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U.S. National Forests adapt to climate change through Science–Management partnerships

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Abstract Developing appropriate management options for adapting to climate change is a new challenge for land managers, and integration of climate change concepts into operational management and planning on United States national forests is just starting. We established science–management partnerships on the Olympic National Forest (Washington) and Tahoe National Forest (California) in the first effort to develop adaptation options for specific national forests. We employed a focus group process in order to establish the scientific context necessary for understanding climate change and its anticipated effects, and to develop specific options for adapting to a warmer climate. Climate change scientists provided the scientific knowledge base on which adaptations could be based, and resource managers developed adaptation options based on their understanding of ecosystem structure, function, and management. General adaptation strategies developed by national forest managers include: (1) reduce vulnerability to anticipated climate-induced stress by increasing resilience at large spatial scales, (2) consider tradeoffs and conflicts that may affect adaptation success, (3) manage for realistic outcomes and prioritize treatments that facilitate adaptation to a warmer climate, (4) manage

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dynamically and experimentally, and (5) manage for structure and composition. Specific adaptation options include: (1) increase landscape diversity, (2) maintain biological diversity, (3) implement early detection/rapid response for exotic species and undesirable resource conditions, (4) treat large-scale disturbance as a management opportunity and integrate it in planning, (5) implement treatments that confer resilience at large spatial scales, (6) match engineering of infrastructure to expected future conditions, (7) promote education and awareness about climate change among resource staff and local publics, and (8) collaborate with a variety of partners on adaptation strategies and to promote ecoregional management. The process described here can quickly elicit a large amount of information relevant for adaptation to climate change, and can be emulated for other national forests, groups of national forests with similar resources, and other public lands. As adaptation options are iteratively generated for additional administrative units on public lands, management options can be compared, tested, and integrated into adaptive management. Science-based adaptation is imperative because increasing certainty about climate impacts and management outcomes may take decades.

1 Introduction

Planning and managing for the anticipated effects of climate change on natural resources is in its infancy on public lands in the United States (U.S.). Despite the fact that over 20 years of data are available from federally funded research programs, federal and state agencies have been slow to integrate climate change as a factor in projected future conditions of resources, planning strategies, and on-the-ground applications. This slow response is due to absence of a policy-driven mandate to respond to climate change, lack of local information on which to base decision making, reticence to address a complex issue for which the magnitude and timing of anticipated changes are uncertain, and a division of values among stakeholders.

Awareness of the need to incorporate climate change into resource management and planning has increased in association with the Fourth Assessment by the Intergovernmental Panel on Climate Change (IPCC 2007) and in western North America in association with well-publicized reports on regional climate and hydrologic trends (Hayhoe et al. 2004; Mote et al. 2005; Knowles et al. 2006). Recent efforts on adaptation to climate change have focused primarily on conceptual issues addressed through general scientific discussion (MacIver and Dallmeier 2000; Wilkinson et al. 2002; Hansen et al. 2003; Easterling et al. 2004; FAO 2007), social and economic adaptation (Kane and Yohe 2000; Smith et al. 2003), and proposed actions by governmental institutions (Rojas Blanco 2006; Joyce et al. 2007; Ligeti et al. 2007; Snover et al. 2007).

Efforts to develop strategies that facilitate adaptation to documented (e.g., altered hydrologic systems (Barnett et al. 2008)) and expected (e.g., increased area burned by wildfire (Westerling et al. 2006)) responses to climate change are now beginning in earnest by the U.S. federal government. In the most substantive effort to date, the U.S. Climate Change Science Program has developed a summary of adaptation options for federal land management agencies (Julius and West 2008), with one chapter devoted to adaptation on U.S. Forest Service lands (Joyce et al. 2008).

Recent discussions on adaptation emphasize the importance of implementing adaptive management (in a general sense, as opposed to adaptation to climate change), with resource monitoring as a critical feedback to evaluation of management strategies (Millar et al. 2007a, b; Joyce et al. 2008; Bosworth et al. 2008).

Federal agencies have been criticized by the Government Accountability Office for being slow to respond to mitigation and adaptation concerns on federal lands (GAO 2007) despite the huge volume of scientific literature documenting a warming climate and effects of climate change on natural resources (IPCC 2007). Nevertheless, in our experience, resource managers at *local* administrative units (e.g., national forests, national parks) have a strong interest in understanding the effects of climate change on resources, have demonstrated grass-roots leadership on this issue, and are anxious to undertake the job of adapting to those changes. According to Millar et al. (2007a, b), "…the best preparation is for managers and planners to remain informed both about emerging climate science as well as land-use changes in their region, and to use that knowledge to shape effective local solutions". It is unclear, however, what methods will facilitate the necessary co-development of knowledge between scientists and managers to achieve such a development of effective local solutions.

In order to approach this problem, we initiated science–management collaborations on national forests in the western U.S. where resource managers showed a keen interest in science-based options for adaptation to climate change. This was the first attempt to work with national forests to develop specific concepts and applications that could potentially be implemented in management and planning. In this paper, we describe the results of that effort: (1) a process that was used to develop adaptation options for Olympic National Forest and Tahoe National Forest, (2) general strategic approaches that can be used to guide successful adaptation, and (3) specific adaptation options that can be implemented in planning and on-the-ground applications.

2 Biogeographic setting and natural resources

2.1 Olympic National Forest

The Olympic Peninsula in western Washington (Fig. 1) consists of a mountain range (to nearly 2,500 m) and foothills surrounded by marine waters to the west, north, and east and low elevation, forested land (south). The Olympic mountains create a strong precipitation gradient, with historic averages of ∼500 cm in the lowlands of the southwestern peninsula, 750 cm in the mountains, and 40 cm in the northeastern lowlands, and most of the precipitation falls in winter. The biophysical landscape is diverse, with coastal estuaries , forests, mountain streams and lakes, temperate rainforests, alpine tundra, and mixed conifer forests, including over 2,000 vascular plant species (Buckingham et al. 1995). Low elevation forests are predominantly second growth, and most subalpine forests have never been logged. Wind is the most frequent disturbance, with occasional major cyclonic wind events. Fire regimes are mostly characterized as high severity, with return intervals of 100–500 years. Crown fires that encompass >50,000 ha are observed in paleohistorical records (Henderson

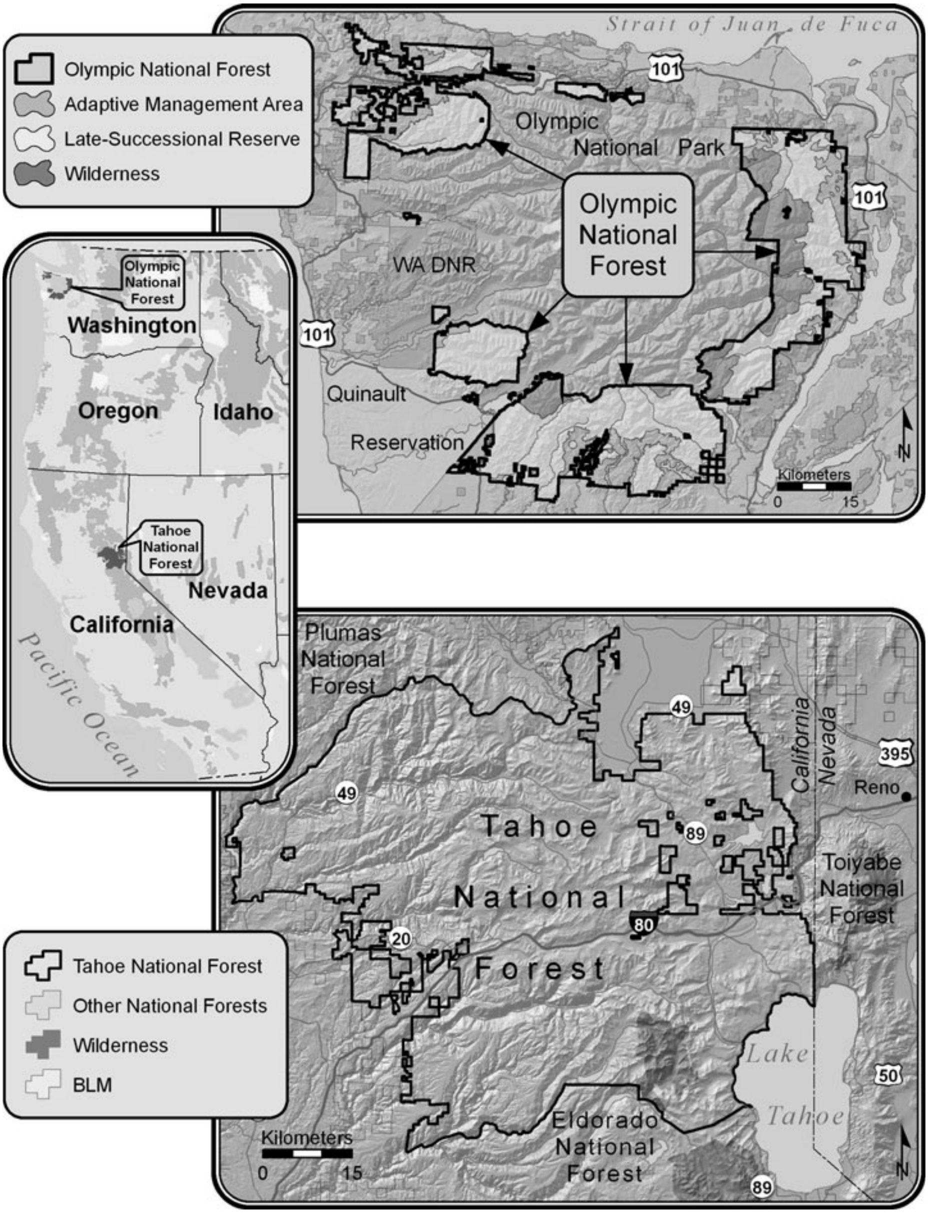

Fig. 1 Location of Olympic and Tahoe National Forests. Note the diversity of other land ownerships that need to be considered for adaptation to climate change. Figure: Robert Norheim

et al. 1989). Many insect species and fungal pathogens cause small patches of tree mortality (<10 ha) but rarely occur over large areas.

Ecosystems on the peninsula are contained within a mosaic of federal, state, tribal, and private ownership. Olympic National Forest (ONF), comprising

~257,000 ha (including five wilderness areas), surrounds Olympic National Park (ONP; ~364,000 ha). Additional land managers on the peninsula include 12 Native American tribes, the Washington Department of Natural Resources, several forest products and timber companies, and nonindustrial private forest owners. Approximately 3.5 million people live within four hours' travel of ONF. Ecosystem services from ONF include water supply to several municipal watersheds, nearly pristine air quality, a wide range of recreational opportunities, and abundant fish and wildlife, including several endemic species of plants and animals such as the Olympic marmot (*Marmota olympus*) and Roosevelt elk (*Cervus elaphus roosevelti*), and critical habitat for four threatened species of birds and anadromous fish.

Before 1990, ONF produced large amounts of timber and generated significant revenue in a forest economy. The harvest practices associated with this activity, however, simplified the landscape by converting the existing vegetation distribution and variation to relatively young plantation-like forest dominated by Douglas-fir (*Pseudotsuga menziesii*) (Swanson and Franklin 1992). Timber production from ONF declined an order of magnitude after the 1994 Northwest Forest Plan (NWFP), which mandated long-term management for late-successional forest for the protection of the northern spotted owl (*Strix occidentalis caurina*), marbled murrelet (*Brachyramphus marmoratus*), and aquatic systems. Fisheries and wildlife, watershed protection, and recreation are emphasis areas for management. Several large floods in Olympic National Forest rivers during the past decade have damaged roads, campgrounds, and drainage systems. Rebuilding and maintaining infrastructure to standards that are resistant to anticipated future increases in winter flooding (e.g., installing larger culverts, removing or re-engineering of roads with high erosion potential) is one current topic of discussion with respect to climate change because of the projected increase in extreme precipitation events in the region (Salathé et al. 2010).

2.2 Tahoe National Forest

Tahoe National Forest (TNF) is located in eastern California, where it straddles the northern Sierra Nevada (Fig. 1). The administrative boundary encompasses 475,722 ha, one-third of which is privately owned forest industry lands arranged in alternating "checkerboard" sections with TNF land. Elevations range from 365 m at the edge on the west slope to 2,788 m at the crest of the Sierra. The eastern slopes of TNF abut high-elevation (~1,525 m), arid steppes of the Great Basin. TNF experiences a Mediterranean-type climate with warm, dry summers and cool, wet winters. The orientation of the Sierra Nevada creates a steep west-east climatic gradient that contributes to strong orographic effects in temperature and a precipitation rain shadow. Near the TNF western boundary, average precipitation is 125 cm, highest at west-side mid-elevations (200 cm) and lowest near the eastern boundary (50 cm). Snow dominates winter precipitation in the upper elevations, providing water reserves during dry summers.

Floral and faunal diversity of the TNF parallels the topographic and climatic gradients of the Sierra Nevada, with strong zonation along elevational bands. The long Mediterranean drought is a primary influence on species that can persist in the presence of relatively frequent natural disturbance. Terrestrial and aquatic environments of the TNF support critical habitat for 387 vertebrate species and over

400 plant species (TNF 1990 *public communications*,[1] Shevock 1996). Several plant species depend on limited old-growth forest conditions or other rare habitats.

Cultural legacies play significant roles in shaping present forest conditions and vulnerabilities on the TNF. Timber harvest, irrigation, mining, and grazing starting in the mid-1800s remained intensive uses until the late twentieth century. Low- to mid-elevation forests were logged in the mid-1800s through early 1900s and subsequent fire exclusion has contributed to dense, even-age stands and low structural diversity. Managing fire hazard is a high priority because high forest fuel loadings have contributed to large, severe wildfires in recent years. Residential and commercial expansion in communities adjacent to TNF have created wildland-urban interface issues (Duane 1996), which, combined with the resource values of new residents, have forced re-evaluation of TNF goals and practices. For example, recreation is now a primary use of TNF lands, and timber management is minor. Fuels reduction is a key issue for reducing wildfire severity to protect natural resource values and adjacent communities. Thinning and prescribed burning are used in mixed-conifer forest on the Tahoe National Forest to modify fuel structures and reduce severity of wildfire. Management of stand densities and fuel loads is a potential option for increasing resilience to wildfire, resistance to insect attack, and overall tree vigor

3 Methods

We chose to work at the National Forest level because of the potential application to forest management plans, which are approached at the forest level. While project level planning is an important piece of adaptation on National Forests, much of the planning, regulatory, and management expertise required for these dialogues exists at the forest level. We used a 2-day focus group process to review existing climate change information and elicit recommendations for adaptation options. The first day focused on biosocial and management contexts of climate change on the ONF and TNF, through presentations by several scientists and discussion among scientists and resource management staff on the anticipated effects of climatic variability and change on natural resources (hydrology, ecological disturbance, vegetation, wildlife, fisheries), with emphasis on the scientific basis for inferences. The second day focused on elicitation of feedback from ONF and TNF resource managers about their concerns regarding climate change and recommendations for strategies and specific actions that would promote adaptation. The following questions were posed to resource managers:

- What are priorities for long-term resource management (>50 years)? How can climate change be integrated in planning at this time scale?
- What is the policy and regulatory environment in which management and planning are currently done?
- What are the biggest concerns and ecological/social sensitivities in a changing climate?
- Which management strategies can be used to adapt to potentially rapid change in climate and resource conditions?

[1] http://www.fs.fed.us/r5/tahoe/documents/forest_plan/1990_tnf_lrmp.pdf

- Which aspects of the policy and regulatory environment facilitate or hinder management that adapts to climate change?
- Which tools and information are needed to develop adaptation strategies?

Although the questions were addressed in the order listed, discussions were far-ranging and often digressed to topics that had been discussed earlier. The scientists (first three authors of this paper) facilitated discussion and recorded responses (Peterson and Littell at ONF, Millar at TNF). The responses were then summarized by topic and reviewed by ONF and TNF staff for accuracy. The results of the focus group sessions are presented below. In some cases, detail has been reduced to highlight the primary ideas and promote clarity.

4 Anticipated climate change and effects on resources

4.1 Olympic National Forest

Temperature in the Pacific Northwest region (PNW; Washington, Oregon, Idaho, western Montana) has warmed 0.7–0.9°C since 1920 (Mote 2003). Decadal variability has dominated annual precipitation trends, and is the most important feature of precipitation during the twentieth century. Regional climate models suggest an increase in mean temperature of 0.9 to 2.9°C (mean 2.0°C) by the 2040s and 1.2 to 5.5°C (mean 3.3°C) by the 2080s (Mote et al. 2005; Salathé 2005; Salathé et al. 2007), and summer temperatures are expected to increase more than winter temperatures (Table 1). Precipitation changes are less certain, but slight increases in annual and winter precipitation are expected, whereas slight decreases in summer precipitation are possible (Salathé 2005). At lower elevations, declines in April 1 snow water equivalent have occurred in the Olympic Mountains (Mote et al. 2005), and the timing of spring runoff is 10–30 days earlier in 2000 than in 1948 (Stewart et al. 2004). If these trends continue, then snowpacks at low to mid elevation will decrease, with a shift in timing of spring snowmelt and runoff, and summer evapotranspiration will increase (Mote et al. 2005; Hamlet et al. 2007). Winter runoff (October to March) will increase, summer runoff (April to September) will decrease (Hamlet et al. 2007), and streamflow will increase in winter and decrease in summer. Floods will increase in frequency because buffering by snowpacks will decrease, because more precipitation will occur as rain rather than snow, and because future extreme precipitation may be more frequent (Salathé et al. 2010).

4.2 Tahoe National Forest

The trend of temperature increase over the twentieth century for California and the Sierra Nevada has paralleled the global pattern (IPCC 2007) although at greater magnitude (1.5–2.0°C; Millar et al. 2004; WRCC 2005 *unpublished data*,[2] Cayan and Hanemann 2008) (Table 1). Regional climate models for California suggest an increase in mean temperature of 1.3 to 2.0°C (mean 1.6°C) by the 2040s and 2.3 to 5.8°C (mean 3.7°C) by the 2090s, with summer temperatures expected to increase

[2](http://wrcc.dri.edu)

Table 1 Anticipated effects of climate change on natural resources in Olympic and Tahoe National Forests

Natural resource status or condition	Olympic National Forest	Tahoe National Forest
Climate		
Temperature	2.0°C increase by 2040s, 3.3°C increase by 2080s	1.6°C increase by 2040s, 3.7°C increase by 2090s
Precipitation	Small increase in winter	Small decrease in winter
Snow	Decrease at <1,500 m; decrease in snow:rain ratio	Large decrease at all elevations
Water		
Runoff[a]	Increase in winter, decrease in summer	Increase in winter, decrease in summer
Streamflow[a]	Large increase in winter, large decrease in summer	Increase in winter, decrease in summer
Tree growth	Decrease at low elevation, increase at high elevation	Decrease at all elevations
Vegetation distribution and abundance	Significant shifts but poorly quantified; no change in forest cover	Significant shifts but poorly quantified; large decrease in forest cover
Aquatic systems	Decrease in habitat quality for anadromous and resident fish	Large decrease in habitat quality for anadromous and resident fish; extirpations possible
Disturbance		
Wildfire area burned	Small increase[b]	Large increase
Insect attack	Possible increase	Large increase
Windstorms	Unknown but increased storms would have major impact	Unknown

See text for citations and more detailed information

[a]The expected trends for runoff and streamflow will occur only for basins dominated by snow hydrology, with the magnitude of impact dependent on how much the rain/snow ratio increases

[b]Threshold relationships may exist in forest ecosystems with high-severity fire regimes that dominate the Olympic Peninsula. Although fires have historically been infrequent (200–500 year fire-free intervals), they are often very large (hundreds of thousands of hectares) when they do occur (Henderson et al. 1989)

more than winter temperatures (Cayan et al. 2008; Hidalgo et al. 2008; Hayhoe et al. 2004; Table 1) and extreme temperatures expected to increase as well (Cayan and Hanemann 2008).

Precipitation over the course of the twentieth century in the northern Sierra has been variable, following interannual to decadal ocean circulation phases and transient synoptic climatic events (Cayan et al. 1999), as well as anthropogenic inputs (Barnett et al. 2008). Although previous projections were inconclusive (Cayan et al. 2006; Hayhoe et al. 2004), recent modeling runs that incorporate more current downscaled information indicate drying for the second half of the twenty-first century, suggesting that northern California mountains are likely to be drier than the recent past (Barnett et al. 2008; Cayan et al. 2008; Cayan and Hanemann 2008; Hidalgo et al. 2008).

Although multi-year droughts have been as common in recent as in past centuries in northern California (NOAA 2005), interaction of drought with increased temperature has resulted in higher stress to Sierra Nevada vegetation than under cooler climates of prior centuries (Millar et al. 2007a, b). Forest insect and disease, mortality, and fire events have become more frequent or severe in the Sierra Nevada during the twentieth century (Westerling and Bryant 2006; Westerling et al. 2006; Millar et al. 2007a, b; Van Mantgem and Stephenson 2007; Battles et al. 2008). Decreases in average snowpack up to 80% are documented for 1950–1997 in parts of the West including the Sierra Nevada (Hayhoe et al. 2004; Knowles et al. 2006) with peak snowpacks as much as 45 days earlier (Hamlet et al. 2005; Mote et al. 2005), peak streamflow up to 3 weeks earlier in spring (Stewart et al. 2005) leading to early stream run-off (Dettinger et al. 2004), decreased overall runoff (Stewart et al. 2004; Maurer 2007) and increased spring extreme flood events (Cayan and Hanemann 2008). Snowpacks are modeled as declining up to 97% at 1,000 m elevation and 89% for all elevations in California (Hayhoe et al. 2004; Knowles et al. 2006). For northern California specifically, the number of years projected to have snowpacks as low as the 1961–1990 10th percentile average will increase after 2050 to over half the years (Cayan et al. 2008; Cayan and Hanemann 2008). The combined effects of continued warming, declining snowpacks, and earlier stream runoff portend longer summer droughts and increasing soil moisture deficits during summer relative to the past century. This may have altered montane vegetation zones (Thorne et al. 2008) and may increase opportunities for invasive species (Hellmann et al. 2008).

4.3 Effects on resources

Increased summer temperature may lead to increases in evapotranspiration from vegetation and land surfaces (McCabe and Wolock 2002) would be likely to decrease growth (Nakawatase and Peterson 2006; Holman and Peterson 2006; Littell et al. 2008) and fuel moisture in lower elevation (e.g., Douglas-fir, western hemlock [*Tsuga heterophylla*]) forests while increasing growth (Peterson and Peterson 2001; Peterson et al. 2002; Nakawatase and Peterson 2006) and regeneration (Woodward et al. 1995) in high elevation (e.g., subalpine fir [*Abies lasiocarpa*], mountain hemlock [*T. mertensiana*]) forests. Higher temperatures would also affect the range and decrease generation time of forest insects such as the mountain pine beetle (*Dendroctonus ponderosae*) (Logan and Powell 2001; Logan et al. 2003), as well as increase the area burned by fire in ecoprovinces of western Washington (Littell et al. 2009). Distribution and abundance of plant and animal species will probably change over time (Zolbrod and Peterson 1999), and these changes will be facilitated by large disturbances such as fire or windstorms that kill much of the overstory and reset succession. Higher temperatures and lower summer flows will negatively affect most anadromous and resident fish species (Francis and Mantua 2003).

On TNF, Coupling climate models with vegetation models suggests major contractions and expansions in cover of dominant montane vegetation types by the late twenty-first century (Hayhoe et al. 2004; Lenihan et al. 2008) increases in invasive species (Hellmann et al. 2008), and declines in endemic flora (Loarie et al. 2008). By 2070–2099, alpine and subalpine forest types are modeled to decline as much as 90%, shrublands by 75%, and mixed evergreen woodland by 50%. In contrast, mixed evergreen forest and grasslands are each modeled to expand by 100%. The following conditions are expected to be exacerbated on the TNF as a result of anticipated changes (Dettinger et al. 2004; Hayhoe et al. 2004; Cayan et al. 2006;

Westerling and Bryant 2006; Westerling et al. 2006; Westerling 2008; confidence levels in parentheses): (1) increased fuel build-up and risk of severe and widespread forest fire (highest); (2) longer fire seasons; year-round fires in some areas (highest); (3) wildfire and insect outbreaks occurring at higher elevations than they have historically (highest); (4) increased interannual variability in precipitation, leading to fuels build-up and additional forest stress, promoting high fire hazard (high); (5) increased water temperature in rivers and lakes and lower water levels in late summer (high); (6) increased stress to forests during periodic multi-year droughts; increased forest mortality (high) ; (7) decreased water quality as a result of increased watershed erosion and sediment flow (moderate-high); (8) increased severe flood events (moderate-high); (9) loss of seed and other germplasm sources as a result of population extirpation (low-moderate).

5 Policy, planning and management environments

5.1 Olympic National Forest

Current natural resource management issues in ONF stem primarily from policy mandates, historical land use and forest fragmentation, and multi-agency land ownership on the Olympic Peninsula (Fig. 1). ONF is considered to be a restoration forest, charged with managing large, contiguous areas of second growth forest. Most ONF management objectives are focused on restoring habitat, enhancing native biodiversity (and managing for individual threatened and endangered species under the U.S. Endangered Species Act [ESA]), promoting development of late-successional forests, restoring and protecting aquatic ecosystems from the impacts of an aging road infrastructure, rehabilitating or restoring logging roads, controlling invasive species, and monitoring. The NWFP stongly affects ONF management because the management plan and planning guidelines for ONF are structured by mandates from the NWFP (and the National Forest Management Act [NFMA]). Project planning is often a time- and resource-intensive process, because National Environmental Policy Act (NEPA) procedures generally include review from stakeholders and the general public. Incorporating regional climate change information into Environmental Assessments and Environmental Impact Statements can be difficult, because assessment typically occurs at spatial scales of a few thousand hectares or less, whereas climate change information is available at regional to subregional scales.

Adaptation to climate change has not been addressed in the ONF land management plan or in planning for most management activities. Current management objectives include efforts to confer resilience by promoting landscape diversity and biodiversity, an approach that is compatible with adaptation to climate change. To this end, approaches available to ONF managers include restoration of aquatic systems (especially the minimization of the impacts of roads, bridges, and culverts), active management of terrestrial systems (through thinning and planting), and treatment of invasive species. Prescribed fire and wildland fire use are unlikely tools because of the low historical area burned, limitations of the U.S. Clean Air Act, and low funding levels. The range of strategies and information for using these tools varies across ONF land use designations. Late Successional Reserves and Wilderness have less flexibility for active management than designated Adaptive Management

Areas, because there are more explicit restrictions on land use and silvicultural options.

5.2 Tahoe National Forest

In addition to national laws and regional management directives, management goals and direction for the lands and resources of the TNF are specified by overarching planning documents that relate to different spatial scales and locations. The TNF land management plan (TNF 1990) is the comprehensive document for all resource management. Specific objectives, desired future conditions, and standards and guidelines in the plan are detailed for recreation, interpretive services, visual management, cultural resources, wilderness, wildlife and fish, forage and wood resources, water and riparian areas, air quality, minerals management, facilities, economic efficiency, human and community resources, and research.

Specific direction in the TNF plan has been amended by the Sierra Nevada Forest Plan Amendment (FPA) (USFS 2004) and the Herger-Feinstein Quincy Library Group Forest Recovery Act (1998). The FPA is a multi-forest plan that specifies goals and direction for protecting old forests, wildlife habitats, watersheds and communities on the 11 national forests of the Sierra Nevada and Modoc Plateau. Goals for late-successional forests focus on protection, enhancement, and maintenance of old forest ecosystems and their associated species through increasing the number of large trees, increasing structural diversity of vegetation, and improving continuity of old forests at large spatial scales.

With regard to aquatic, riparian, and meadow habitat, the FPA goals and management direction are intended to improve the quantity, quality, and extent of degraded wetlands throughout the Sierra Nevada, and to improve habitat for aquatic and wetland-dependent wildlife species such as willow flycatcher (*Empidonax traillii*). Direction for managing fire and fuels provides a coordinated strategy for addressing the risk of large wildfires by reducing hazardous fuels while maintaining ecosystem functions and providing local economic benefits. Specific approaches to these goals are conditioned by the National Fire Plan of 2002 (USDA/USDOI 2000, *public communication*[3]) and the Healthy Forests Restoration Act of 2003 (HFRA 2003) which emphasize strategic placement of fuel treatments, removal of fuels to reduce fire severity, and economic efficiency.

The FPA contains a Sierra-wide adaptive management and monitoring strategy and is being implemented as a pilot project on the TNF, including scientifically rigorous design, treatment, and analysis approaches to fire and forest health, watershed health, and wildlife. The Herger-Feinstein Quincy Library Group Forest Recovery Act (1998) provides specific management goals and direction for the Sierraville Ranger District of the TNF and adjacent national forests. Derived from an agreement among representatives of fisheries, timber, county government, and local non-governmental organizations, the Act launched a pilot project to test alternative strategies for managing sensitive species, a new fire and fuels strategy, and a new adaptive management strategy. The pilot project assesses the effectiveness of fuel breaks, silvicultural strategies, conservation of high-priority habitats, and riparian restoration.

[3]http://www.forestsandrangelands.gov/reports/documents/2001/8-20-en.pdf

6 Adapting to climate change through management and planning

6.1 Olympic National Forest and Tahoe National Forest

Few management policies or plans for ONF or TNF currently specifically address climate or climate adaptation. Thus, while it would appear that "no adaptation" is the dominant paradigm on both forests, many practices are potentially "climate smart" (i.e., consistent with or mindful of projected climate change and its impacts) if trends or potential changes in climate are considered by management. For example, on TNF, planned post-disturbance treatments were developed to attain current goals for ecosystem conditions (e.g., watershed protection, succession to forest after wildfire, fuel reduction after insect mortality) rather than catalyzing climate-adaptive conditions. Such management practices are consistent with adaptive conditioning for climate contexts. For example, limited timber harvest following fire facilitates planting of trees of appropriate species and genotypes, and integrating monitoring and treatment of invasives provides an example. Although this is difficult to implement quickly at large spatial scales, TNF has been able to respond on small areas following disturbance when NEPA documentation has withstood appeals and litigation (Levings 2003, *unpublished report*[4]). In these circumstances, watershed protection measures are implemented, and species and seed sources tolerant of a warmer climate are matched to specific sites.

Although TNF has not directly addressed climate through active management, the resource management staff has been discussing implications of climate change for many years. This thinking has pre-conditioned TNF to consider climate in management actions, with discussion among staff regarding potential changes in strategic planning areas. In addition, advances have been made in integrated planning processes that may be useful for incorporating climate-adaptive treatments, thereby facilitating proactive management. ONF has spent less time directly engaged on climate change, but took advantage of high density of climate change expertise in the region and more importantly, strong leadership and support at ONF, to move forward quickly with understanding the implications and adaptation strategies available.

7 General adaptation strategies developed by ONF and TNF staff in the focus groups

Both the ONF and TNF focus groups generated adaptation strategies that are more general or conceptual in nature (Table 2):

Manage dynamically and experimentally (*TNF*) Currently available opportunities (i.e., under current policy) can be used to truly implement adaptive management over several decades, including feedback from resource monitoring to the decision-making process. For example, management plans that encompass critical species can favor active management at advancing edges or optimal habitat rather than at static or stressed margins.

[4]Economics of delay. On file at the Tahoe National Forest, 6 pages.

Table 2 General adaptation strategies and specific adaptation options identified by resource managers for adapting to climate change in Olympic and Tahoe National Forests[a]

Olympic National Forest	Tahoe National Forest
General adaptation strategies	
Prioritize treatments, manage for realistic outcomes	Prioritize treatments, manage for realistic outcomes
Manage for resilience, reduce vulnerability	Manage dynamically and experimentally
Consider tradeoffs and conflicts	Manage for process
Specific adaptation options	
Increase landscape diversity	Increase landscape diversity
Treat large-scale disturbance as a management opportunity	Treat large-scale disturbance as a management opportunity
Promote education and awareness about climate change	Promote education and awareness about climate change
Maintain biological diversity	Increase resilience at large spatial scales
Implement early detection/rapid response for invasive species	Increase management unit size
Match engineering of infrastructure to expected future conditions	
Collaborate with a range of partners on adaptation strategies	

[a]Order and wording differ from text to better illustrate similarities between national forests

Manage for process (*TNF*) *and Manage for resilience, decrease vulnerability* (*ONF*) Project planning and management can be used to maintain or enhance ecological processes rather than to design structure or composition. For example, novel mixes of species and spacing can be used following fire in order to reflect potential natural dynamic processes of adaptation. The success of adaptation strategies can be defined by their ability to reduce the vulnerability of resources to a changing climate while attaining specific management goals for the condition of resources and production of ecosystem services.

Manage for realistic outcomes (*TNF*) *and Prioritize climate-smart treatments* (*ONF*) Current projects that are part of the current planning process on TNF may have a higher failure rate in a warmer climate, and it will become increasingly important to assess the viability of management goals and desired outcomes in this context. For example, restoring salmon species to TNF rivers is a goal in the current land management plan. However, as stream temperatures become warmer, they may become unsuitable spawning and rearing habitat. Therefore, choosing not to restore salmon may be an appropriate decision. Similarly, it may be appropriate to not restore mountain meadows with grasses and forbs (an approved management activity) if those meadows will inevitably become dominated by trees in a warmer climate. ONF suggested prioritizing those treatments most likely to be effective in the long run, recognizing that some treatments may cause short-term detrimental effects but have long-term benefits. For example, fish species may be vulnerable to increased sedimentation associated with flood-driven failures of unmaintained roads, but road rehabilitation may produce temporary sedimentation and may invite invasive weeds. Ideally, triage situations could be avoided, but given limited financial resources, it will be necessary to prioritize management actions with the highest likelihood of success at the expense of those that divert resources and have less certainty of favorable outcomes.

Consider tradeoffs and conflicts (*ONF*) Future impacts on ecological and socioeconomic sensitivities can result in potential tradeoffs and conflicts for species conservation and other resource values. For example, stress complexes exacerbated by climate change may cause threatened species (e.g., bull trout [*Salvelinus confluentus*], spotted owl, marbled murrelet, Olympic marmot) to become even rarer, thus undermining the likelihood of successful protection. These tradeoffs and conflicts can be considered collectively and incorporated in land management planning.

8 Specific adaptation options developed by ONF and TNF in the focus groups

Increase landscape diversity

- Plan at large scales with focus on landscape variation (TNF). Managing for a variety of different forest structures and vegetation composition will increase opportunities for adaptation to a warmer climate and large disturbances. Apply targeted forest thinning to increase variability in stand structure, decrease stress by increasing tree vigor, and reduce vulnerability to disturbance (ONF).
- Implement thinning and harvest treatments appropriate for different landscapes and avoid one-size-fits-all standard prescriptions that do not recognize such diversity (ONF and TNF). Plan fuel reduction projects strategically using “firesheds” (i.e., strategic placement of fuel treatment to minimize spread or severity of wildfires) addresses fire management and simultaneously creates a variety of landscape patterns at large spatial scales. (TNF). Creating forest gaps large enough for elk habitat but small enough to minimize invasive species and maintaining corridors that link habitat for migratory species and species with large home ranges addresses restoration needs and also creates a variety of landscape patterns (ONF).

Increase management unit size (*TNF*) Management units are often <50 ha because of logistical and financial considerations. Increasing the size of management units to hundreds or thousands of hectares across watersheds will decrease “administrative fragmentation” (i.e., different management actions applied to different portions of a landscape within a single forest) and improve the likelihood of accomplishing adaptation objectives. Ecosystem-based management at large spatial scales and for multiple species and resource values will favor adaptability to climate-related challenges.

Increase resilience at large spatial scales (*TNF*) Proactive management that improves the resilience of natural resources to ecological disturbance and environmental stressors probably improves adaptive capability for climate change. Resilience management decreases the number of situations in which TNF must respond to crises and increases the number of situations in which planning and strategic action avert crisis. Strategies consistent with this approach include:

- Protect riparian areas, which have disproportionately high value for biodiversity. New policies for riparian and watershed management limit road construction across perennial streams. Helicopters are used for logging where roads cannot be built. This maintains riparian reserves of biodiversity and reduces fragmentation and erosion.

- Manage watersheds to maintain water quantity and quality. Water is a valuable resource within TNF as aquatic habitat and downstream for human use and fisheries. Treatments that improve infiltration could be implemented in order to increase groundwater storage capacity. For example, reduced road density throughout TNF and fewer skid trails for timber harvest would help minimize soil compaction. Timely revegetation of areas that have been burned by severe fires is needed to minimize erosion and sediment loss, thus requiring limited timber harvest and often tree planting soon after disturbance. Although this is current policy, implementation is often delayed because of NEPA requirements and litigation. Increased frequency and severity of disturbances could make watershed protection challenging.

Maintain biological diversity (*ONF*) Appropriate species and genotypes can be planted in anticipation of a warmer climate, assuming that credible scientific justification is available on which to base planting decisions. This allows resource managers to hedge their bets by diversifying the phenotypic and genotypic template on which climate and competition interact, and to avoid widespread mortality at the regeneration stage.

- Plant multiple tree species rather than monocultures. This would include common local species and perhaps species that are common in adjacent warmer landscapes.
- Plant nursery stock from warmer, drier locations than what is prescribed in genetic guidelines based on current seed zones.
- Plant nursery stock from a variety of geographic locations.

Implement early detection / rapid response for invasive species (*ONF*) A focus on treating small problems before they become large, unsolvable problems recognizes that proactive management is more effective than crisis management. For example, the ONF land management plan recognizes that invasive plant species that establish in small patches can sometimes be eradicated. Although designed for situations like invasive plants, early detection / rapid response is also appropriate for climate change because it can allow managers to respond quickly to extreme events (disturbances, floods, windstorms) with an eye towards adaptation.

Treat large-scale disturbance as a management opportunity (*ONF and TNF*) Large-scale disturbances can cause rapid changes in ecosystems, but also provide opportunities to apply adaptation strategies. ONF is climatically buffered from disturbance complexes already evident in drier forests, but age-class studies and paleoecological evidence indicate that large-scale disturbances occurred in the past. In nearby British Columbia, fire suppression and harvest practices played a role in the current mountain pine beetle outbreak by homogenizing forest structure over large areas (Taylor et al. 2006). In ONF, the amount of young forest (as a result of twentieth century harvest) is both a risk (hence ONF emphasis on restoration) and an opportunity. Large disturbances (e.g., blowdowns caused by cyclonic winds in December 2007) can be used to influence the future structure and function of forests through planting and silviculture. Carefully designed management experiments for adapting to climate change can be implemented, provided that plans are in place in anticipation of large disturbances.

- Plan for post-disturbance recovery. Because large fires and other disturbances are expected, incorporating them into the planning process will encourage post-disturbance management actions that take climate into account, rather than treating disturbance as a crisis. Standard post-fire restoration practices do not typically consider climate, and it is desirable to develop more dynamic approaches to recovery following major disturbances.
- Plan for and implement revegetation and silvicultural options appropriate for a warmer climate. High-severity fires provide the opportunity for planting tolerant genotypes, mixed genotypes, and mixed species of trees and possibly other vegetation that will probably survive over decades to centuries. For example, on TNF, white fir (*Abies concolor*) could be favored over red fir (*Abies magnifica* var. *shastensis*), pines would be preferentially harvested over fir at high elevations, and species would be shifted upslope within seed transfer guides.
- Plan for large-scale vegetation dominance. The potential for rapid establishment of shrubs following post-disturbance tree mortality must be dealt with swiftly to allow forest regeneration through natural seeding and planting

Match engineering of infrastructure to expected future conditions (*ONF*) ONF managers identified road management as a nexus of several problems and priorities. Specific strategies included: (1) design and maintain roads to accommodate increased winter runoff; (2) install culverts that can handle increased peak flows of water and debris movement in winter; and (3) maintain drainage systems that limit increased sediment delivery to streams during winter peak flows.

Promote education and awareness about climate change Both ONF and TNF identified a critical role of public perception and employee knowledge in adaptation. Both suggested conducting trainings to ensure that employees understand climate change science and educational materials that document the role of active management in adaptation. TNF further identified a need for employees to know how to implement that science in management. ONF suggested (1) developing interpretive programs and materials that help educate ONF visitors and stakeholders and working with the scientific community to ensure awareness of recent scientific discoveries, whereas TNF was more specific an wanted to ensure that climate-change education is institutionalized and supported by line officers (TNF).

Collaborate with a variety of partners on adaptation strategies (*ONF*) ONF suggested it was important to work closely with Olympic National Park and other landowners and stakeholders to ensure compatibility of management objectives and adaptation strategies and to develop support for adaptation strategies.

One important difference between the two forests was the explicit focus on experimentation as part of adaptive management as a component of adaptation to climate change by TNF. This may be a dual consequence of the differences in the regional limitations imposed by the different panning requirements (NWFP vs SNFP) and the different natural and historical disturbance regimes on the two forests—TNF may have a longer history of active management beyond timber harvest, and clearly has a stronger need currently to deal with fire and its role in planning and adaptation. ONF's focus on restoration, introduction of landscape complexity back into its forests, and on species' habitat and connectivity is a direct response to the NWFP and informed by less frequent fire. When comparing the general adaptation strategies developed by ONF and TNF staffs in the focus groups, it became apparent that these were different conceptual approaches to forest management—both had elements of landscape management (e.g., connectivity, patch size) and resilience (e.g., managing for resource function and biodiversity at multiple scales), but the specific processes and species of concern reflect the challenges faced by the different forests—the approaches identified were broadly similar, but the endpoints that drove them were often quite different. For example, ONF's focus on increasing landscape diversity was to decrease the dominance of post-logging monoculture, but TNF's focus was on fire management and riparian areas. This suggests that the regionally unique natural and physical contexts of adaptation strongly affect the strategies and tools adopted by managers, but also that there are some common perceptions among managers of very different systems about the theoretical reasons for adopting the tools they do.

9 Opportunities and barriers for adapting to climate change

9.1 Olympic National Forest

The coordinated development of land management plans between ONF, Mt. Baker-Snoqualmie NF, and Gifford Pinchot NF is an important opportunity for adapting to climate change at the regional scale (Table 3). These national forests are all located on the west side of the Cascade Range in Washington and have similar natural resources and management issues. Although the target date for beginning this forest planning effort is not until 2015, resource management staffs have expressed strong support for collaborating on plans for adaptation in similar ecosystems subject to similar stressors. ONF has implemented a strategic plan that has similar capacity for guiding prioritization and can incorporate climate change science now, rather than waiting for the multi-forest plan. ONF can formalize the use of climate change concepts in management by explicitly addressing resilience to climate change—sand simultaneously developing any science needed to do so—in the ONF land management plan.

Integrating climate change into NWFP guidelines would be a major step forward for adaptation on national forests in the Pacific Northwest. The legacy of the twentieth-century timber economy in this region created ecological problems, but opportunities exist for current-day management. The composition and structure of forests in early successional stages can be influenced by timely management actions, and prescriptions such as targeted thinning and planting designed to promote resilience to climate change can be implemented. By recognizing the potential future effects of climate change on forest ecosystems (e.g., altered disturbance regimes), revised land management plans can become an evolving set of guidelines for resource managers. Key questions for national forests covered by the NWFP and for ONF in particular are: (1) will current and planned late-successional reserves remain resilient to a warmer climate and altered disturbance regimes? and (2) will management

Table 3 Opportunities and barriers for adapting to climate change in Olympic and Tahoe National Forests[a]

Olympic National Forest	Tahoe National Forest
Opportunities	
Collaborate with adjacent landowners and the general public	Collaborate with adjacent landowners and the general public
Integrate climate-change science into planning and management guidelines	Integrate climate-change science into planning and management guidelines
Coordinate development of land management plans among multiple national forests	Expand internal and external education about climate change
Improve science–management collaboration	Expand fuel treatments due to decreased snowpack
Barriers	
Limited financial resources and management personnel	Limited financial resources and management personnel
Constraints imposed by policies, laws, and regulations that are static relative to climate	Constraints imposed by policies, laws, and regulations that are static relative to climate
National and regional budget policies and processes	Legacy of past management and regulatory constraints, including small management units
Traditional focus on historical references for restoration and management	"Checkerboard" pattern of land ownership
	Expansion of residential development and recreational activities on private land
	Regulatory standards that restrict quantity and timing of management actions
	Appeals and litigation of proposed projects

[a]Order and wording differ from text to better illustrate similarities between national forests

practices need to change to ensure that late-successional reserves persist through time?

ONF staff are committed to nurturing ongoing collaborative relationships (e.g., with Olympic National Park) and starting new ones with agencies and organizations on the Olympic Peninsula. Cooperation can facilitate institutional and political leverage and compatible management strategies across boundaries. In addition, multi-agency partnerships improve the likelihood of successful adaptation by increasing the land base and resources for addressing issues and responding to unexpected outcomes. Multi-agency collaboration can be difficult because of conflicting legislation, mandates, and organizational cultures, but such collaboration will probably be a hallmark of successful adaptation to climatic change.

Barriers to adaptation on the ONF include limited (and declining) financial and human resources, policies that do not recognize climate change as a significant issue, and lack of an official science–management partnership. National and regional budget policies and processes constrain the potential for altering or supplementing current management practices to enable adaptation to climate change. For example, the current emphasis on hazardous fuel treatments in dry forest systems on the east side of the Cascade Range has reduced resources for stand density management and pathogen management in other forests. Increased collaboration between scientists and managers would streamline the process of proposing testable scientific questions and applying knowledge to management decisions and actions.

Policies, laws, and regulations based on a static view of the environment do not consider the flexibility required to adapt to changing conditions outside historical observations. The NFMA limits some management actions, and the NEPA delays implementation of actions. The ESA requires fine-scale conservation strategies for imperiled species and may be unrealistic if a rapidly changing climate results in habitat change at large spatial scales. As a result, protecting systems and landscape diversity may be more sustainable and a more efficient use of funding than attempting to protect individual species. The NWFP partially embraces this strategy, but does not focus specifically on climate change. In addition, the U.S. Clean Water Act could become a barrier as stream temperatures increase, resulting in unattainable standards. The above laws and policies focus on historical reference points in relatively static environments, but adaptation requires that future effects of climate change be included in the planning process.

9.2 Tahoe National Forest

TNF has maintained the capacity to implement adaptive projects through the NEPA process by emphasizing timely and effective response to public concerns through active dialog (Table 3). In addition, education of interested publics through workshops, scoping meetings, and face-to-face conversations have helped to develop support for plans, reduced the number of appeals, and enabled implementation of projects. For example, TNF gained public approval for some timber harvest activities through the use of computer visualizations, on-the-ground demonstration projects, and field-based education. An opportunity exists to further educate the public about climate change and the need for active management. Finally, when new personnel are hired, those positions can be required to have expertise in climate change, thus allowing TNF to gradually improve its institutional ability to respond to changing resource conditions.

TNF fire managers are taking advantage of lower snowpacks and earlier spring runoff by continuing fuel treatments beyond the time when historically these treatments could be done. For example, some prescribed fires can now be conducted in winter. This enables treating more land area with adaptive practices than if only summer were available. In addition, emerging carbon markets may promote the (re-)development of regional biomass and biofuels industries that could provide economic incentives for forest thinning and fuel reduction projects as a component of adaptation.

TNF staff expressed interest in conducting an assessment of planning documents (e.g., the land management plan) with an eye towards adaptation to climate change and improvement in current plans and operations. This assessment could rate the value of management direction (written policy), management practices (implementation), and conservation priorities for specific species and processes (fire, insects, disease) with respect to adaptation to climate change, and recommend needed improvements. The FPA and the TNF land management plan have the highest priority for assessment. The existence of the FPA adaptive management project and the Herger-Feinstein Quincy Library Group Forest Recovery Act (1998) means that opportunities exist for implementation of active management at broad spatial scales.

Barriers to adaptation exist because of the legacy of past resource conditions and management and because of regulatory and social constraints. For example, decades of fire exclusion, increasing stand densities, accumulating fuels, and expansion of human developments adjacent to TNF have increased the need for active management beyond the capacity of current personnel and funding. Alternating sections of TNF and private land create barriers to coordinated planning and management at large spatial scales. Achieving mutually agreeable management goals regarding prescribed fire, road building, fire suppression, post-fire recovery, and many other landscape treatments is extremely difficult. This is especially challenging in the central TNF where wildlife corridors and riparian forests could be enhanced through active management but cannot be implemented because of mixed ownership.

The use of small units (typically <50 ha) for timber harvest and other management activities across much of the TNF has resulted in a fragmented landscape at a scale different from what would be expected if fire and other ecological disturbances occurred unimpeded by human activities. This legacy of past land use has altered ecological structure and processes, requiring aggregation of smaller units into larger units that are more compatible with management of ecosystem processes. Management of larger units presents logistical and regulatory challenges, although TNF staff recognize that it is necessary to scale up practices in order to improve resilience to climate change. In addition, a traditional focus on maintaining, retaining, and restoring resource conditions has resulted in planning documents that enforce static resource conditions and limit dynamic planning and management.

Expansion of residential and recreational communities on private lands adjacent to TNF has created challenges for implementing silivicultural practices and prescribed burning, and has increased public opposition to those activities. Urban residents moving into the area often have little experience with fire and low tolerance for smoke. Many residents are reticent to adopt Fire-Safe Council recommendations for maintaining vegetation and fuels, thus putting their homes at risk from wildfire. In addition, strict regional regulatory standards for smoke and particulates enhance air quality, but they limit the capacity of the TNF to conduct prescribed fires to accomplish fuel reduction.

Declining funding for most operational functions over the past decade means many approved projects that would contribute to resilience cannot be implemented, and the annual federal budget process constrains long-term planning because of uncertainty about funding. Loss of key management divisions and a general decline in resource staff and planning expertise translate to lower capacity to respond adaptively. In addition, internal agency targets and rewards often focus on narrowly prescribed targets (e.g., total land area on which hazardous fuels have been reduced), leading to a focus on meeting targets through easily accomplished activities rather than on strategic development and implementation of landscape management.

Existing environmental laws (e.g., ESA, NEPA, NFMA) that were developed outside the context of climate change are perceived by TNF staff as a constraint on adaptive management (Levings 2003, *unpublished report*). Although coarse-filter (e.g., ecosystem-based) approaches are typically more adaptive, many existing laws force a fine-filter (e.g., single species or populations) approach to management. In addition, current federal management paradigms limit the capability to address dynamic ecosystem function. For example, policies based on historic range of variability or other historic references restrict adaptive capability. Some regional policies and procedures also limit adaptive response. For example, post-fire rehabilitation generally consists of short-term practices designed to reduce erosion and does not address long-term objectives for vegetation composition, structure, and function.

Appeals and litigation of proposed projects are perceived as a barrier to active management that would improve resilience to climate change (Levings 2003, *unpublished report*), creating a reactive approach to management rather than a visionary approach. If adaptive management projects involve on-the-ground disturbance (e.g., forest thinning), advocacy organizations often attempt to prohibit their implementation. This means that a large proportion of staff time is allocated to preparing "appeal-proof" (i.e., decisions that are unlikely to be successfully appealed because they document sufficient support for the action) NEPA documents rather than project implementation. This often results in no management action being taken, regardless of the intent to accomplish resource objectives, such as reducing hazardous fuels or improving tree vigor.

10 Tools and information needed for adaptation

10.1 Olympic National Forest

Information and tools needed to assist adaptation to climate change are primarily a long-term science–management partnership and decision-specific scientific information (Table 4). ONF staff expressed a specific request to scientists: natural resource managers need a manager's guide with scientific concepts and techniques to guide adaptation. Critical gaps in scientific information hinder adaptation by limiting assessment of risks, efficacy, and sustainability of actions. Managers would also like assistance and consultation on interpreting climate and ecosystem model output, so that the context and relevance of model predictions can be reconciled with managers' priorities for adaptation.

ONF managers identified a need to determine effectiveness of prevention and control efforts for exotic species, especially given that monitoring is critical and expensive. Data on genetic variability of dominant and rare species are needed to determine their potential to adapt to a warmer climate. Hydrologic modeling output is needed to inform forecasts of the quantity, seasonal patterns, and temperature of stream flow in the river systems on the Olympic Peninsula. Given budgetary constraints and ongoing mandates for resource monitoring, ONF managers realize that new data collection will be implemented only if it will be highly relevant, scientifically robust, and inform management objectives including adaptation to climate change.

10.2 Tahoe National Forest

TNF resource managers recognize that appropriate and practical management strategies are needed to address the challenges and contexts of climate change. Scientifically supported practices for integrating resource goals (e.g., fuels, sensitive species, water, fire) will lead to more effective ecosystem-based management (*sensu*

Table 4 Tools and information needed to facilitate adaptation to climate change in Olympic and Tahoe National Forests[a]

Olympic National Forest	Tahoe National Forest
Long-term science–management partnership focused on landscape and project planning	Long-term science–management partnership focused on landscape and project planning
Web-based clearinghouse with scientific information, tools, and guidelines to inform adaptation, planning, and priority setting	Web-based clearinghouse with scientific information, tools, and guidelines to inform adaptation, planning, and priority setting
Simulations of quantity, seasonal patterns, and temperature of stream flow for river systems on the Olympic Peninsula	Simulations of future climate, vegetation, and species movements, and uncertainties associated with these projections
Assistance with interpreting simulation output, so forecasts can be reconciled with management priorities for adaptation	Case studies of planning and practices for adaptive responses to climate, including demonstration examples that can be quickly disseminated
Technique to determine effectiveness of prevention and control for exotic species	Seed banks of native species and genotypes stocked to capacity for vegetation establishment following disturbance
Data on genetic variability of dominant and rare plant species to determine potential to adapt to a warmer climate	

[a] Order and wording differ from text to better illustrate similarities between national forests

Daniels and Walker 2001), which means that input from syntheses, integrated assessments, and relevant modeling output are needed from the scientific community to improve the capacity to respond adaptively.

Specific information needs cited by TNF managers include (Table 4):

- Modeled simulations of future climate, vegetation, species movements; and uncertainties associated with these projections.
- Seed banks of appropriate native species and genotypes stocked to capacity as a source for vegetation establishment following disturbance and population extirpation.
- Case studies of management planning and practices implemented as adaptive responses to climate, including demonstration examples that allow ideas to be quickly disseminated quickly and iteratively improved.
- A scientifically credible set of “climate smart” tools for fine-scale and coarse-scale management that inform and facilitate adaptation, strategic planning, and priority setting.
- Science–management partnerships focused on dynamic landscape and project planning, rather than static (or simply historical reference) resource conditions and targets.
- A Web-based scientific clearinghouse with current scientific information that is relevant to planning and management issues on national forests at all spatial scales.

11 Conclusions

Our effort to develop science-management partnerships on the ONF and TNF was successful in developing both general strategies and specific options for adapting to climate change—the first step in integrating climate change in management and planning. The next step will be to move forward with an action plan for implementing these options in management and planning processes at all levels of national forest operations, though it would be useful to approach this with a more structured approach to social assessment. Through the focus group process, we reached a mutual understanding that (1) climate change and its impacts are identifiable regionally, (2) adaptation to climatic change is necessary to ensure the sustainability of ecosystem services, and (3) current information, concepts, and tools can be used as a starting point for adaptation, but approaches that explicitly recognize climate change impacts and anticipate likely future conditions will be required. Many national forest management priorities are consistent with adaptation to climate change and with promoting resilience to the effects of climate change. However, limited financial resources and personnel make adaptation at large spatial scales difficult. Moreover, the effectiveness of adaptation strategies and practices is uncertain, which creates a challenge for resource managers accustomed to using specific practices to accomplish specific outcomes.

We are impressed with the diversity of adaptation options suggested by national forest resource managers. This gives us confidence that resource managers with professional expertise on local landscapes can adapt to climate change if scientists can provide the scientific basis for decision making. We are also encouraged that the outcomes of two focus group efforts on the Olympic and Tahoe National Forests have considerable overlap (Table 2). This suggests that there may be a core set of management strategies on which adaptation to climate change in national forests can be based (Millar et al. 2007a, b; Joyce et al. 2008). It should be possible to emulate this approach on additional national forests to improve our understanding of modal adaptation options as well as the range of options necessary for specific national forests.

The current political and regulatory environment for managing national forests is considered a severe limitation on adaptation to climate change. Policies, regulations, and administrative guidelines, though well intended for conservation objectives, cannot incorporate climate change because they focus on static rather than dynamic resource conditions. In addition, lengthy planning, review, and approval processes can delay timely implementation of management actions (e.g., following a large wildfire) that could facilitate adaptation. Some of these constraints can be overcome by making the science–management partnership on climate change permanent and by jointly developing a guide to climate change adaptation. Incorporating climate change explicitly into national, regional, and national forest policy would be a major step forward in implementing climate change in established planning processes and fostering “climate smart” management. Policies and regulations that provide guidance but allow for local/forest level strategies and management actions that increase resilience and reduce vulnerability to climate change would also promote adaptation. Finally, educational efforts to promote awareness of climate change will help create a more consistent approach within the Forest Service and gain support from various stakeholders for appropriate adaptation options.

ONF and TNF are at a crossroads. Some effects of climate change on forest ecosystems and natural resources in North America are already detectable (IPCC 2007). Adapting to those changes and sustaining ecosystem services is a priority, but adaptive capacity is limited by lack of local scientific information and uncertainty

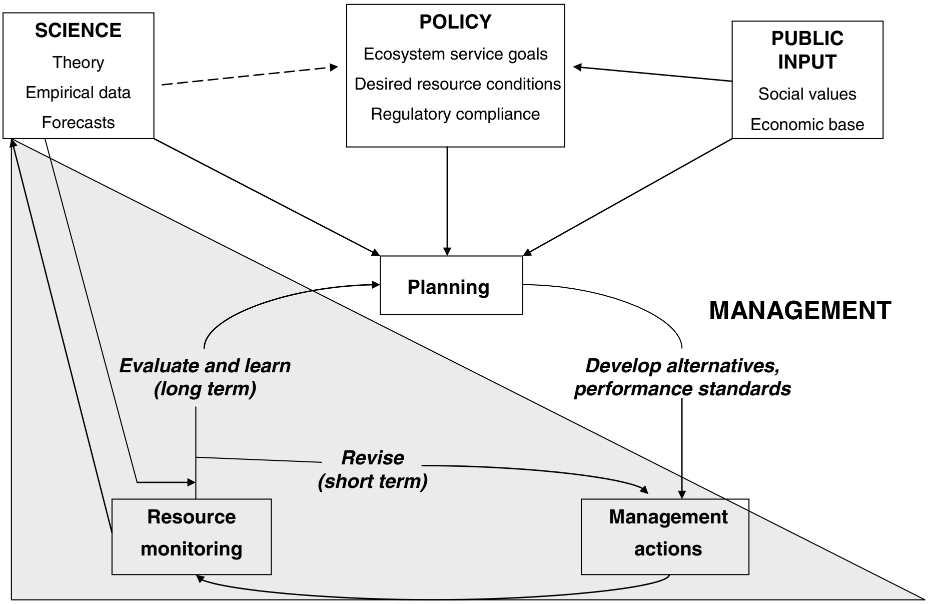

Fig. 2 By assuming that management is an ongoing experiment, the adaptive management process can be used as a framework for adaptation to climate change. Most adaptation to climate change occurs through the science–management partnership contained within the *shaded triangle*. A strong commitment to resource monitoring is the key to detecting the effects of climate change, evaluating the effectiveness of management actions, and making appropriate revisions. The *dotted line* from Science to Policy indicates a relatively weak connection

about outcomes of adaptive strategies. Adaptive management is the best general strategy for learning how to detect and manage the effects of climate change on forest ecosystems (Fig. 2), but if there is little flexibility in legally responding to dynamic ecosystem conditions, then adaptation options are severely limited. National forest managers indicated that, given current knowledge, regulations, and levels of funding and personnel, they would continue to emphasize management for diversity at all spatial scales as a no-regrets (e.g., de Loë et al. 2001; Luers and Moser 2006) strategy for building resilience to potentially adverse climate change effects.

We envision a future in which policy, planning, and scientific aspects of ecosystem-based management co-evolve with changes in climate and ecosystems. This vision requires trust, collaboration, and education among policy makers, land managers, scientists and the publics they serve. Climate will continue to change, effects on ecosystems will be difficult to predict, and land managers will endeavor to adapt to changes with limited resources. Strong science–management partnerships can produce information needed for credible decision making at all spatial scales of national forests and at all agency organizational levels. Less certain is how opportunities for adaptation will be realized while retaining public support for active resource management. ONF and TNF have already transitioned organizationally and socially from producing commodities to producing a broader range of ecosystem services. However, coevolution of adaptive management in the context of science, policy, and planning must progress quickly in order for adaptation to keep pace with anticipated effects of climate change.

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