary 3.1

Tahoe National Forest, California

Pacific Southwest United States

Why this case study was chosen

The Tahoe National Forest:

- Is representative of the 18 national forests on the west slope of the Sierra Nevada range, which have great ecological value and a complex institutional context;
- Shares common geology, forest ecosystems, wildlife habitat, climate, snowpack characteristics, hydrological properties, elevation gradients, diversity of stakeholders, institutional contexts, recreational issues, and resource issues and conflicts with 18 other national forests on the west slope of the Sierra Nevada range;
- Can serve as a model for examining climate change impacts and adaptations for application across the entire Sierra Nevada.

Management context

The principal mission of the Tahoe National Forest (TNF) is to “serve as the public’s steward of the land, and to manage the forest’s resources for the benefit of all American people …[and]…to provide for the needs of both current and future generations.” The 1990 Tahoe National Forest Land and Resource Management Plan (TNF LRMP) details specific goals, objectives, desired future conditions, standards, and guidelines for a variety of resources including recreation, wilderness, wildlife, timber, water, air quality, minerals, and research.

The Sierra Nevada Forest Plan Amendment (FPA; USFS, 2004) and the Herger-Feinstein Quincy Library Group Forest Recovery Act (US Congress, 1998) provide additional specific direction for the TNF. The FPA is a multi-forest plan that specifies goals and direction for (1) reducing buildup of woody fuels and minimizing fire risk, and (2) protecting old forests, wildlife habitats, watersheds, and communities on the national forests of the Sierra Nevada and Modoc Plateau. Forest practices, riparian management, and treatments to reduce the likelihood of severe fires specified in the FPA replace sections of the TNF LRMP. Adaptive management is a key component of the FPA, and the TNF plays a central role in the Sierra Nevada Adaptive Management Program.

The Herger-Feinstein Quincy Library Group Forest Recovery Act of 1998 also supersedes the TNF LRMP for specific resource and geographic areas in the Sierra Nevada, including the Sierraville Ranger District of the TNF. The Act was derived from an agreement by a broad coalition of local stakeholders to promote ecologic and economic health for selected federal lands and communities in the northern Sierra Nevada. The Act launched a pilot project to test a new adaptive management strategy for managing sensitive species as well as fire and woody fuels. In addition to implementing a riparian restoration program, the emphasis of the pilot project is to test, assess, and demonstrate the effectiveness of fuel-breaks, group selection, individual tree selection, and avoidance or protection of specified areas for managing sensitive species and wildfire.

Key climate change impacts

Projected increase of 2.3–5.8°C in annual temperatures by 2100;

- Projected decline in annual snowpack (97% at 1,000 m elevation and 89% for all elevations) by 2100;
- Observed increase in interannual and annual variability of precipitation;
- Observed increase in intensity of periodic multi-year droughts over the past century;

- Observed increase in large fire events in recent years;
- Projected increase in length of fire seasons and risk of uncharacteristically severe and widespread fire events;
- Expected increase in water temperatures in rivers and lakes and decrease in snow, water, and stream runoff in the warm season;
- Observed increase in severity of higher-elevation insect and disease outbreaks.

Opportunities for adaptation

- Science-based rapid assessments of existing plans and policies would be a valuable first step toward understanding current levels of climate change preparedness and areas for potential improvements in operations.
- A revision of the comprehensive assessment of the Sierra Nevada Forest Plan Amendment could be pursued as an opportunity to integrate climate change considerations into management planning.
- The TNF could be a valuable addition to the U.S. Forest Service Ecosystem Services program as a pilot study.
- Increasing the sizes of management units for the forest would allow management of whole landscapes (watersheds, forest types) in a single resource plan, and may decrease administrative fragmentation.
- Actions to improve infiltration of water to groundwater reservoirs (such as decreasing road densities and modifying grazing practices to change surfaces from impervious to permeable) could be used to reduce losses from runoff and increase the quantity of stored groundwater for dry periods.
- Erosion and sediment loss following disturbances could be addressed by promptly reforesting affected areas and salvage-harvesting affected trees (where this activity will not cause further damage), so that a new forest canopy can be established before shrubs “capture” the site;
- A focus on reversing post-disturbance mortality and shrub invasion would increase the chances of successful forest regeneration, leading to restoration of key wildlife habitat and critical watershed protection functions.
- Fuel treatments could be implemented far beyond the season in which they have historically been employed, by further supporting and extending the seasonal tour of fire and fuels staff.
- TNF managers and staff have the expertise and are already prepared to seize adaptive opportunities that would be enabled by a regional biomass and biofuels industry, should a carbon market or regulatory environment develop to support these opportunities.
- Regular planning cycles afford a chance to build flexibility and responsiveness to climate change into management policies.
- “Climate-smart” capacity could be increased, when possible, through staff additions or staff training.
- Education and outreach activities can be used to increase awareness among policy makers, managers, the local public, and other stakeholders about the scientific bases for climate change, the implications for the northern Sierra Nevada and the TNF, and the need for active resource management

Conclusions

In many cases, best management practices (*e.g.*, post-disturbance treatments) may be effective climate change adaptation strategies even though they may be intended to achieve other goals (*e.g.*, maintain ecosystem health). This creates an opportunity for “win-win” strategies to be implemented, whereby benefits would accrue even if the climate did not change.

Barriers to adaptation include public opposition, insufficient funding, limited staff capacity, current large scope of on-the-ground needs, disjointed ownership patterns, and existing environmental legislation. Some barriers result from the interaction of individual barriers, such as when limited staff capacity and insufficient funding result in a continuous reactive approach to priority-setting, rather than a long-term planning process. Changing community demographics influence what landowners adjacent to the TNF accept in terms of ecosystem management, such as smoke from prescribed fires.

Opportunities exist for overcoming barriers to adaptation. Current or potential future opportunities include the possibility of year-round management for reducing woody fuels, active dialog with the public on adaptive management projects, the use of demonstration projects to respond to public concerns, and the potential of emerging carbon markets to promote the development of regional biomass and biofuels industries. Examples of promising areas for development include new management strategies that are operationally appropriate and practical to address climate change, scientifically supported practices for integrated management where resource management goals are integrated rather than partitioned into individual plans, prioritization tools for managing a range of species and diverse ecosystems, and dynamic landscape and project planning that incorporates probabilistic measures of habitat quality and availability in a temporal and spatial context.

Case Study Summary 3.2

Olympic National Forest, Washington

Pacific Northwest United States

Why this case study was chosen

The Olympic National Forest:

- Is located within a geographic mosaic of lands managed by federal and state agencies, tribal groups, and private land owners;
- Supports a diverse set of ecosystem services, including recreation, timber, water supply to municipal watersheds, pristine air quality, and abundant fish and wildlife—including several endemic species of plants and animals, as well as critical habitat for four threatened species of birds and anadromous fish;
- Is considered an urban forest because of its proximity to the cities of the greater Seattle area;
- Has numerous stakeholders and land management mandates associated with its natural and cultural resources.

Management context

The Olympic National Forest (ONF) is a “restoration forest” charged with managing large contiguous areas of second-growth forest. Natural resource objectives include managing for native biodiversity and promoting the development of late-successional forests; restoring and protecting aquatic ecosystems from the impacts of an aging road infrastructure; and managing for individual threatened and endangered species as defined by the Endangered Species Act or other policies related to the protection of rare species. Most management focuses on restoring old-growth forests, pristine waterways, and other important habitats; rehabilitating or restoring areas affected by unmaintained logging roads; invasive species control; and monitoring. Because the Northwest Forest Plan dictates that the ONF collaborate with other agencies, it will be important to reach consensus so that differing agency mandates, requirements, and strategies do not hinder adaptation to climate change.

Key climate change impacts

- Observed increase of 1.0°C in annual temperatures since 1920, with most warming in winters and since 1950;
- Observed decrease (30–60%) in spring snowpack, especially at lower elevations since 1950;
- Observed one-to-four-week advance in spring runoff in 2000 versus 1948;
- Projected increase in temperatures of 1.2–5.5°C by 2090, with greatest increases in summer;
- Projected decrease in snowpack, shifts in snowmelt and runoff timing, and increases in summer evapotranspiration;
- Expected negative consequences of higher temperatures and lower summer flows for resident fish species;
- Expected forest growth decrease at lower elevations and increase at higher elevations;
- Expected increase in floods and area burned by fire;
- Expected shift in species distribution and abundance.

Opportunities for adaptation

- The priorities for the ONF already emphasize management for landscape and biological diversity, and actions expected to be the most effective in this regard could be further promoted now as an important first step toward adaptation to climate change.
- The ONF’s strategic plan leaves enough flexibility so that it can take immediate steps to incorporate climate change science into management actions and to enhance resilience to climate change, while at the same time fostering scientific research to support these actions.
- The early successional forests predominating in the ONF as a result of past timber management offer an opportunity to adapt to climate change with carefully considered management actions, because these early successional stages are most easily influenced.

- The ONF's experience collaborating with other agencies and organizations could be leveraged to develop innovative climate change adaptations that benefit multiple stakeholders; continued cooperation with existing and new partners in adapting to climate change will improve the likelihood of success by increasing the overall land base and resources.
- By anticipating future impacts of climatic change on forest ecosystems, revised forest plans can become an evolving set of guidelines for forest managers.
- Coordinated revision of forest plans for the Olympic, Mt. Baker-Snoqualmie, and Gifford Pinchot National Forests offers an opportunity to develop regional-scale adaptations for similar ecosystems that are subject to similar stressors.

Conclusions

The management priorities for the ONF could facilitate managers' efforts to adapt to climate change and promote resilience to its impacts, but adaptive capacity is limited by the current allocation of scarce resources, policy environment, and lack of scientific information on the effects of climate change and the likely outcomes of adaptations. Increased support for adaptation, specific guidance on climate change impacts and adaptations for managers, and incorporating climate change explicitly into forest policies and planning at multiple scales are some of the ways these barriers can be overcome. In addition, the availability of regional climate and forest-climate research—and especially a proactive management-science partnership—set the stage for increases in adaptive capacity.

In the absence of more specific scientific guidance on how to adapt to climate change, and without new funding and additional staff, the ONF will likely manage for climate change by continuing to manage for biodiversity, which is a reasonable approach assuming that prioritizing landscape and biological diversity will confer adequate resilience to climate change over the long term. An adaptation strategy with more specific guidance could include a vision of what is needed; removal of as many barriers as possible; increased collaboration among agencies, managers, and scientists at multiple scales; and implementation of proven management actions (*e.g.*, early detection/rapid response).

Case Study Summary 3.3

Uwharrie National Forest, North Carolina

Southeast United States

Why this case study was chosen

The Uwharrie National Forest:

- Consists of 61 separate parcels, intermingled within private land;
- Supports a wide variety of ecosystem services, including one of the greatest concentrations of archeological sites in the Southeast;
- Is currently seeing an increased demand for recreational opportunities associated with camping, hiking, fishing, boating, and hunting;
- Expects the regional changes in land use and population to amplify the challenges already faced by forest managers;
- Is in the process of incorporating climate change considerations into a revised forest plan.

Management context

The Uwharrie National Forest (UNF) consists of 61 separate fragments that provide key ecosystem services—recreation, fresh water, wildlife habitat, and wood products—to millions of people because of the UNF's close proximity to several major cities. This combination of fragmentation and high demand for goods and services already poses unique forest management challenges, which are expected to become more difficult as the regional population increases over the next 40 years. For example, climate change is expected to significantly affect regional water reserves, including Badin Lake, one of the largest water bodies in the region. Much of the area had been converted from drought and fire-resistant tree species to faster growing but less resistant tree species over the past 60 years. Conversion back to original vegetation is now under consideration in response to climate change.

Key climate change impacts

- Projected increase in wildfire risk and concerns about sustaining forest productivity;
- Projected increase in water shortages as biological and anthropogenic demand increases and supply decreases;
- Expected increase in soil erosion and stream sedimentation due to projected increase in frequency of intense storms;
- Projected increase in insect outbreaks due to longer growing season and drier forest conditions.

Opportunities for adaptation

- Re-establishment of more fire- and drought-tolerant longleaf pine through selective forest management and replanting could provide increased resistance to potential future drought and unusually severe wildlife events.
- Restoration of historical sites of longleaf pine savannas on the UNF through logging or controlled burning would result in reduced forest water use, water stress, wildfire fuel loads, and wildfire risk as the region continues to warm;
- Opportunities to relocate trails farther from streams, and thus increase the size of stream buffer zones, could minimize soil erosion and stream sedimentation under conditions of increasing storm intensity;
- Opportunities to engage in a dialogue with surrounding landowners on wildfire management might encourage clearing and removal of fuels around buildings and dwellings, and thus minimize risks to property and lives from the expected increase in wildfires within the landscape mosaic containing the UNF and these landowners.

Conclusions

Even without climate change, management of the UNF is a complex task. Continued increases in population and fragmentation of the landscape will only be compounded by climatic change and variability. While an extensive and well-maintained road network across the forest provides excellent access for wildfire suppression, and the patchy nature of the forest also helps to isolate fires, ecosystem services on the UNF are influenced by activities on the surrounding highly fragmented landscape. The forest’s proximity to population centers increases the UNF’s visibility and raises the public’s awareness of the need for management action to mitigate negative impacts. The UNF could serve as a valuable example for other land managers on how forests can be managed to reduce climate change impacts through the modification of established forest management strategies and tools.

3.10 Figures

Figure 3.1. Timeline of National Forest System formation and the legislative influences on the mission of the national forests.

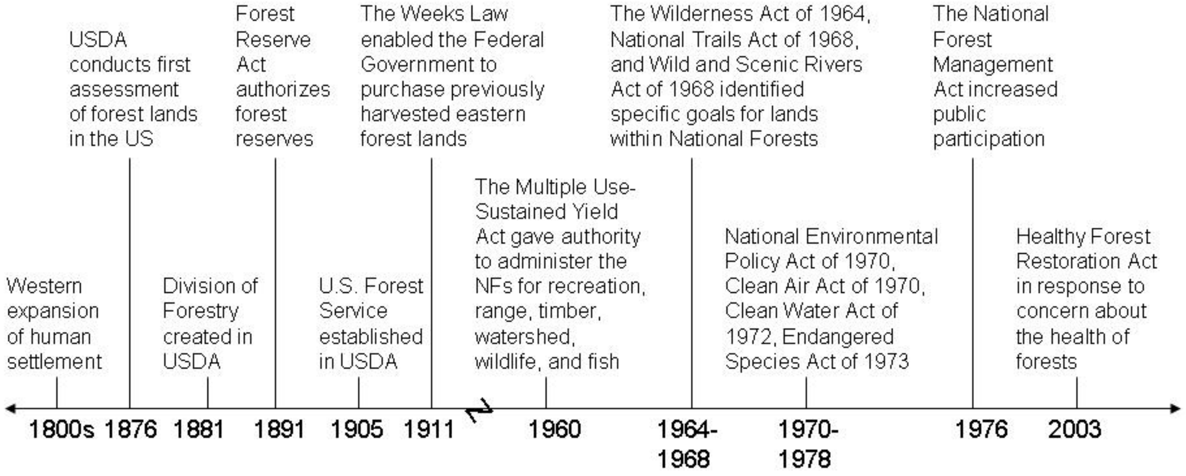
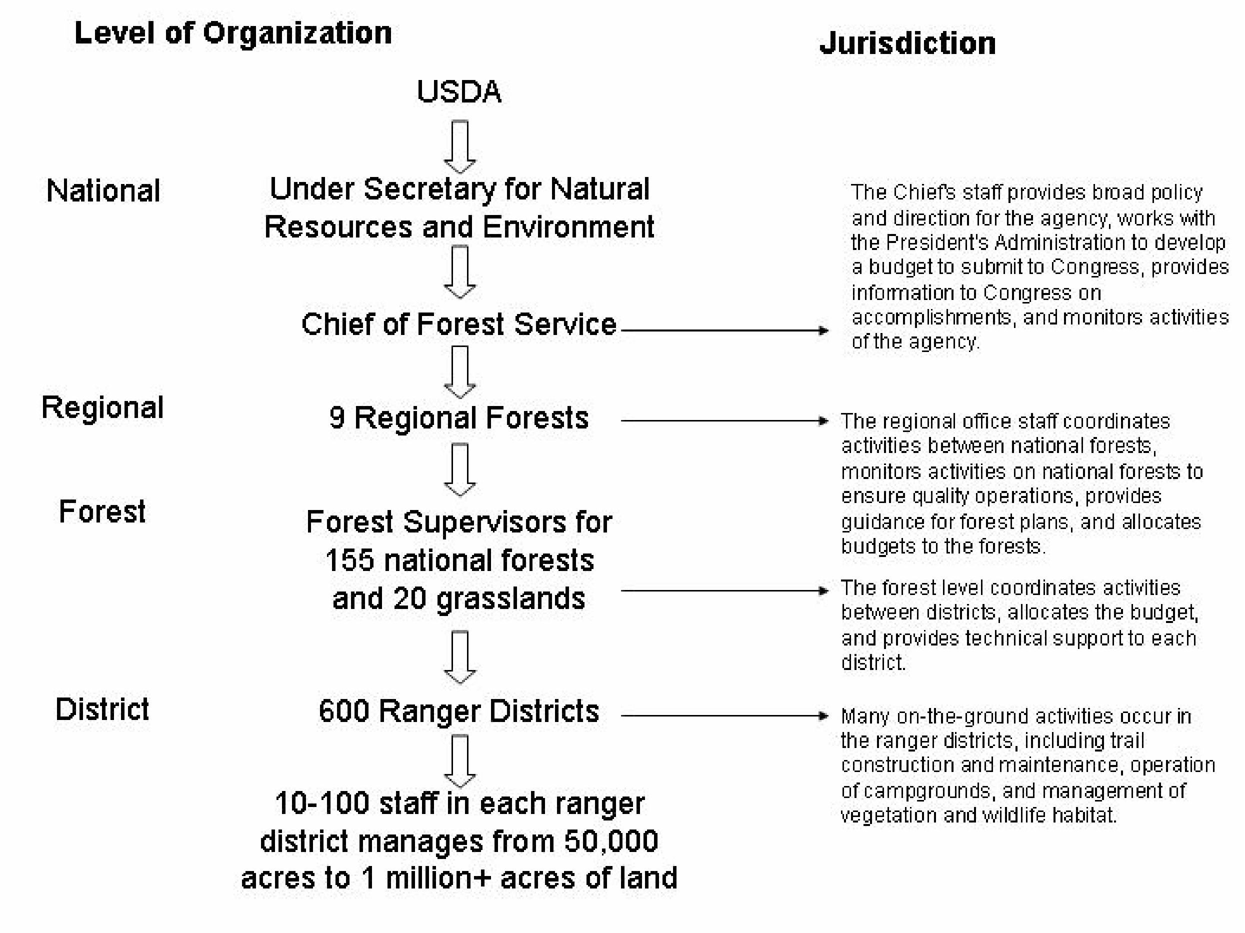


Figure 3.2. Jurisdiction and organizational levels within the National Forest System.



The Chief's staff provides broad policy and direction for the agency, works with the President's Administration to develop a budget to submit to Congress, provides information to Congress on accomplishments, and monitors activities of the agency.

The regional office staff coordinates activities between national forests, monitors activities on national forests to ensure quality operations, provides guidance for forest plans, and allocates budgets to the forests.

The forest level coordinates activities between districts, allocates the budget, and provides technical support to each district.

Many on-the-ground activities occur in the ranger districts, including trail construction and maintenance, operation of campgrounds, and management of vegetation and wildlife habitat.

Figure 3.3. One hundred fifty-five national forests and 20 national grasslands across the United States provide a multitude of goods and ecosystems services, including biodiversity.[6]

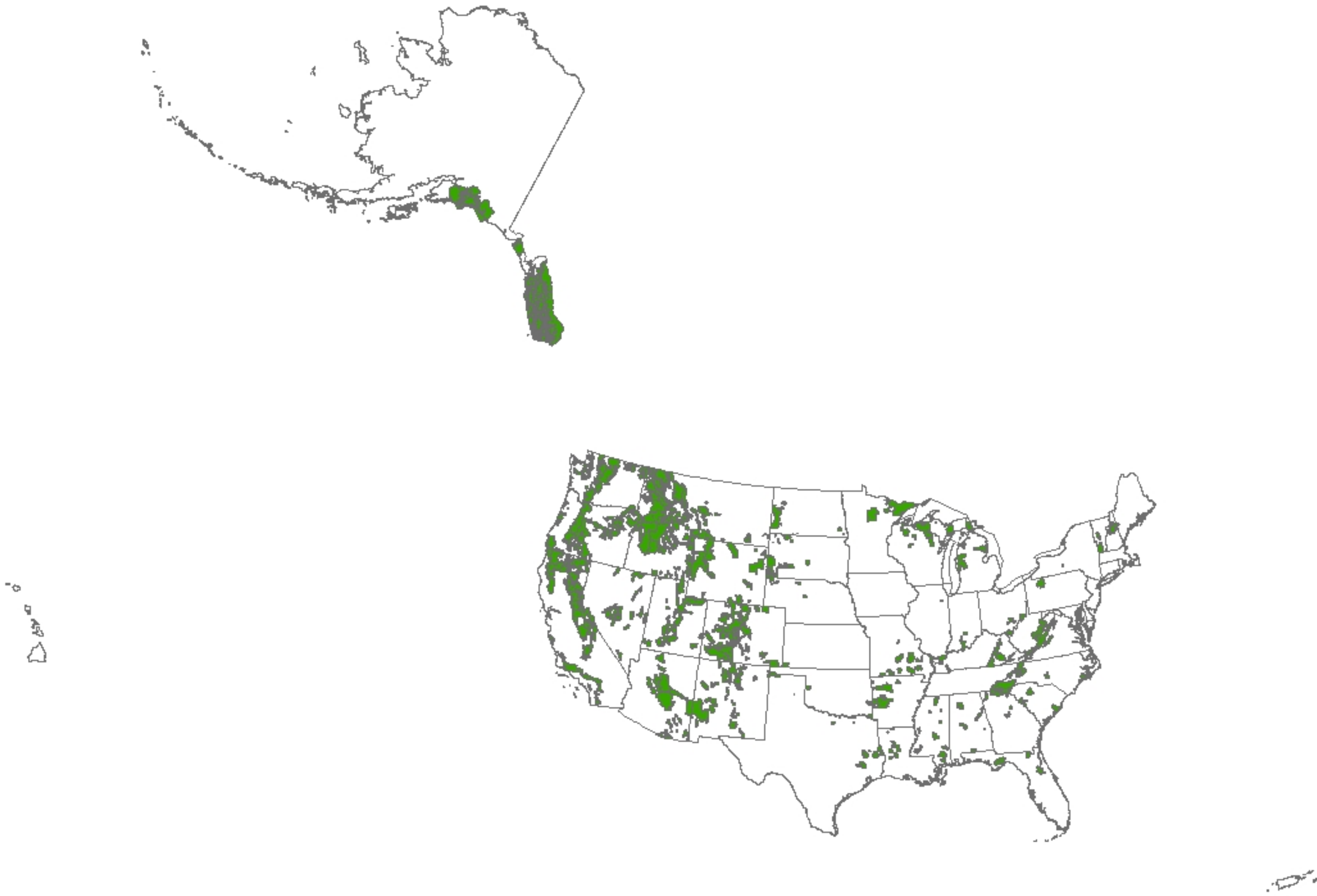


Figure 3.5. Wildland Urban Interface across the United States (Radeloff *et al.*, 2005).

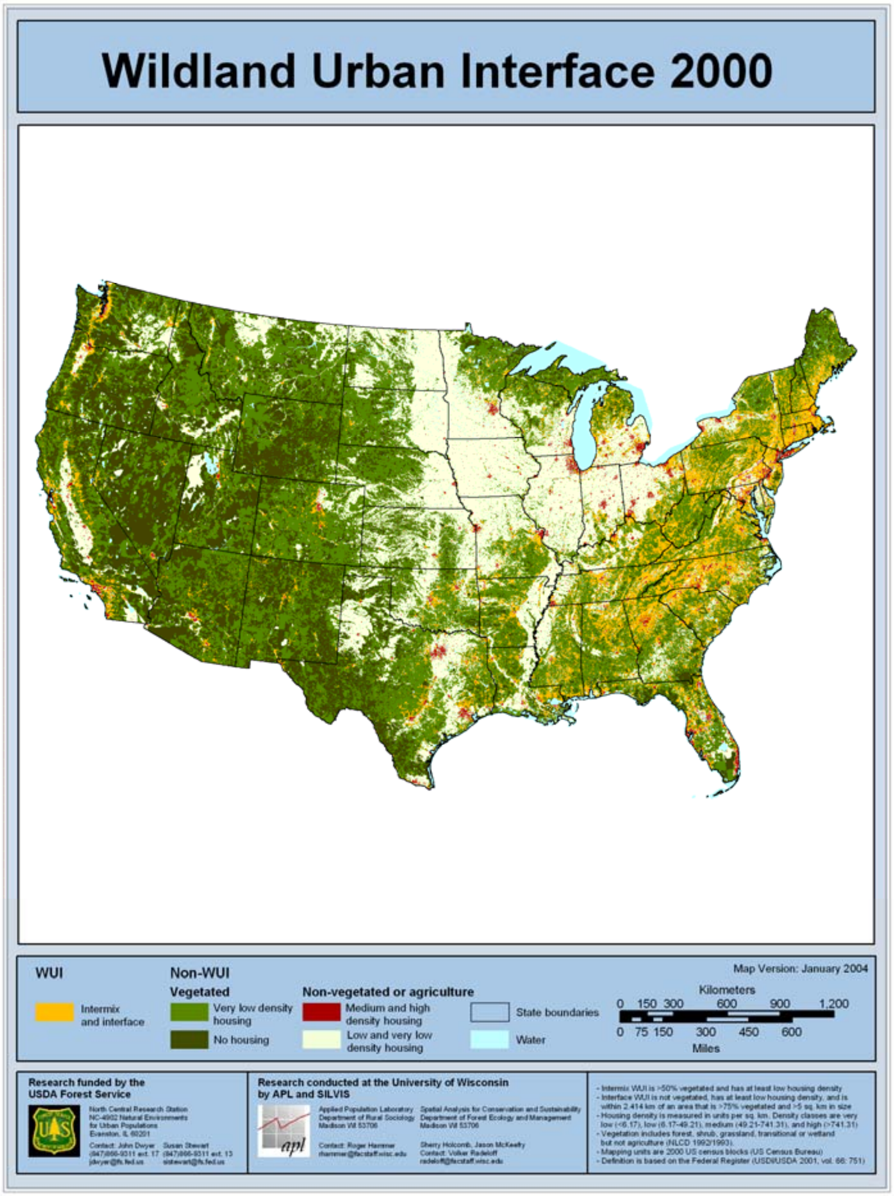


Figure 3.6. Influence of non-native earthworms on eastern forest floor dynamics (Frelich *et al.*, 2006). Forest floor and plant community at base of trees before (a, left-hand photo) and after (b) European earthworm invasion in a sugar maple-dominated forest on the Chippewa National Forest, Minnesota, USA. Photo credit: Dave Hansen, University of Minnesota Agricultural Experimental Station.

Figure 3.7. Conceptual model of the relative time scales for disturbance vs. climatic change alone to alter ecosystems. Times are approximate. Adapted from (McKenzie *et al.*, 2004).

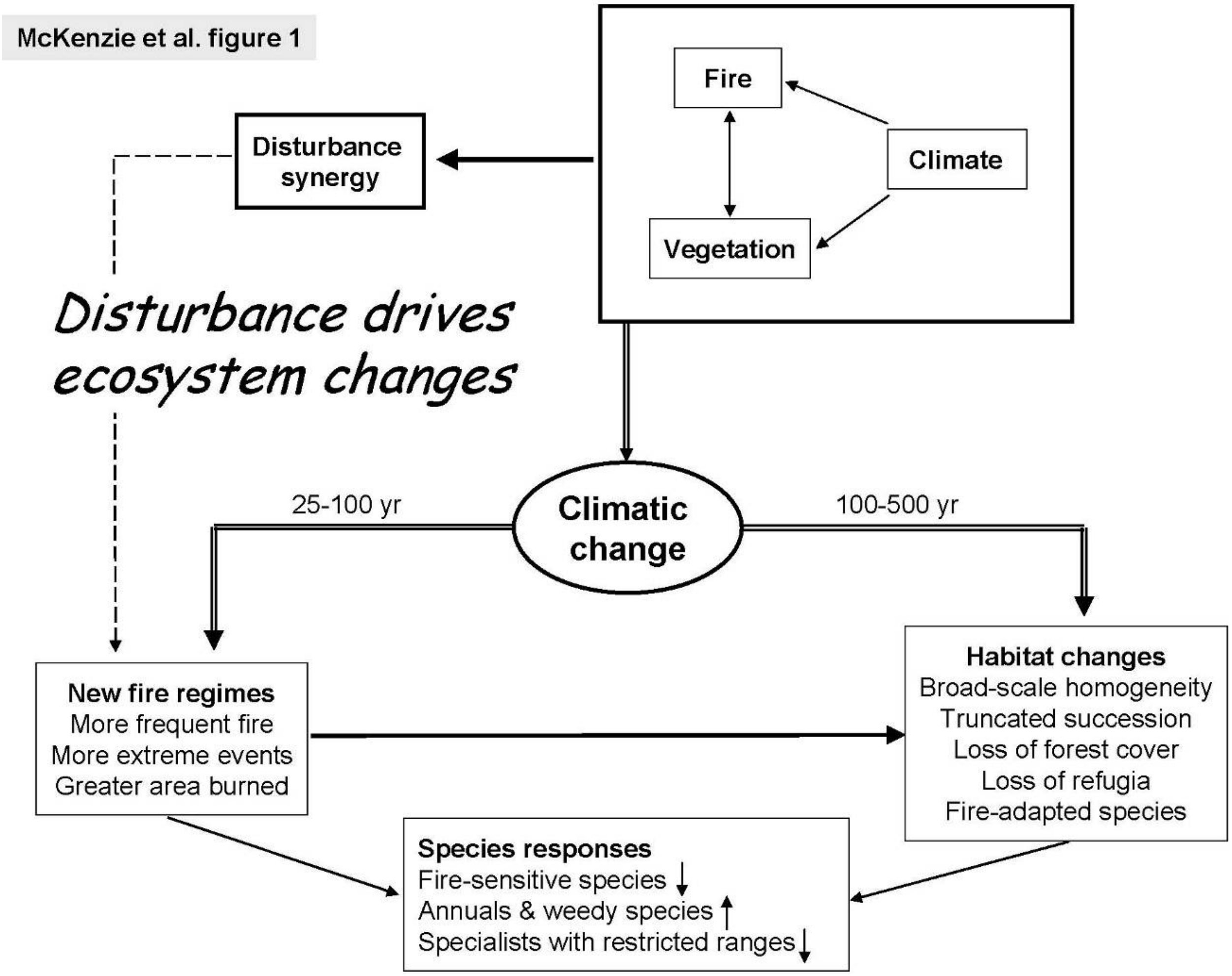


Figure 3.8. Stress complex in piñon-juniper woodlands of the American Southwest. From McKenzie *et al*. (2004).

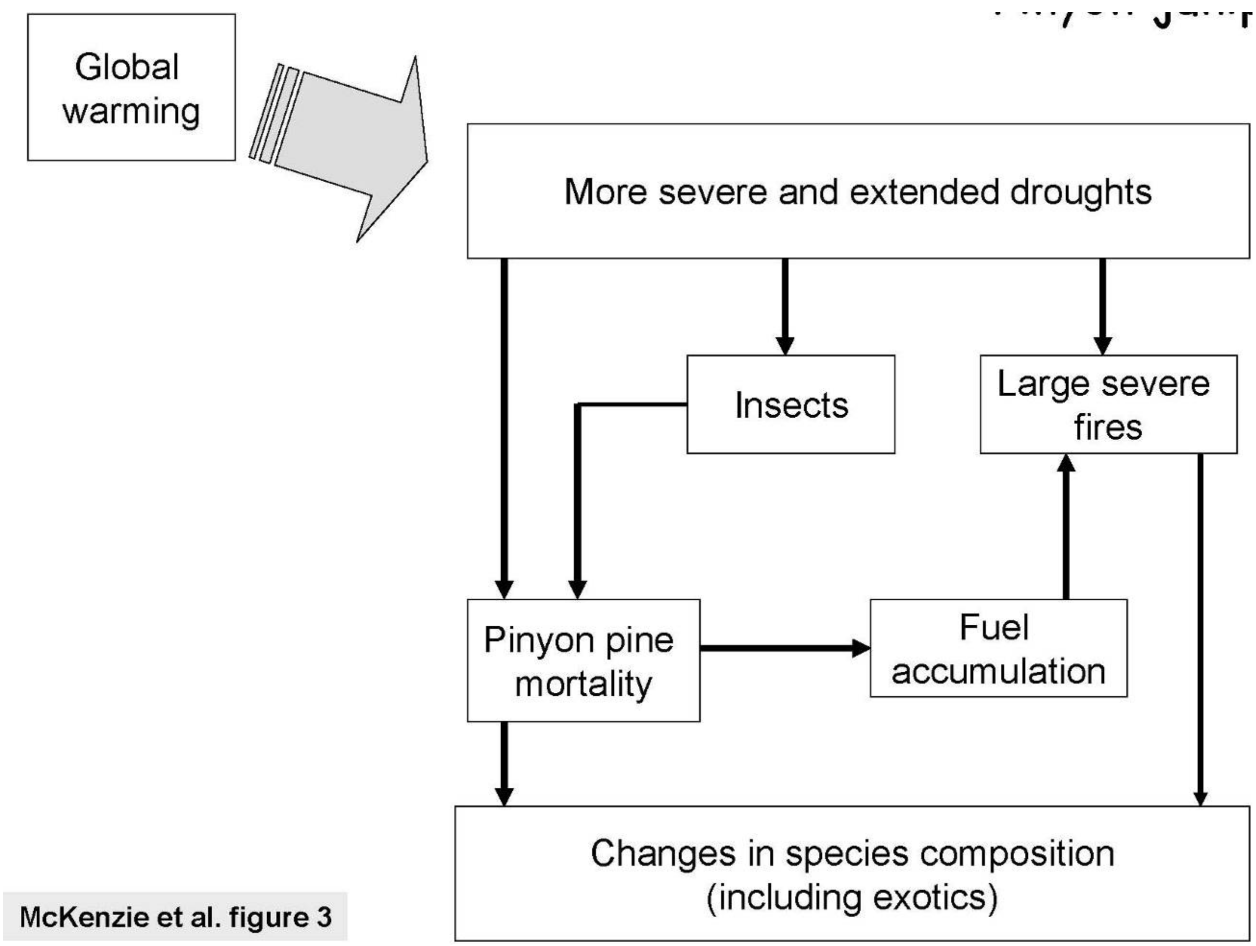


Figure 3.9. Stress complex in Sierra Nevada and southern Californian mixed-conifer forests. From McKenzie, Peterson, and Littell (forthcoming).

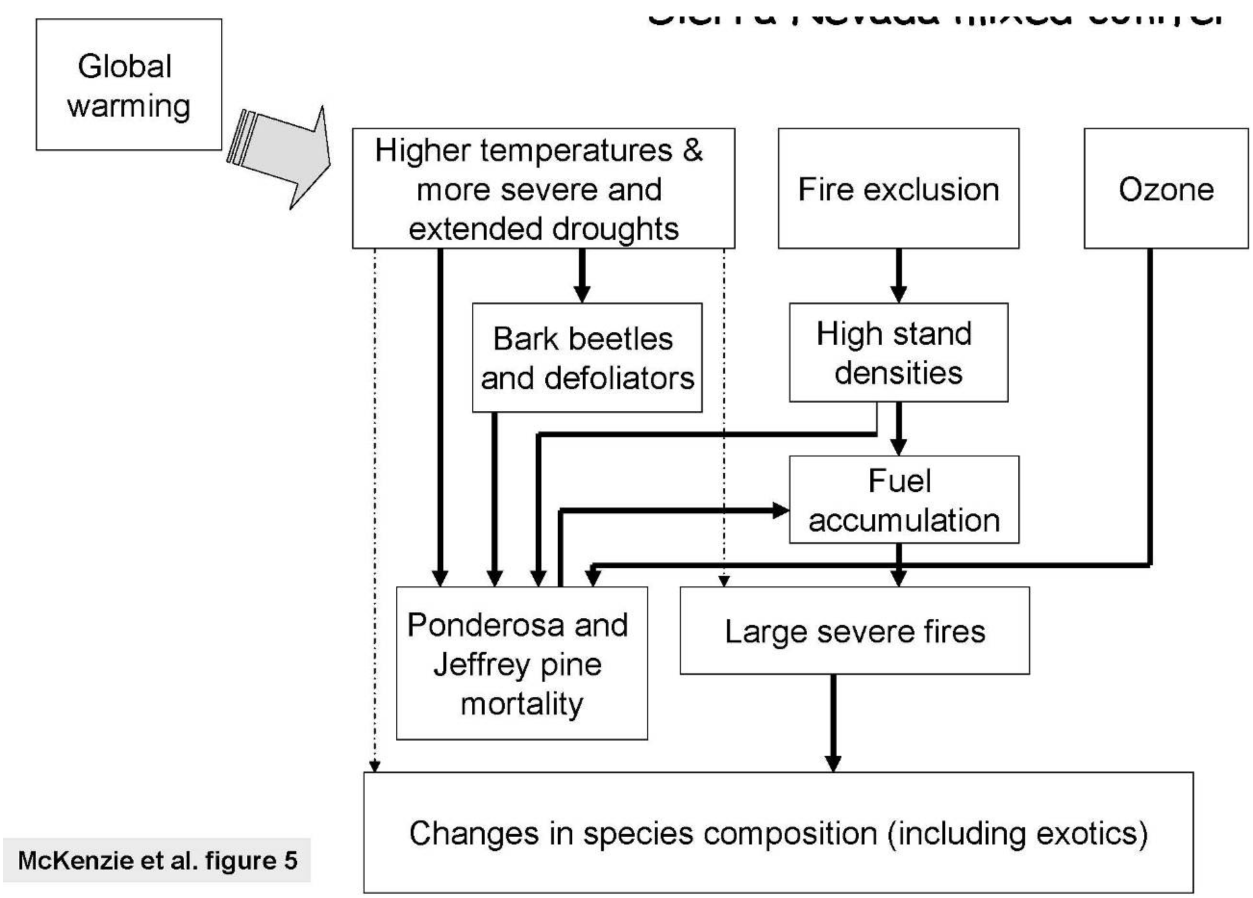


Figure 3.10. Stress complex in interior (BC and USA) lodgepole pine forests. From McKenzie, Peterson, and Littell (forthcoming).

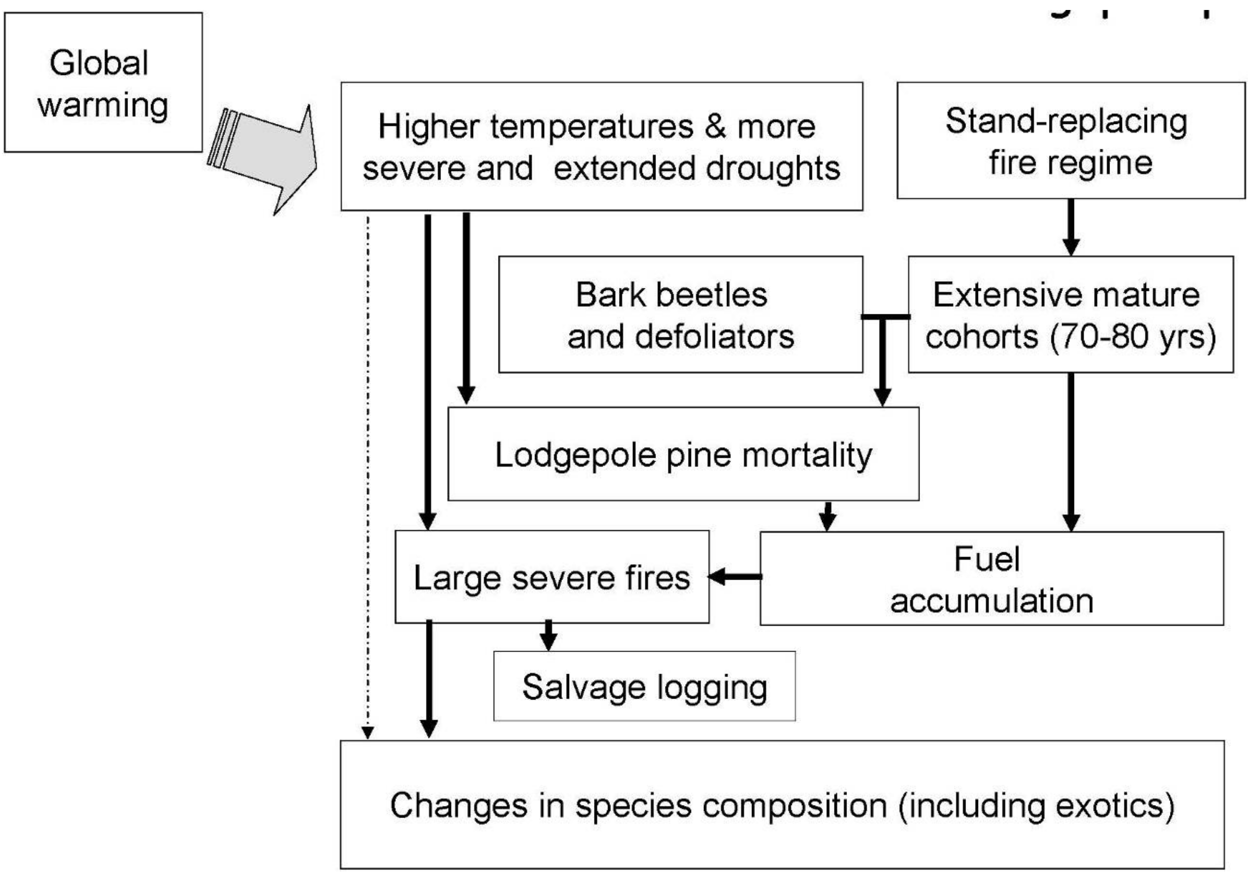


Figure 3.11. Stress complex in the interior and coastal forests of Alaska. From McKenzie, Peterson, and Littell (forthcoming).

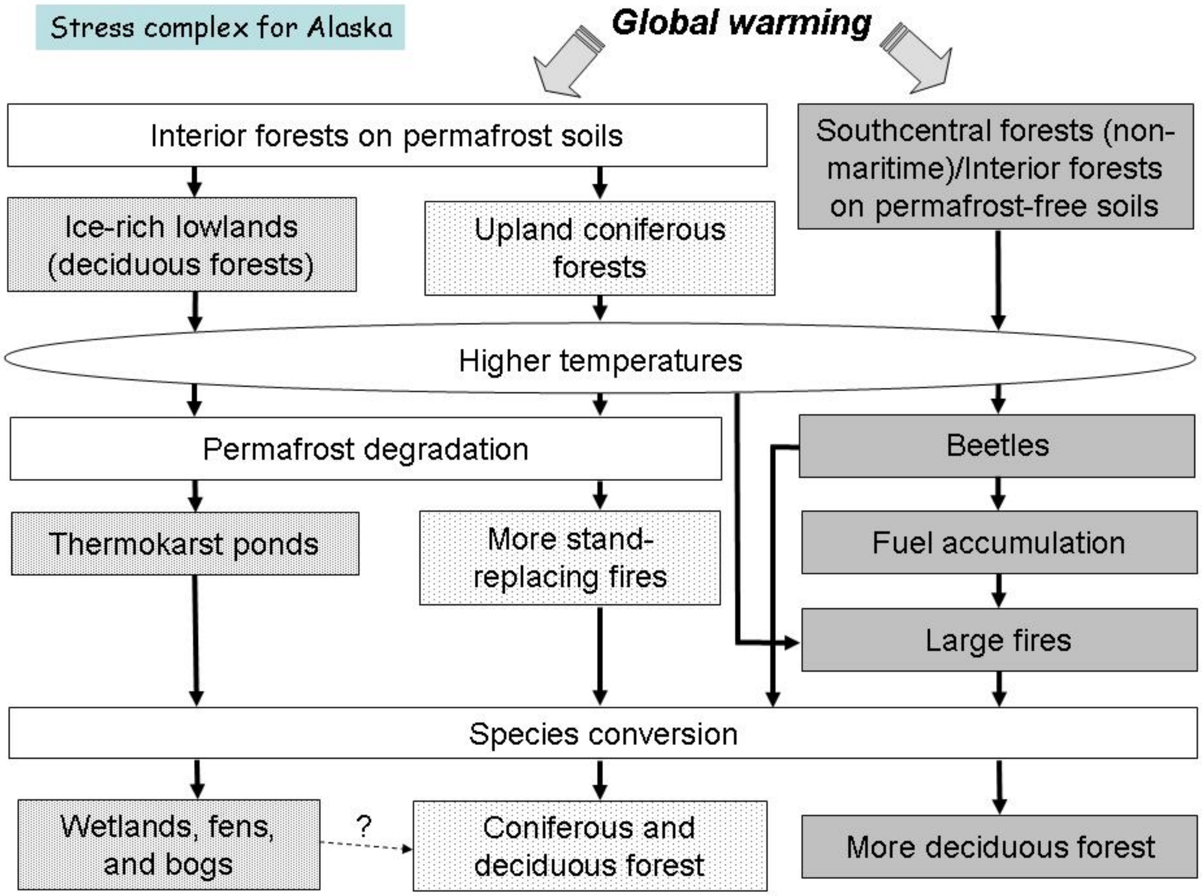


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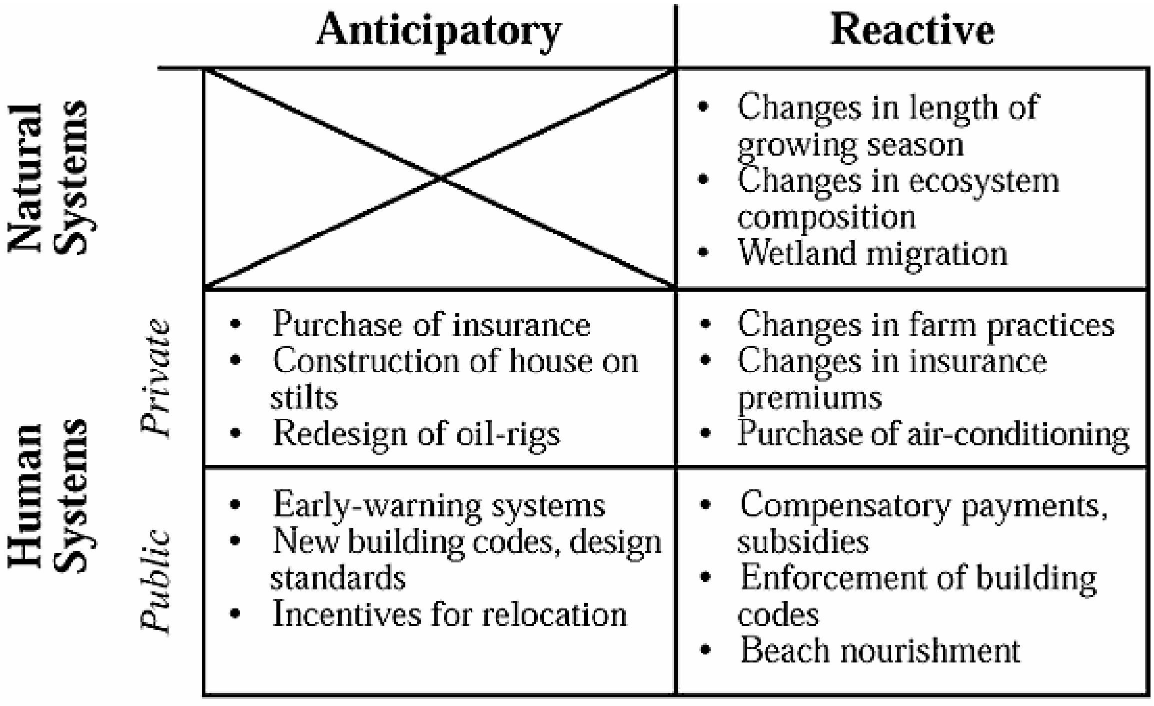
Figure 3.12. Anticipatory and reactive adaptation for natural and human systems (IPCC, 2001b).



		Anticipatory	Reactive
Natural Systems			• Changes in length of growing season • Changes in ecosystem composition • Wetland migration
Human Systems	*Private*	• Purchase of insurance • Construction of house on stilts • Redesign of oil-rigs	• Changes in farm practices • Changes in insurance premiums • Purchase of air-conditioning
	Public	• Early-warning systems • New building codes, design standards • Incentives for relocation	• Compensatory payments, subsidies • Enforcement of building codes • Beach nourishment