

1 U.S. NATIONAL FORESTS ADAPT TO CLIMATE CHANGE THROUGH
2 SCIENCE-MANAGEMENT PARTNERSHIPS
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25 *Abstract.* Developing appropriate management options for adapting to climate change is
26 a new challenge for land managers, and integration of climate change concepts into operational
27 management and planning on United States national forests is just starting. We established
28 science-management partnerships on the Olympic National Forest (Washington) and Tahoe
29 National Forest (California) in the first effort to develop adaptation options for specific national
30 forests. We employed a focus group process in order to establish the scientific context necessary
31 for understanding climate change and its anticipated effects, and to develop specific options for
32 adapting to a warmer climate. Climate change scientists provided the scientific knowledge base
33 on which adaptations could be based, and resource managers developed adaptation options based
34 on their understanding of ecosystem structure, function, and management.

35 General adaptation strategies developed by national forest managers include: (1) reduce
36 vulnerability to anticipated climate-induced stress by increasing resilience at large spatial scales,
37 (2) consider tradeoffs and conflicts that may affect adaptation success, (3) manage for realistic
38 outcomes and prioritize treatments that facilitate adaptation to a warmer climate, (4) manage
39 dynamically and experimentally, and (5) manage for structure and composition. Specific
40 adaptation options include: (1) increase landscape diversity, (2) maintain biological diversity,
41 (3) implement early detection/rapid response for exotic species and undesirable resource
42 conditions, (4) treat large-scale disturbance as a management opportunity and integrate it in
43 planning, (5) implement treatments that confer resilience at large spatial scales, (6) match
44 engineering of infrastructure to expected future conditions, (7) promote education and awareness
45 about climate change among resource staff and local publics, and (8) collaborate with a variety
46 of partners on adaptation strategies and to promote ecoregional management.

47 The process described here can quickly elicit a large amount of information relevant for
48 adaptation to climate change, and can be emulated for other national forests, groups of national
49 forests with similar resources, and other public lands. As adaptation options are iteratively
50 generated for additional administrative units on public lands, management options can be
51 compared, tested, and integrated into adaptive management. Science-based adaptation is
52 imperative because increasing certainty about climate impacts and management outcomes may
53 take decades.

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55 *Key words: Adaptation; adaptive management; climate change; Olympic National Forest,*
56 *science-management partnership; Tahoe National Forest.*

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INTRODUCTION

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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.

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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. 2000), and proposed actions by governmental institutions (Rojas Blanco 2006, Joyce et al. 2002, Ligeti et al. 2007, Snover et al. 2007).

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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. 2006a]) 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

81 Program has developed a summary of adaptation options for federal land management agencies
82 (Julius and West 2008), with one chapter devoted to adaptation on U.S. Forest Service lands
83 (Joyce et al. 2008). Recent discussions on adaptation emphasize the importance of implementing
84 adaptive management (in a general sense, as opposed to adaptation to climate change), with
85 resource monitoring as a critical feedback to evaluation of management strategies (Millar et al.
86 2007, Joyce et al. 2008, Bosworth et al. in press).

87 Federal agencies have been criticized by the Government Accountability Office for being
88 slow to respond to mitigation and adaptation concerns on federal lands (GAO 2007) despite the
89 huge volume of scientific literature documenting a warming climate and effects of climate
90 change on natural resources (IPCC 2007). Nevertheless, in our experience, resource managers at
91 *local* administrative units (e.g., national forests, national parks) have a strong interest in
92 understanding the effects of climate change on resources, have demonstrated grass-roots
93 leadership on this issue, and are anxious to undertake the job of adapting to those changes.

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

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BIOGEOGRAPHIC SETTING AND NATURAL RESOURCES

104 *Olympic National Forest*

105 The Olympic Peninsula in western Washington (Fig. 1) consists of a mountain range and
106 foothills surrounded by the Pacific Ocean (west), the Strait of Juan de Fuca (north) and Puget
107 Sound (east) and low elevation, forested land (south). Its elevation profile extends from sea level
108 to nearly 2500 m at Mount Olympus in the Olympic Mountains. The range creates a strong
109 precipitation gradient, with historic precipitation averages of about 500 cm in the lowlands of the
110 southwestern peninsula, 750 cm in the high mountains, and 40 cm in the drier northeastern
111 lowlands. The climate is mild temperate rainy with a Mediterranean (dry) summer; most of the
112 precipitation falls in winter, and at higher elevations nearly all of it is snow that persists well into
113 summer. The biophysical landscape comprises a diverse array of ecological conditions with
114 coastal estuaries and forests, mountain streams and lakes, temperate rainforests, alpine tundra,
115 and mixed conifer forests, including over 2000 vascular plant species (Buckingham et al. 1995).
116 Low elevation forests are predominantly second growth, and most subalpine forests have never
117 been logged. Wind is a prevalent disturbance at multiple spatial scales, with occasional major
118 cyclonic wind events. Fire regimes are mostly characterized as high severity, with return
119 intervals of 100-500 years. Crown fires that encompass >50,000 ha are common in the historical
120 and paleohistorical records (Henderson et al. 1989). Many insect species and fungal pathogens
121 cause small patches of tree mortality (<10 ha) but rarely occur over large areas.

122 Ecosystems on the peninsula are contained within a mosaic of federal, state, tribal, and
123 private ownership. Olympic National Forest (ONF), comprising ~257,000 ha (including five
124 wilderness areas), surrounds the core of the peninsula, Olympic National Park (ONP; ~364,000
125 ha). Additional land managers on the peninsula include 12 Native American tribes, the
126 Washington Department of Natural Resources, several companies that produce timber for wood

127 products, and many nonindustrial private forest owners. Approximately 3.5 million people live
128 within four hours' travel of ONF. Ecosystem services from ONF include water supply to several
129 municipal watersheds, nearly pristine air quality, a wide range of recreational opportunities, and
130 abundant fish and wildlife, including several endemic species of plants and animals such as the
131 Olympic marmot (*Marmota olympus*) and Roosevelt elk (*Cervus elaphus roosevelti*), and critical
132 habitat for four threatened species of birds and anadromous fish.

133 Before 1990, ONF produced large amounts of timber and generated significant revenue
134 for local mills, secondary processing, and shipping. Timber production from ONF was greatly
135 reduced following implementation of the 1994 Northwest Forest Plan (NWFP) which mandated
136 long-term management for late-successional forest structure for the protection of northern
137 spotted owl (*Strix occidentalis caurina*), marbled murrelet (*Brachyramphus marmoratus*), and
138 aquatic systems. Fisheries and wildlife, watershed protection, and recreation are emphasis areas
139 for management.

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141 *Tahoe National Forest*

142 Tahoe National Forest (TNF) is located in eastern California, where it straddles the
143 northern Sierra Nevada (Fig. 1). The administrative boundary encompasses 475,722 ha, one-
144 third of which is privately owned forest industry lands arranged in alternate “checkerboard”
145 sections with TNF land. Elevations range from 365 m at the edge on the west slope to 2788 m at
146 the crest of the Sierra. The eastern slopes of TNF abut high-elevation (~1525 m), arid steppes of
147 the Great Basin. TNF experiences a Mediterranean-type climate with warm, dry summers
148 alternating with cool, wet winters. The orientation of the Sierra Nevada paralleling the Pacific
149 coast creates a steep west-east climatic gradient that contributes to strong orographic effects in

150 temperature and a precipitation rain shadow. Near the TNF western boundary, average
151 precipitation is 125 cm, highest at west-side mid-elevations (200 cm) and lowest near the eastern
152 boundary (50 cm). Snow dominates winter precipitation in the upper elevations, providing water
153 reserves during dry summers.

154 Floral and faunal diversity of the TNF parallels the topographic and climatic gradients of
155 the Sierra Nevada, with strong zonation along elevational bands. The long Mediterranean
156 drought is a primary influence on species that can persist in the presence of relatively frequent
157 natural disturbance. Pine forests occupy low elevations on the west side, grading upslope to a
158 broad zone of ecologically and economically important mixed-conifer forests. True-fir forests
159 dominate at the elevation of the rain-snow zone, and diverse subalpine forests dominate at higher
160 elevations. East of the crest, low-density pine forests grade downslope to woodlands and
161 shrublands of the Great Basin. Terrestrial and aquatic environments of the TNF support critical
162 habitat for 387 vertebrate species and over 400 plant species (TNF 1990 *public communications*¹,
163 Shevock 1996). Several plant species depend on limited old-growth forest conditions or other
164 rare habitats.

165 Cultural legacies play significant roles in shaping present forest conditions and
166 vulnerabilities on the TNF. Timber, water, mining, and grazing starting in the mid-1800s
167 remained intensive uses until the late 20th century. Low- to mid-elevation forests were logged in
168 the mid-1800s through early 1900s and subsequently re-grew, and although they continued to be
169 harvested until recently, fire exclusion has contributed to dense stands, even-age classes, and low
170 structural diversity. As a result, accumulations of hazardous fuels have been involved in large,
171 severe wildfires in recent years, and managing fire hazard is a high priority. Population increase

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

172 and residential and commercial expansion in communities adjacent to TNF have created
173 wildland-urban interface issues (Duane 1996), which, combined with the resource values of new
174 residents, have forced re-evaluation of TNF goals and practices. For example, recreation is now
175 a primary use of TNF lands, and timber management is minor. Fuels reduction is a key issue for
176 reducing wildfire severity to protect natural resource values and adjacent communities.

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METHODS

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We used a two-day focus group process to review 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:

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- 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?

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

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

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205 ANTICIPATED CLIMATE CHANGE AND EFFECTS ON RESOURCES

206 *Olympic National Forest*

207 Temperature in the Pacific Northwest region (PNW; Washington, Oregon, Idaho,
208 western Montana) has warmed 0.7-0.9°C since 1920, with most of the warming since 1950, and
209 winter has warmed faster than summer (Mote 2003). Decadal variability has dominated annual
210 precipitation trends. Annual precipitation in the PNW increased 14% during 1930-1995,
211 although this trend is not significant. Decadal variability is therefore the most important feature
212 of precipitation during the 20th century. Regional climate models suggest an increase in mean
213 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
214 2080s (Mote et al. 2005, Salathé 2005, Salathé et al. 2007), and summer temperatures are
215 expected to increase more than winter temperatures (Table 1). Precipitation changes are less
216 certain, but slight increases in annual and winter precipitation are expected, whereas slight
217 decreases in summer precipitation are possible (Salathé 2005).

218 Winter temperature increase has caused the form of winter precipitation to change at low
219 and mid elevations, with up to 60% declines in April 1 snow water equivalent in the Olympic
220 Mountains (Mote et al. 2005). The timing of spring runoff is 10-30 days earlier in 2000 than in
221 1948 (Stewart et al. 2004). If these trends continue, then snowpacks at low to mid elevation will
222 decrease, with a shift in timing of spring snowmelt and runoff, and summer evapotranspiration
223 will increase (Mote et al. 2005, Hamlet et al. 2007). Winter runoff (October to March) will
224 increase, summer runoff (April to September) will decrease (Hamlet et al. 2007), and streamflow
225 will increase in winter and decrease in summer. Floods will increase in frequency because
226 buffering by snowpacks will decrease and because more precipitation will occur as rain rather
227 than snow. Higher temperatures and lower summer flows will have negatively affect most
228 anadromous and resident fish species (Francis and Mantua 2003).

229 Proxy records indicate that climatic variability has affected ecological processes on the
230 Olympic Peninsula for millennia (e.g., Gavin et al. 2001). For example, pollen spectra from
231 subalpine lakes in the Olympics indicate common responses after the retreat of Pleistocene
232 glaciers, divergent vegetation in the early Holocene, and convergent responses in the late
233 Holocene (McLachlan and Brubaker 1995). Modern studies have quantified the effects of
234 climatic variability on growth and limiting factors for regeneration (Woodward et al. 1995) and
235 growth (Peterson and Peterson 2001, Peterson et al. 2002, Nakawatase and Peterson 2006) of
236 most tree species. Paleo and modern studies indicate that, for a given regional shift in climate,
237 the ecological and climatic context of a particular site determines the degree and nature of the
238 response, to such an extent that high vs. low elevation and west (wet) vs. east (dry) side of the
239 Olympics will have different (and sometimes opposite) responses to a uniform climate change
240 (Holman and Peterson 2006).

241 Increased summer temperature may lead to non-linear increases in evapotranspiration
242 from vegetation and land surfaces (McCabe and Wolock 2002). This, in turn, would decrease
243 growth (Nakawatase and Peterson 2006, Littell et al. 2008) and fuel moisture in lower elevation
244 (e.g., Douglas-fir [*Pseudotsuga menziesii*], western hemlock [*Tsuga heterophylla*]) forests while
245 increasing growth (Peterson and Peterson 2001, Peterson et al. 2001, Nakawatase and Peterson
246 2006) and regeneration (Woodward et al. 1995) in high elevation (e.g., subalpine fir [*Abies*
247 *lasiocarpa*], mountain hemlock [*T. mertensiana*]) forests. Higher temperatures would also affect
248 the range and decrease generation time of climatically-limited forest insects such as the mountain
249 pine beetle (*Dendroctonus ponderosae*) (Logan et al. 2003), as well as increase the area burned
250 by fire in ecoprovinces of western Washington (Littell et al., in press).

251 Distribution and abundance of plant and animal species will probably change over time
252 (Zolbrod and Peterson 1999), given that paleoecological data show that this has always been a
253 result of climatic variability in the range expected for future warming. This change may be
254 difficult to observe at small scales, and will be facilitated by large disturbances such as fire or
255 windstorms that remove much of the overstory and “clear the slate” for a new cohort of
256 vegetation. The regeneration phase will be the key stage at which species will compete and
257 establish in a warmer climate, thus determining the composition of future vegetative assemblages
258 and animal habitat.

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Tahoe National Forest

261 The trend of temperature increase over the 20th century for California and the Sierra
262 Nevada has paralleled the global pattern (IPCC 2007) although at greater magnitude (1.5-2.0°C;

263 Millar et al. 2004, WRCC 2005 *unpublished data*², Cayan and Hanemann 2008) (Table 1).
264 Regional climate models for California suggest an increase in mean temperature of 1.3 to 2.0°C
265 (mean 1.6°C) by the 2040s and 2.3 to 5.8°C (mean 3.7°C) by the 2090s, with summer
266 temperatures expected to increase more than winter temperatures (Cayan et al. 2008; Hidalgo et
267 al. in press; Hayhoe et al. 2004; Table 1). Projections from downscaled regional climate models
268 indicate that mean annual temperatures after 2050 in northern California will consistently be at
269 or above 90th-percentile values of the 1960-1990 average, and the number of days exceeding the
270 99.99th-percentile from the 1961-1999 record will rise exponentially to about 40 days per year
271 by the end of the century (Cayan and Hanemann 2008).

272 Precipitation over the course of the 20th century in the northern Sierra has not shown
273 strong directional changes, but has been variable at annual and interannual scales following
274 ocean circulation phases and transient synoptic climatic events (Cayan et al. 1999), as well as
275 anthropogenic inputs (Barnett et al. 2008). Until recently, projections for future precipitation in
276 the northern Sierra Nevada have not conclusively indicated drier or wetter conditions for the 21st
277 century (Cayan et al. 2006; Hayhoe et al. 2004). Recent modeling runs that incorporate the most
278 current downscaled information, however, are indicating a preponderance of dry years in model
279 outputs for the second half of the 21st century, leading climate scientists to tentatively warn that
280 the future in northern California mountains is likely to be drier than the recent past (Barnett et al.
281 2008, Cayan et al. 2008, Cayan and Haneman 2008, Hidalgo et al. in press).

282 Although multi-year droughts have been as common in recent as in past centuries in
283 northern California (NOAA 2005), interaction of drought with increased temperature has
284 resulted in higher stress to Sierra Nevada vegetation than under cooler climates of prior centuries

² (<http://wrcc.dri.edu>)

285 (Millar et al. 2007). Forest insect and disease, mortality, and fire events have become more
286 frequent or severe in the Sierra Nevada during the 20th century (Westerling et al. 2006a, 2006b;
287 Millar et al. 2007; Van Mantgem et al. 2007; Battles et al. 2008). Decreases in average
288 snowpack up to 80% are documented for 1950-1997 in parts of the West including the Sierra
289 Nevada (Hayhoe et al. 2004, Knowles et al. 2006) with peak snowpacks as much as 45 days
290 earlier (Hamlet et al. 2005, Mote et al. 2005), peak streamflow up to three weeks earlier in spring
291 (Stewart et al. 2005) leading to early stream run-off (Dettinger et al. 2004), decreased overall
292 runoff (Stewart et al. 2004, Maurer et al. 2007) and increased spring extreme flood events
293 (Cayan and Hanemann 2008). Snowpacks are modeled as declining up to 97% at 1000 m
294 elevation and 89% for all elevations in California (Hayhoe et al. 2004, Knowles et al. 2006). For
295 northern California specifically, the number of years projected to have snowpacks as low as the
296 1961-1990 10th percentile average will increase after 2050 to over half the years (Cayan et al.
297 2008; Cayan and Hanemann 2008). The combined effects of continued warming, declining
298 snowpacks, and earlier stream runoff portend longer summer droughts and increasing soil
299 moisture deficits during summer relative to the past century. This may have altered montane
300 vegetation zones (Thorne et al. in press) and increased invasive species (Johnson 2008).

301 Coupling climate models with vegetation models yields with moderate confidence major
302 contractions and expansions in cover of dominant montane vegetation types by the late 21st
303 century (Hayhoe et al. 2004, Lenihan et al. 2005 *public communications*³), increases in invasive
304 species (Johnson 2008), and declines in endemic flora (Loarie et al. 2008). By 2070-2099,
305 alpine and subalpine forest types are modeled to decline as much as 90%, shrublands by 75%,
306 and mixed evergreen woodland by 50%. In contrast, mixed evergreen forest and grasslands are

³ www.climatechange.ca.gov/climate_action_team/reports/

307 each modeled to expand by 100%. The following conditions are expected to be exacerbated on
308 the TNF as a result of anticipated changes (Dettinger et al. 2004; Hayhoe et al. 2004; Cayan et al.
309 2006; Westerling et al. 2006a, 2006b; confidence levels in parentheses):

- 310 • Increased fuel build-up and risk of severe and widespread forest fire (highest)
- 311 • Longer fire seasons; year-round fires in some areas (highest)
- 312 • Wildfire and insect outbreaks occurring at higher elevations than they have historically
313 (highest)
- 314 • Increased interannual variability in precipitation, leading to fuels build-up and additional
315 forest stress, promoting high fire hazard (high)
- 316 • Increased water temperature in rivers and lakes and lower water levels in late summer (high)
- 317 • Increased stress to forests during periodic multi-year droughts; increased forest mortality
318 (high)
- 319 • Decreased water quality as a result of increased watershed erosion and sediment flow
320 (moderate-high)
- 321 • Increased severe flood events (moderate-high)
- 322 • Loss of seed and other germplasm sources as a result of population extirpation (low-
323 moderate).

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325 **POLICY, PLANNING AND MANAGEMENT ENVIRONMENTS**

326 *Olympic National Forest*

327 Current natural resource management issues in ONF stem primarily from policy
328 mandates, historical land use and forest fragmentation, and multi-agency land ownership on the
329 Olympic Peninsula (Fig. 1). ONF is a “restoration forest” charged with managing large,

330 contiguous areas of second growth forest. Management objectives include enhancing native
331 biodiversity and promoting the development of late-successional forests (e.g., the NWFP),
332 restoring and protecting aquatic ecosystems from the impacts of an aging road infrastructure, and
333 managing for individual threatened and endangered species as defined by the U.S. Endangered
334 Species Act (ESA) or other policies related to the protection of rare species.

335 Most ONF management activities are focused on restoring important habitats (e.g., late-
336 successional forests, pristine streams), rehabilitating or restoring logging roads, controlling
337 invasive species, and monitoring. Collaboration with other agencies is a cornerstone of the
338 NWFP. Planning guidelines for ONF are structured by mandates from the National Forest
339 Management Act (NFMA) and the NWFP. The ONF land management plan is influenced by the
340 NWFP. Project planning is often a time- and resource-intensive process, because National
341 Environmental Policy Act (NEPA) procedures generally include review from stakeholders and
342 the general public. Incorporating regional climate change information into Environmental
343 Assessments and Environmental Impact Statements can be difficult, because assessment
344 typically occurs at spatial scales of a few thousand hectares or less, whereas climate change
345 information is available at regional to subregional scales.

346 Adaptation to climate change has not been addressed in the ONF land management plan
347 or in planning for most management activities. Current management objectives include efforts to
348 confer resilience by promoting landscape diversity and biodiversity, an approach that is
349 compatible with adaptation to climate change. To this end, approaches available to ONF
350 managers include restoration of aquatic systems (especially the minimization of the impacts of
351 roads, bridges, and culverts), active management of terrestrial systems (through thinning and
352 planting), and treatment of invasive species. Prescribed fire and wildland fire use are unlikely

353 tools because of the low historical area burned, limitations of the U.S. Clean Air Act, and low
354 funding levels. The range of strategies and information for using these tools varies across ONF
355 land use designations. Late Successional Reserves and Wilderness have less flexibility for active
356 management than designated Adaptive Management Areas, because there are more explicit
357 restrictions on land use and silvicultural options.

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Tahoe National Forest

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

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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.

376 With regard to aquatic, riparian, and meadow habitat, the FPA goals and management
377 direction are intended to improve the quantity, quality, and extent of degraded wetlands
378 throughout the Sierra Nevada, and to improve habitat for aquatic and wetland-dependent wildlife
379 species such as willow flycatcher (*Empidonax traillii*). Direction for managing fire and fuels
380 provides a coordinated strategy for addressing the risk of large wildfires by reducing hazardous
381 fuels while maintaining ecosystem functions and providing local economic benefits. Specific
382 approaches to these goals are conditioned by the National Fire Plan of 2002 (USDA/USDO
383 2000 *public communication*⁴) and the Healthy Forests Restoration Act of 2003 (HFRA 2003)
384 which emphasize strategic placement of fuel treatments, removal of fuels to reduce fire severity,
385 and economic efficiency.

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

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397 **ADAPTING TO CLIMATE CHANGE THROUGH MANAGEMENT AND PLANNING**

⁴ <http://www.forestsandrangelands.gov/reports/documents/2001/8-20-en.pdf>

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Olympic National Forest

The ONF regulatory and policy environment demands a high level of responsibility for management and planning, but scientific information and guidance for adaptation to climate change have only recently been synthesized in a form useful for resource managers (Joyce et al. 2008). Nevertheless, resource managers in the focus groups developed both general and specific adaptation approaches to address potential effects of climate change (Table 2). General adaptation strategies developed by ONF staff include the following:

Manage for resilience, decrease vulnerability

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.

Prioritize climate-smart treatments

Prioritizing treatments with the greatest likelihood of being effective in the long run recognizes 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 (Fig. 2), 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.

421 *Consider tradeoffs and conflicts*

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

428

429 Specific adaptation options developed by ONF staff in the focus group are:

430

431 *Increase landscape diversity*

- 432 • Apply targeted forest thinning to increase variability in stand structure, increase resilience to
433 stress by increasing tree vigor, and reduce vulnerability to disturbance.
- 434 • Implement thinning and harvest treatments appropriate for different landscapes and avoid
435 “one size fits all” management prescriptions.
- 436 • Create forest gaps large enough for elk habitat but small enough to minimize invasive
437 species.
- 438 • Maintain corridors that link habitat for animal species that migrate and have large home
439 ranges.

440

441 *Maintain biological diversity*

442 Appropriate species and genotypes can be planted in anticipation of a warmer climate,
443 assuming that credible scientific justification is available on which to base planting decisions.

444 This allows resource managers to “hedge their bets” by diversifying the phenotypic and
445 genotypic template on which climate and competition interact, and to avoid widespread mortality
446 at the regeneration stage.

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

452

453 *Implement early detection / rapid response for invasive species*

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

461

462 *Treat large-scale disturbance as a management opportunity*

463 Large-scale disturbance causes rapid changes in ecosystems, but also provides
464 opportunities to apply adaptation strategies. ONF is climatically buffered from disturbance
465 complexes already evident in drier forests, but age-class studies and paleoecological evidence
466 indicate that large-scale disturbances occurred in the past. In nearby British Columbia, fire

467 suppression and harvest practices played a role in the current mountain pine beetle outbreak by
468 homogenizing forest structure over large areas (Taylor et al. 2006). In ONF, the amount of
469 young forest (as a result of 20th-century harvest) is both a risk (hence ONF emphasis on
470 restoration) and an opportunity. Large disturbances (e.g., blowdowns caused by cyclonic winds
471 in December 2007) can be used to influence the future structure and function of forests through
472 planting and silviculture. Carefully designed management experiments for adapting to climate
473 change can be implemented, provided that plans are in place in anticipation of large disturbances.

474

475 *Match engineering of infrastructure to expected future conditions*

- 476 • Design and maintain roads to accommodate increased winter runoff.
- 477 • Install culverts that can handle increased peak flows of water and debris movement in winter.
- 478 • Maintain drainage systems that limit increased sediment delivery to streams during winter
479 peak flows.

480

481 *Promote education and awareness about climate change*

- 482 • Conduct trainings at ONF to ensure that employees understand climate change science.
- 483 • Develop interpretive programs and materials that help educate ONF visitors and
484 stakeholders.
- 485 • Develop educational materials that document the role of active management in adaptation.
- 486 • Work with the scientific community to ensure awareness of recent scientific discoveries

487

488 *Collaborate with a variety of partners on adaptation strategies*

- 489 • Work closely with Olympic National Park and other landowners to ensure compatibility of
490 management objectives and adaptation strategies.
- 491 • Work with a diversity of local landowners, agencies, and stakeholders to develop support for
492 adaptation strategies.

493

494

Tahoe National Forest

495 Few management policies or plans for the TNF specifically address climate or climate
496 adaptation. Thus, while it would appear that “no adaptation” is the dominant paradigm on TNF,
497 many practices are potentially “climate smart” if trends or potential changes in climate can be
498 qualitatively or quantitatively considered by management. Most post-disturbance treatments
499 planned by TNF were developed to attain goals for ecosystem conditions (e.g., watershed
500 protection, succession to forest after wildfire, fuel reduction after insect mortality) rather than
501 catalyzing climate-adaptive conditions. Nonetheless, many management practices are consistent
502 with adaptive conditioning for climate contexts. For example, limited timber harvest following
503 fire facilitates planting of trees of appropriate species and genotypes. Although this is difficult to
504 implement quickly at large spatial scales, TNF has been able to respond on small areas following
505 disturbance when NEPA documentation has withstood appeals and litigation (Levings 2003
506 *unpublished report*⁵). In these circumstances, watershed protection measures are implemented,
507 and species and seed sources tolerant of a warmer climate are matched to specific sites.

508 Although the TNF has not directly addressed climate through active management, the
509 resource management staff has been discussing implications of climate change for many years.
510 This thinking has pre-conditioned the TNF to consider climate in management actions, with

⁵ Economics of delay. On file at the Tahoe National Forest.

511 discussion among staff regarding potential changes in strategic planning areas. In addition,
512 advances have been made in integrated planning processes that may be useful for incorporating
513 climate-adaptive treatments, thereby facilitating proactive management. General adaptation
514 strategies developed by TNF staff in the focus group include (Table 2):

515

516 *Manage dynamically and experimentally*

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

522

523 *Manage for process*

524 Project planning and management can be used to maintain or enhance ecological
525 processes rather than to design structure or composition. For example, novel mixes of species
526 and spacing can be used following fire in order to reflect potential natural dynamic processes of
527 adaptation.

528

529 *Manage for realistic outcomes*

530 Projects that are currently a component of the planning process may have a higher failure
531 rate in a warmer climate, and it will become increasingly important to assess the viability of
532 management goals and desired outcomes in this context. For example, restoring salmon species
533 to TNF rivers is a goal in the current land management plan. However, as water in streams

534 becomes warmer, those streams may become unsuitable spawning and rearing habitat.
535 Therefore, choosing not to restore salmon may be an appropriate decision. Similarly, it may be
536 appropriate to not restore mountain meadows with grasses and forbs (an approved management
537 activity) if those meadows will inevitably become dominated by trees in a warmer climate.

538

539 Specific adaptation options developed by TNF managers in the focus group are:

540

541 *Treat large-scale disturbance as a management opportunity*

- 542 • Plan for post-disturbance recovery. Because large fires and other disturbances are expected
543 periodic occurrences, incorporating them into the planning process will encourage post-
544 disturbance management actions that take climate into account, rather than treating
545 disturbance as an anomaly or crisis. Standard post-fire restoration practices do not typically
546 consider climate, and it is desirable to develop more dynamic approaches to recovery
547 following major disturbances.
- 548 • Plan for and implement revegetation and silvicultural options appropriate for a warmer
549 climate. High-severity fires provide the opportunity for planting tolerant genotypes, mixed
550 genotypes, and mixed species of trees and possibly other vegetation that will probably
551 survive over decades to centuries. For example, where appropriate based on anticipated
552 changes, white fir (*Abies concolor*) could be favored over red fir (*Abies magnifica* var.
553 *shastensis*), pines would be preferentially harvested over fir at high elevations, and species
554 would be shifted upslope within seed transfer guides.

- 555 • Plan for large-scale vegetation dominance. The potential for rapid establishment of shrubs
556 following post-disturbance tree mortality must be dealt with swiftly to allow forest
557 regeneration through natural seeding and planting.

558

559 *Increase landscape diversity*

- 560 • Implement landscape planning at large spatial scales. Managing for a variety of different
561 forest structures and vegetation composition will increase opportunities for adaptation to a
562 warmer climate and large disturbances. This includes thinning and harvest treatments
563 appropriate for different landscapes, rather than “standard” prescriptions (Fig. 3). Planning
564 for “firesheds” in terms of vegetation and fuel patterns addresses fire management and
565 simultaneously creates a variety of landscape patterns at large spatial scales.

- 566 • Plan fuel reduction projects strategically. TNF has an assertive program to reduce fuel
567 accumulations in order to minimize fire severity and the potential for large crown fires. By
568 arraying these treatments in patterns presumed to reduce fire spread, it may be possible to
569 increase the resilience of TNF forests to more frequent fires and to increase tree vigor.

570

571 *Increase resilience at large spatial scales*

- 572 • Implement resilience management as a pathway to adaptation. Proactive management that
573 improves the resilience of natural resources to ecological disturbance and environmental
574 stressors generally improves adaptive capability for climate change. Resilience management
575 decreases the number of situations in which TNF must respond in “crisis mode.”

- 576 • Protect riparian areas. Riparian areas are landscape features for specific types of habitat and
577 animal species and have high value for biodiversity. New policies for riparian and watershed

578 management limit roads for timber management from being constructed across perennial
579 streams. Helicopters are used for logging where roads cannot be built. This maintains
580 reserves of biodiversity across large landscapes and reduces fragmentation and erosion.

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

590

591 *Increase management unit size*

592 Management units are often <50 ha because of logistical and financial considerations.
593 Increasing the size of management units to hundreds or thousands of hectares across logical
594 biogeographic entities such as watersheds will decrease “administrative fragmentation” over
595 space and time and improve the likelihood of accomplishing objectives. Ecosystem-based
596 management at large spatial scales and for multiple species and resource values will favor
597 adaptability to climate-related challenges.

598

599 *Promote education and awareness about climate change*

- 600 • Conduct trainings to ensure that TNF employees understand climate change science and
601 know how to implement it in management.
- 602 • Ensure that climate-change education is institutionalized and supported by line officers.
- 603 • Develop educational materials that document the role of active management in adaptation.

604

605 **OPPORTUNITIES AND BARRIERS FOR ADAPTING TO CLIMATE CHANGE**

606 *Olympic National Forest*

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

618 Integrating climate change into NWFP guidelines would be a major step forward for
619 adaptation on national forests in the Pacific Northwest. The legacy of the 20th-century timber
620 economy in this region created ecological problems, but opportunities exist for current-day
621 management. The composition and structure of forests in early successional stages can be
622 influenced by timely management actions, and prescriptions such as targeted thinning and

623 planting designed to promote resilience to climate change can be implemented. By recognizing
624 the potential future effects of climate change on forest ecosystems (e.g., altered disturbance
625 regimes), revised land management plans can become an evolving set of guidelines for resource
626 managers. Key questions for national forests covered by the NWFP and for ONF in particular
627 are: (1) will current and planned late-successional reserves remain resilient to a warmer climate
628 and altered disturbance regimes, and (2) will management practices need to change to ensure that
629 late-successional reserves persist through time?

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

638 Barriers to adaptation on the ONF include limited (and declining) financial and human
639 resources, policies that do not recognize climate change as a significant issue, and lack of an
640 “official” science-management partnership. National and regional budget policies and processes
641 constrain the potential for altering or supplementing current management practices to enable
642 adaptation to climate change. For example, the current emphasis on hazardous fuel treatments in
643 dry forest systems on the east side of the Cascade Range has reduced resources for stand density
644 management and pathogen management in other forests. Increased collaboration between

645 scientists and managers would streamline the process of proposing testable scientific questions
646 and applying knowledge to management decisions and actions.

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

658

659 *Tahoe National Forest*

660 The TNF has maintained the capacity to implement adaptive projects through the NEPA
661 process by emphasizing timely and effective response to public concerns through active dialog
662 (Table 3). In addition, education of interested publics through workshops, scoping meetings, and
663 face-to-face conversations have helped to develop support for plans, reduced the number of
664 appeals, and enabled implementation of projects. For example, TNF gained public approval for
665 some timber harvest activities through the use of computer visualizations, on-the-ground
666 demonstration projects, and field-based education. An opportunity exists to further educate the
667 public about climate change and the need for active management. Finally, when new personnel

668 are hired, those positions can be required to have expertise in climate change, thus allowing TNF
669 to gradually improve its institutional ability to respond to changing resource conditions.

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

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

686 Barriers to adaptation exist because of the legacy of past resource conditions and
687 management and because of regulatory and social constraints. For example, decades of fire
688 exclusion, increasing stand densities, accumulating fuels, and expansion of human developments
689 adjacent to TNF have increased the need for active management beyond the capacity of current
690 personnel and funding. Alternating sections of TNF and private land create barriers to

691 coordinated planning and management at large spatial scales. Achieving mutually agreeable
692 management goals regarding prescribed fire, road building, fire suppression, post-fire recovery,
693 and many other landscape treatments is extremely difficult. This is especially challenging in the
694 central TNF where wildlife corridors and riparian forests could be enhanced through active
695 management but cannot be implemented because of mixed ownership.

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

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

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

722 Existing environmental laws (e.g., ESA, NEPA, NFMA) that were developed outside the
723 context of climate change are perceived by TNF staff as a constraint on adaptive management
724 (Levings 2003).⁶ Although coarse-filter (e.g., ecosystem-based) approaches are typically more
725 adaptive, many existing laws force a fine-filter (e.g., single species or populations) approach to
726 management. In addition, current federal management paradigms limit the capability to address
727 dynamic ecosystem function. For example, policies based on historic range of variability or
728 other historic references restrict adaptive capability. Some regional policies and procedures also
729 limit adaptive response. For example, post-fire rehabilitation generally consists of short-term
730 practices designed to reduce erosion and does not address long-term objectives for vegetation
731 composition, structure, and function.

732 Appeals and litigation of proposed projects are perceived as a barrier to active
733 management that would improve resilience to climate change (Levings 2003),⁷ creating a
734 reactive approach to management rather than a visionary approach. If adaptive management
735 projects involve on-the-ground disturbance (e.g., forest thinning), advocacy organizations often

⁶ Economics of delay. On file at the Tahoe National Forest.

⁷ Economics of delay. On file at the Tahoe National Forest.

736 attempt to prohibit their implementation. This means that a large proportion of staff time is
737 allocated to preparing “appeal-proof” NEPA documents rather than project implementation.
738 This often results in no management action being taken, regardless of the intent to accomplish
739 resource objectives, such as reducing hazardous fuels or improving tree vigor.

740

741 **TOOLS AND INFORMATION NEEDED FOR ADAPTATION**

742 *Olympic National Forest*

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

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

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Tahoe National Forest

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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* 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.

767

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

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- 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.

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CONCLUSIONS

Our effort to develop scientific-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. Through the focus group process, we reached a mutual understanding that climate change and its impacts are identifiable regionally and that adaptation to climatic change is necessary to ensure the sustainability of ecosystem services. 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.

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

805 The current political and regulatory environment for managing national forests is
806 considered a severe limitation on adaptation to climate change. Policies, regulations, and
807 administrative guidelines, though well intended for various conservation objectives, often fail to
808 incorporate climate change and therefore focus on static rather than dynamic resource objectives.
809 In addition, lengthy planning, review, and approval processes can delay timely implementation
810 of management actions (e.g., following a large wildfire) that could facilitate adaptation. Some of
811 these constraints can be overcome by making the science-management partnership on climate
812 change permanent and by jointly developing a guide to climate change adaptation. Incorporating
813 climate change explicitly into national, regional, and national forest policy would be a major step
814 forward in implementing climate change in established planning processes and fostering “climate
815 smart” management. Policies and regulations that provide guidance but allow for local/forest
816 level strategies and management actions that increase resilience and reduce vulnerability to
817 climate change would also promote adaptation. Finally, educational efforts to promote

818 awareness of climate change will help create a more consistent approach within the Forest
819 Service and gain support from various stakeholders for appropriate adaptation options.

820 ONF and TNF are at a crossroads. Some effects of climate change on forest ecosystems
821 and natural resources in North America are already detectable (IPCC 2007). Adapting to those
822 changes and sustaining ecosystem services is a priority, but adaptive capacity is limited by lack
823 of local scientific information and uncertainty about outcomes of adaptive strategies. Adaptive
824 management is the best general strategy for learning how to detect and manage the effects of
825 climate change on forest ecosystems (Fig. 4), but if there is little flexibility in legally responding
826 to dynamic ecosystem conditions, then adaptation options are severely limited. National forest
827 managers indicated that, given current knowledge, regulations, and levels of funding and
828 personnel, they would continue to emphasize management for diversity at all spatial scales as a
829 “no regrets” strategy for building resilience to potentially adverse climate change effects.

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

840 coevolution of adaptive management in the context of science, policy, and planning must
841 progress quickly in order for adaptation to keep pace with anticipated effects of climate change.

842

843

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TABLE 1. Anticipated effects of climate change on natural resources in Olympic and Tahoe National Forests. See text for citations and more detailed information.

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 <1500 m; decrease in snow:rain ratio	Large decrease at all elevations
Water		
Runoff ¹	Increase in winter, decrease in summer	Increase in winter, decrease in summer
Streamflow ¹	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 ²	Large increase
Insect attack	Possible increase	Large increase
Windstorms	Unknown but increased storms would have major impact	Unknown

¹ 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.

² 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 yr fire-free intervals), they are often very large (hundreds of thousands of hectares) when they do

occur (Henderson et al. 1989).

TABLE 2. General adaptation strategies and specific adaptation options identified by resource managers for adapting to climate change in Olympic and Tahoe National Forests.¹

Olympic National Forest	Tahoe National Forest
<i>General adaptation strategies</i>	
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
<i>Specific adaptation options</i>	
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	

¹ Order and wording differ from text to better illustrate similarities between national forests.

TABLE 3. Opportunities and barriers for adapting to climate change in Olympic and Tahoe National Forests.¹

Olympic National Forest	Tahoe National Forest
<i>Opportunities</i>	
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
<i>Barriers</i>	
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

¹ Order and wording differ from text to better illustrate similarities between national forests.

TABLE 4. Tools and information needed to facilitate adaptation to climate change in Olympic and Tahoe National Forests.¹

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	

¹ Order and wording differ from text to better illustrate similarities between national forests.

Figure captions

FIGURE 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 2. Several large floods by rivers on the Olympic National Forest 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) will improve resilience to climate change.

FIGURE 3. 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.

FIGURE 4. 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.

FIGURE 1

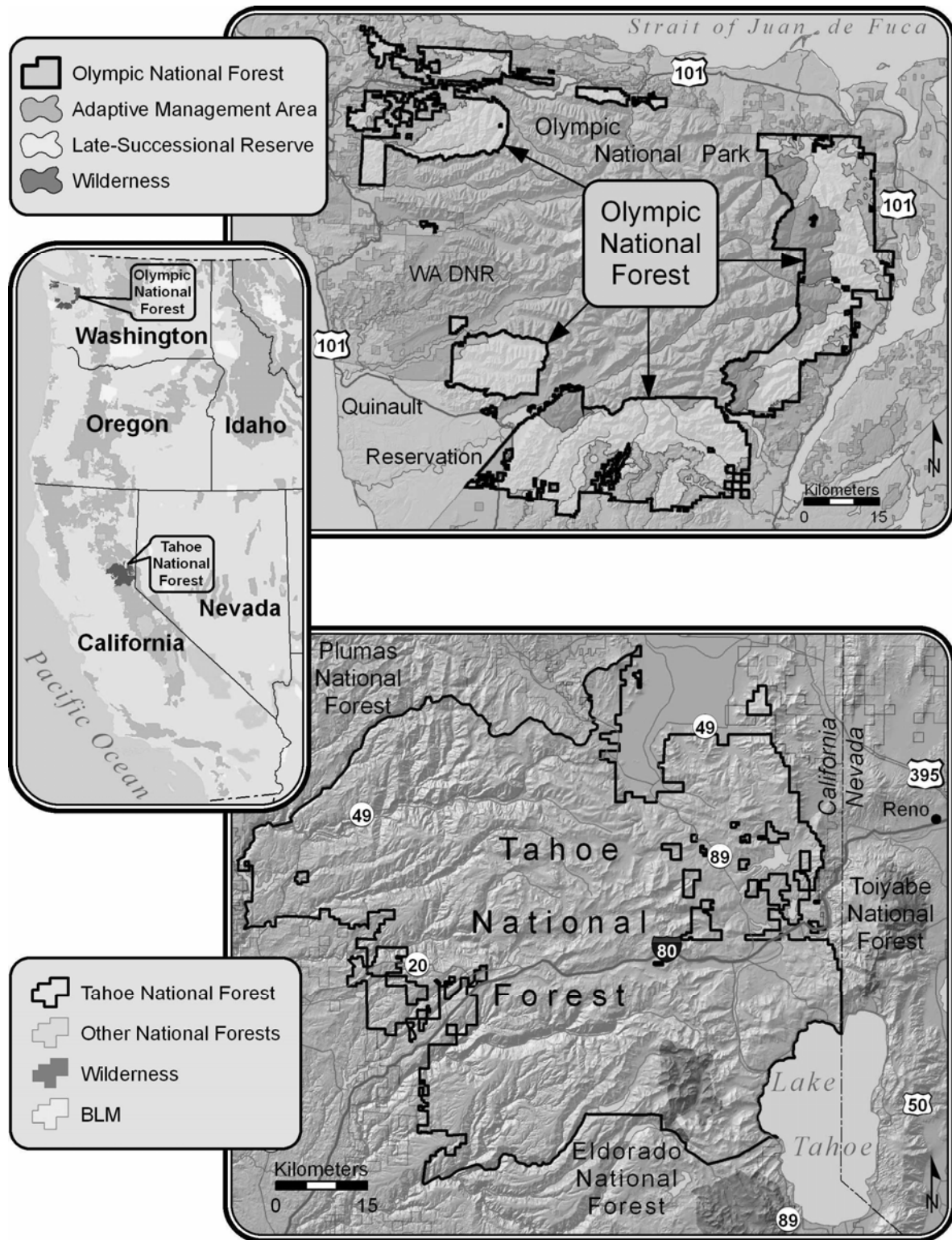


FIGURE 2



FIGURE 3



FIGURE 4

