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Adapting to Climate Change at Olympic National Forest and Olympic National Park

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Butterfly photo by Betsy Howell, Forest Service (Olympic NF).
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Abstract

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Climate change presents a major challenge to natural resource managers both because of the magnitude of potential effects of climate change on ecosystem structure, processes, and function, and because of the uncertainty associated with those potential ecological effects. Concrete ways to adapt to climate change are needed to help natural resource managers take the first steps to incorporate climate change into management and take advantage of opportunities to counteract the negative effects of climate change. We began a climate change adaptation case study at Olympic National Forest (ONF) in partnership with Olympic National Park (ONP) to determine how to adapt management of federal lands on the Olympic Peninsula, Washington, to climate change. The case study began in the summer of 2008 and continued for 1½ years. The case study process involved science-based sensitivity assessments, review of management activities and constraints, and adaptation workshops in each of four focus areas (hydrology and roads, fish, vegetation, and wildlife). The process produced adaptation options for ONF and ONP, and illustrated the utility of place-based vulnerability assessment and science-management workshops in adapting to climate change. The case study process provides an example for other national forests, national parks, and natural resource agencies of how federal land management units can collaborate in the initial stages of climate change adaptation. Many of the ideas generated through this process can potentially be applied in other locations and in other agencies.

Keywords: Adaptation, climate change, fish habitat management, hydrology, road management, science-management partnerships, vegetation management, wildlife habitat management.

Summary

In this report, we describe results of the Olympic Climate Change Case Study, a science-management collaboration initiated to develop climate change adaptation strategies and actions for Olympic National Forest (ONF) and Olympic National Park (ONP). The case study was one of three parallel climate change adaptation case studies on national forests and adjacent national parks in the Western United States as a part of a larger effort, the WestWide Climate Initiative. This initiative was created by scientists of the U.S. Forest Service to address the urgent need to communicate climate change information to land managers and work with them to develop adaptation options.

For the Olympic Climate Change Case Study, we conducted a vulnerability assessment to facilitate development of adaptation strategies and actions for ONF and ONP. The first step in the vulnerability assessment process involved a review of available climate model projections to determine likely levels of exposure to climate change (degree of deviation in temperature and precipitation) on the Olympic Peninsula (chapter 3). In the next step, we reviewed relevant literature on effects of climate change and available projections to identify likely climate change sensitivities in each of four focus areas on the Olympic Peninsula, including hydrology and roads (chapter 4), fish (chapter 5), vegetation (chapter 6), and wildlife (chapter 7). We worked with regional scientists and specialists to interpret available information and apply it more directly to Olympic Peninsula ecosystems. Finally, we reviewed current management activities at ONF and ONP and identified management constraints to evaluate some aspects of institutional capacity to implement adaptive actions. Review of current management activities was done by focus area and is described in the chapter for each focus area.

The vulnerability assessment process set the stage for development of adaptation options at the forest and park through science-management workshops (also described in the chapter for each focus area). The workshop format gave managers an open forum to brainstorm, express initial thoughts and ideas, and vet those ideas among peers. Direct engagement of scientists and managers in the workshop format fostered development of science-based adaptation strategies. During workshop discussions, managers identified general priority actions for adaptation, as well as priorities for species protection, habitat protection, and monitoring.

Although interagency partnerships exist elsewhere to address specific natural resource issues, the Olympic Climate Change Case Study is an unprecedented example of U.S. Forest Service and National Park Service jointly planning for climate change adaptation. The case study process produced specific and tangible ways for ONF and ONP to incorporate climate change adaptation strategies into management. A key finding of the assessment was that the current general management at both ONF and ONP, with restoration as a primary goal, is consistent with managing for resilience to prepare ecosystems for a changing climate. However, the effort highlighted some potential issues related to climate change that challenge current precepts and management guidelines and helped to identify new potential actions and actions that could be increased and reprioritized.

Climate change adaptation requires systematic monitoring and evaluation to detect changes and determine the success of adaptive management activities. Staying abreast of available information on potential climate change effects is essential to determine additional ways to incorporate climate change adaptation into management. Although further effort will be required, the case study described in this report was an essential first step for ONF, ONP, and their stakeholders in preparing for climate change on the Olympic Peninsula.

Contents

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Chapter 1: Introduction

Jessica E. Halofsky, David L. Peterson, Kathy A. O'Halloran, and Catherine Hawkins Hoffman[1]

There is strong and growing scientific evidence for human-induced global climate change (Pachauri and Reisinger 2007). Global ecological effects triggered by warming in the late part of the 20th century include earlier snowmelt and decreased spatial extent of snow and ice (Barnett et al. 2008, Hamlet et al. 2005, Mote et al. 2005, Pachauri and Reisinger 2007), shifts in species distributions (Parmesan 2006, Parmesan and Yohe 2003, Mote et al. 2005, Root et al. 2003), and rising sea levels (Parry et al. 2007). Despite current and future greenhouse gas mitigation efforts, changes in the climate system will continue owing to already elevated concentrations of carbon dioxide in the Earth's atmosphere (Watson and the Core Writing Team 2001). Thus, climate change adaptation, or "the adjustment in ecological, social, or economic systems in response to climate stimuli and their effects" (Pachauri and Reisinger 2007), will be critical in reducing unwanted effects of climate change on both ecosystems and society.

Climate change presents a major challenge to natural resource managers because of the magnitude of potential effects of climate change on ecosystem structure, process, and function, and because of the uncertainty associated with potential ecological effects. Although general guidelines exist (e.g., Julius et. al. 2008, Millar et al. 2007) to proactively incorporate climate change into planning, decisions, and activities, managers require concrete and place-based methods to adapt to climate change.

Scientists and managers must work together to develop and implement strategies that facilitate adaptation to climate change. Resource managers have the skills and local knowledge to incorporate climate change into management. However, there is an overwhelming amount of climate change information to absorb, a steep learning curve with climate change science, and little time for learning owing to managers' many responsibilities. Given the relative infancy and experimental nature of climate change adaptation strategies, resource managers generally lack specific guidance and directives regarding how to incorporate climate change into program planning and implementation. Scientists have technical knowledge on climate change but often a poor understanding of management and regulatory, policy, and collaborative social processes for resource planning and decisionmaking. Although these two groups of specialists share complementary sets of skills and knowledge, a lack of formal relationships, and differences in work culture, timeframes, and communication styles limit science-management interactions on climate change issues.

In this report, we describe results of the Olympic Climate Change Case Study, a science-management collaboration initiated as part of a larger effort called the WestWide Climate Initiative (USDA Forest Service 2007). Scientists of the U.S. Forest Service created the WestWide Climate Initiative to address the urgent need to provide climate change information and adaptation tools to land managers in the Western United States. As a part of this initiative, parallel case studies were conducted to develop climate change tools and adaptation options at Olympic National Forest (ONF) and Olympic National Park (ONP) (Washington); Tahoe National Forest, Inyo National Forest, and Devils Postpile National Monument (California); and Shoshone National Forest (Wyoming).

The Olympic Climate Change Case Study occurred in two phases. The first phase involved education for managers at ONF on climate change science and potential effects of climate change, and an initial effort to develop

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adaptation strategies (Littell et al. 2011). The second phase, described here, focused on further development of strategies and actions for climate change adaptation. The case study began in the summer of 2008 and continued for 1½ years. The ONP joined with ONF in the second phase of the case study because of the proximity of the park and forest, similarities in management goals, and the importance of collaboration between neighbors in preparing for climate change. Although interagency partnerships exist elsewhere to address specific natural resource issues, this collaborative effort is unprecedented in development of climate change adaptation strategies and actions for a large landscape.

The second phase of the Olympic Climate Change Case Study developed adaptation strategies and actions in four focus areas identified by ONF and ONP managers as being most important: hydrology and roads, fish, vegetation, and wildlife. To develop adaptation actions for each focus area, we conducted a vulnerability assessment, or an assessment of the degree to which geophysical, biological, and socioeconomic systems are susceptible to, and unable to cope with, unwanted impacts of climate change (Parry et al. 2007). **Vulnerability** is a function of system exposure, its sensitivity, and its adaptive capacity (Gallopín 2006, Parry et al. 2007). In a climate change context, **exposure** can be thought of as the degree, duration, or extent of deviation in climate to which a system is exposed. **Sensitivity** is the degree to which a system is affected, either positively or negatively and directly or indirectly, by climate-related stimuli (Parry et al. 2007). **Adaptive capacity** is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Parry et al. 2007).

To determine likely levels of exposure to climate change on the Olympic Peninsula, we reviewed global climate model projections included in the University of Washington Climate Impacts Group Washington State Assessment (Mote and Salathé 2010) (see chapter 3 for further detail). Then, to assess other aspects of climate change vulnerability and develop adaptation options, for each focus area, we used a three-part process that involved:

- An assessment of climate change sensitivity through a topical literature review and review of available climate change impact model output, incorporating information directly applicable to the Olympic Peninsula whenever possible. Sometimes, scientists summarized best-available information in presentations to managers, and scientists and managers worked together to interpret and apply it to Olympic Peninsula ecosystems.
- An assessment of the capacity of ONF and ONP to adapt to climate change through review of current management practices and potential regulatory and institutional constraints.
- Development of adaptation strategies through science-management workshops. The results of the vulnerability assessment provided the starting point for facilitated science-management dialog on possible adaptation strategies in each focus area. The workshop format provided opportunities to transfer information and facilitate discussions between managers and scientists.

In all steps of the case study process, scientists and managers worked together to gather and refine information to identify climate change vulnerabilities and develop adaptation options for ONF and ONP. For consistency across focus areas, two scientists from the Forest Service Pacific Northwest Research Station and the natural resource staff supervisors from ONF and ONP participated in and guided the entire process. Participants in each focus area included forest and park staff specialists, including silviculturists, forest geneticists, botanists, wildlife biologists, engineers, fish biologists, and hydrologists. For each focus area, scientists from the University of Washington Climate Impacts Group and Forest Service scientists provided presentations and participated in discussions of adaptation options. Both the hydrology and roads, and vegetation workshops were limited to forest and park specialists and scientists with specialized knowledge in the focus area because of the need for progress within a specific timeframe, and for continuity and commitment to the process over many months, in addition to the complicated scheduling, logistics, and orchestration of a large-group planning process. However, the wildlife workshops included specialists from other natural resource organizations, including the Washington Department of Natural Resources, the U.S. Geological Survey, and U.S. Fish and Wildlife Service, to take advantage of their specialized knowledge of wildlife on the peninsula and interest in climate change. A science-focused fish workshop included over 100 participants from a variety of state and federal natural resource agencies, watershed organizations, and tribes. The fish workshop was opened to a broader audience because fish (particularly salmonids) are one of the widest ranging, multijurisdictional organisms inhabiting the peninsula. A critical next step will be to work with these and other partners in climate change adaptation on the peninsula.

During workshop discussions, ONF and ONP identified general priority actions for adaptation, as well as priorities for species protection, habitat protection, and monitoring. In developing these adaptation strategies, the goal was to identify no-regrets strategies and actions that are likely to produce favorable outcomes, are compatible with current management objectives, and are adaptable through time. For the purposes of the workshops, it was assumed that there will be no changes in policy mandates (e.g., land allocation designations, Endangered Species Act ([ESA 1973]) listings, or directives in the Northwest Forest Plan) over the next 5 years. These objectives and constraints yielded realistic and tangible adaptation strategies and actions for ONF and ONP.

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Chapter 2: Olympic National Forest and Olympic National Park: Biogeographic Setting, Cultural History, and Policy Context

Jessica E. Halofsky, Kathy A. O'Halloran, Catherine Hawkins Hoffman, David L. Peterson, and Jacilee Wray[1]

The Olympic Peninsula

Located in the northwestern portion of Washington state, USA, the Olympic Peninsula comprises an area of 16 800 km^2 (fig. 2.1). Bounding the peninsula is the Pacific Ocean to the west, the Strait of Juan de Fuca to the north, and Puget Sound and Hood Canal to the east. Elevation on the peninsula ranges from sea level to 2427 m at Mount Olympus, the highest peak of the Olympic Mountains, which dominate the central portion of the peninsula. The steep and dissected topography in the central portion of the peninsula results in temperature and precipitation gradients and varied climatic conditions (Peterson et al. 1997). A wet and humid maritime climate characterizes the western, coastal side of the peninsula, which receives 300 to 500 cm of precipitation per year depending on location, while the crest of the Olympic Mountains receives >600 cm of precipitation per year, making it the wettest location in the coterminous United States (Peterson et al. 1997). In contrast, the northeastern portion of the peninsula is characterized by a drier, more continental climate owing to the rainshadow effect of the Olympic Mountains (and prevailing winds from the southwest during the winter). Rainfall in the northeastern portion of the peninsula is as low as 50 cm per year at lower elevations (Henderson et al. 1989). Most precipitation falls between October and March, and winter precipitation falls mainly as rain below 300 m, as rain and snow between 300 m and 750 m, and as snow above 750 m. Snow at higher elevations persists through the early part of summer.

Varied climatic conditions on the peninsula result in diverse ecological communities. Vegetation assemblages on the peninsula include temperate rain forests, mixed-conifer forests, prairies, alpine tundra, subalpine parklands, wetlands, rivers, streams, and mountain lakes. There are 1,480 native vascular plant species (Buckingham et al. 1995) on the peninsula, including eight endemic species. Several endemic animal species also inhabit the peninsula, including the Olympic marmot, the Olympic pocket gopher, and the Olympic torrent salamander (See Common and Scientific names).

Land ownership on the peninsula is a mix of federal, state, tribal, and private lands (fig. 2.1). Olympic National Park (ONP) occupies the core of the peninsula and includes much of the higher elevation portion. Olympic National Forest (ONF) surrounds the park. The forest and park cover about one-third of the peninsula.

Cultural History of the Olympic Peninsula

The Olympic Peninsula has a rich cultural history involving extensive interaction between native peoples and their environment. Prior to what European Americans call the historic period (less than 200 years before present), there were about 10,000 people living on the Olympic Peninsula, the ancestors of the tribes here today: the Elwha Klallam, Jamestown S'Klallam, Port Gamble S'Klallam, Quinault, Hoh, Quileute, Makah, Queets, and Skokomish (Wray 2002). The tribes of the Olympic Peninsula maintain close ties to all of their ancestral lands and share concern for resource protection. They are an integral part of the ecosystem, as their traditional practices included land management, such as maintaining prairies by burning them to increase edible and medicinal plant populations.

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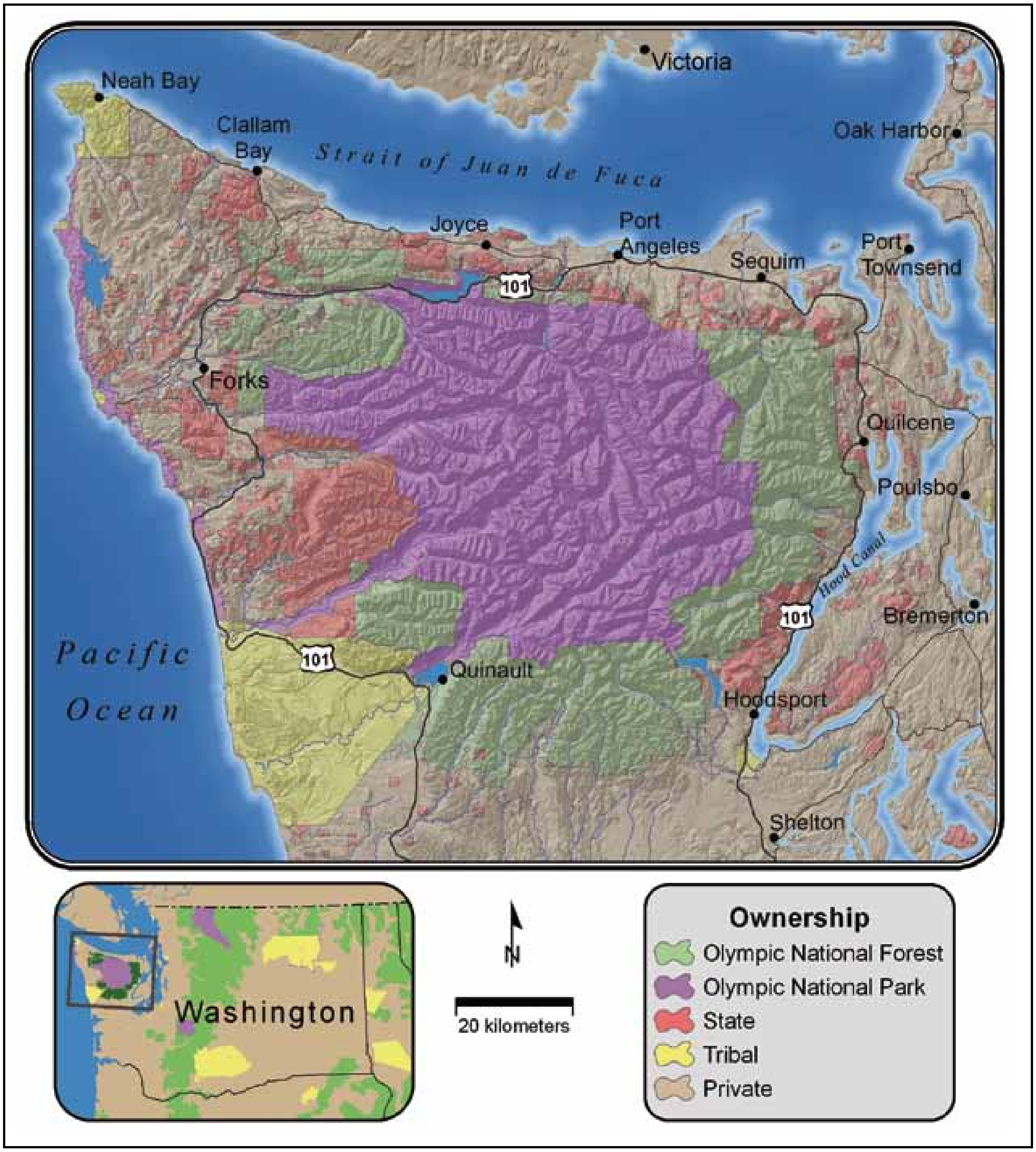

Figure 2.1—Location of and land ownership on the Olympic Peninsula.

In 1854, Governor Issac Stevens, who was also Superintendent of Indian Affairs in Washington Territory, began treaty negotiations to unite the numerous bands of Indians into tribes and to extinguish title to their lands for settlement by U.S. citizens. The treaties established formal relationships between the tribes as sovereigns and the United States and established the Quinault, Skokomish, and Makah reservations. The Quileute and Hoh reservations were established by Executive order and the three

Klallam reservations by Congress. Tribal reservation lands on the peninsula comprise over 89 000 ha, ranging from the Quinault Reservation, encompassing 86 000 ha, to the Jamestown S'Klallam Reservation, with only 2 ha.

The peninsula treaties that ceded the land now within ONP include the Treaty of Point No Point 1855 (Skokomish and Klallam), Treaty of Neah Bay 1855 (Makah), and Treaty of Olympia 1856 (Quinault, Quileute, and Hoh). The treaties specify that the tribes have the right to fish at "usual and accustomed grounds and stations… in common with all citizens… together with the privilege of hunting and gathering roots and berries on open and unclaimed lands." In 1974, Federal District Court Judge George Boldt found that the tribes were guaranteed an equal share or half of the sustainable harvest of anadromous fish in U.S. v. Washington. He also found that the treaties were "not a grant of rights to the Indians, but a grant of rights from them, and a reservation of those not granted" [United States v. State of Washington 384 F. Supp. 312 (1974):323]. In other words, these were not rights given to them, but rights they always had—from time immemorial.

The relationship between the first people and the Olympic Peninsula is recounted in origin legends and mythic events that explain both the creation of the landscape and peoples' relationship to it. These legends depict a strong reliance upon waterways, forests, and valleys for the acquisition of vital resources, and detailed descriptions of travel into the mountains for pleasure, social interchange such as marriage, and spiritual pursuits [Wray 2002].

Trails were used where canoes could not go, following the river drainages to the open meadows and mountain ridgelines. Trails crossed the mountains between the Hoh and the Elwha Rivers and from the Quileute to the Pysht and the Hoko (Gibbs 1877). Other trails led from Hood Canal to Grays Harbor, and crossed the Olympics from the Skokomish and Dosewallips River drainages to the Quinault. Many of the trail routes are the same routes used today by hikers in the park and forest.

The remains of stone tool manufacture, or lithics, have been documented in the Olympic Mountains and surrounding foothills by archeologists. These tools were used for hunting, butchering, and plant processing. In 1993, portions of a woven cedar basket—part of a pack basket used as a backpack—were found in the alpine reaches of ONP. This discovery provides additional evidence of high-country habitation. The basket has been radiocarbon dated to be about 2,880 years old.

Maritime archeological village sites on the Pacific coast, Strait of Juan de Fuca, and Hood Canal had economies that included intertidal gathering, fishing, sealing, and whaling, dating back thousands of years. Animal remains, along with stone and wood artifacts, indicate the presence of an "Early Maritime" culture on the Olympic Peninsula about 3,000 years ago (Bergland 1983). This culture relied on salmon and shellfish, which had likely increased in abundance in response to stabilization of sea level and increased precipitation during that time period (Henderson et al. 1989).

Native peoples of the Olympic Peninsula used native plant materials extensively (Gunther 1945, Norton 1979, as cited in Henderson et al. 1989). Western redcedar was used for a variety of purposes, including cedar plank houses, canoes, fishing tools, cradles, paddles, and arrowshafts (Henderson et al. 1989). The bark of western redcedar was also used to make clothing, baskets, mats, and eating utensils, among other objects (Gunther 1945). Other plants, such as camas, bracken fern, salmonberry, salal, and huckleberries, provided important food sources (Henderson et al. 1989). Prairies were regularly burned to maintain and cultivate camas and other food plants (Norton 1979).

Native plants were also used for medicine and other purposes. For example, stinging nettle was used for medicine and rope (Henderson et al. 1989). Cattail and beargrass were used in basketry. Sitka spruce roots were also used for nets and cordage, and spruce pitch, limbs, bark, and wood were also used (Henderson et al. 1989).

Olympic National Forest

Created in 1907, ONF encompasses an area of 256 440 ha, 15 percent of which is federally designated wilderness. The mission of the Forest Service, and thus ONF, is "to sustain the health, diversity, and productivity of the Nation's forest and grasslands to meet the needs of present and future generations" (USDA FS 2007). Timber production and fresh water were historically the most valued ecosystem services provided by ONF. Timber harvest activities began on ONF in the 1920s. Until the 1990s, timber management generally consisted of clearcutting, broadcast burning, and tree replanting. These management practices resulted in the conversion of over one-third of ONF into relatively young even-aged forests. In addition, over 3500 km of forest roads built for timber harvest remain on the forest road network.

The 1994 Northwest Forest Plan (NWFP) (USDA and USDI 1994) and a change in Forest Service agency management policy led to a movement toward ecosystem management at ONF. Ecosystem management from a Forest Service perspective has four main components including protecting ecosystems, restoring deteriorated ecosystems, providing multiple-use benefits for people within the capabilities of ecosystems, and ensuring organizational effectiveness. The NWFP also mandates management for ecological priorities, mainly the protection, enhancement, and acceleration of late-successional forest conditions. At ONF, a major land allocation under the NWFP is late-successional reserve (LSR), the goal of which is to maintain late-successional and old-growth forest ecosystems. The LSRs are designed primarily to serve as habitat for late-successional and old-growth-related species, including the northern spotted owl.

Olympic National Forest is focused on:

- Managing for native biodiversity and promoting the development of late-successional forests
- Restoring and protecting aquatic ecosystems from the impacts of an aging road infrastructure
- Managing for individual threatened and endangered species as defined by the Endangered Species Act (ESA) (ESA 1973) and related policies

Because of this focus on ecological restoration, forest personnel consider ONF to be a “restoration forest.”

Besides the ESA, other federal statutes guide current management activities at ONF, including the National Forest Management Act (NFMA) (NFMA 1976) and the National Environmental Policy Act (NEPA) (NEPA 1969). The NFMA imposes directives on national forest planning and activities. The NEPA requires all federal government agencies to conduct environmental analyses and prepare environmental documents (environmental assessments or environmental impact statements [EIS]) that assess and disclose the environmental impacts of proposed actions.

The ONF land and resource management plan (LRMP) (as amended by the NWFP; USDA FS 1990) guides management activities at ONF and is revised every 10 years. A key component of the LRMP is the aquatic conservation strategy (ACS), which includes eight objectives for maintaining and restoring watershed processes and functions. To be consistent with the LRMP and the ACS, all management activities at ONF must maintain or help restore watershed conditions.

The ONF also has a forest strategic plan that integrates aquatics, wildlife, silviculture, and fire, helping to identify priority areas for management activities such as habitat restoration, road decommissioning, forest thinning, and fuel reduction treatments. Factors such as habitat improvement potential (specifically for threatened and endangered species and important charismatic species such as Roosevelt elk), economic viability of activities, and existing priorities and land allocation restrictions determine priority actions.

The ONF and the Forest Service in general are just beginning to address climate change and adaptation to climate change. In October 2008, the Forest Service issued the *Forest Service Strategic Framework for Responding to Climate Change* (USDA FS 2008), which identified climate change adaptation as a key goal for the agency and recommended integrating climate change considerations into agency-wide policies and program guidance. The agency also issued national guidance on how climate change can be incorporated in LMRP revision and analyses of projects. Further guidance for adaptation on national forests is in development at this writing.

Olympic National Park

Created in 1938, ONP covers 373 384 ha on the Olympic Peninsula. The park includes both the central, mountainous portion of the Olympic Peninsula, as well as a strip more than 110 km long on the Pacific coast. In 1988, the U.S. Congress designated over 95 percent of the park as a wilderness area. Much of the park is in relatively pristine condition, although effects of past human activities are evident and persistent in some areas.

The foundation for National Park Service (NPS) policies governing the management at ONP is the 1916 Organic Act, which established an NPS with the purpose to "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS 1916). The fundamental purpose of the NPS is to conserve park resources and values and to provide for enjoyment of parks while avoiding or minimizing adverse impacts. Management within parks focuses on preserving physical and biological processes and preserving the "natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (NPS 2006).

The mandate of the NPS requires that parks both conserve natural resources and provide for public enjoyment, although the Redwoods Act (1978) clarified that protecting resources takes precedence over providing for the enjoyment of the public. Nevertheless, this dual mandate entails careful management to avoid conflicts between the two goals. Several other statutes such as the NPS General Authorities Act (NPS 1970), Clean Air Act (1970), ESA (1973), NEPA (1969), Wilderness Act (1964), and Wild and Scenic Rivers Act (1968) constitute additional directives for park management. Management policies of the NPS (2006) provide a stewardship framework and broad guidance to park managers. Individual parks develop long-term management plans and other implementation plans that describe specific management objectives.

The ONP General Management Plan (NPS 2008) established a vision for managing ONP for the next 15 to 20 years and aims to protect natural and cultural resources while improving visitor experiences. The plan designated management zones within the park and established desired resource conditions. The plan also established fundamental objectives including maintaining access to existing developed areas, trails, campgrounds, and facilities; seeking additional partnerships to help provide better visitor access and enjoyment and protection of sensitive resources; making boundary adjustments through purchases or land exchanges to incorporate sensitive resource areas within the park (e.g., fish habitat, wetlands); and providing continued protection of wilderness resources and cultural resources within wilderness. The public participated in the development of this plan.

Other park plans guide management practices, including the ONP backcountry management plan, the fire management plan, and the wilderness management plan (to be developed beginning fall 2010). Besides regulations found in the Code of Federal Regulations (36CFR part 7.28), the ONP superintendant's compendium establishes regulations that are specific to ONP.

Like ONF, ONP is subject to NEPA. As part of NEPA analyses, park managers evaluate management actions within the park to determine their potential effect on ONP resources, select the action that will meet park management needs with the least impacts, and ensure that no activities will result in impairment. Depending on the nature of the activity, compliance may be relatively informal or may require an EIS under NEPA.

Similar to the Forest Service, the NPS is just beginning to address climate change in agency policy and directives. The U.S. Department of the Interior (DOI) issued Secretarial Order No. 3226 directing bureaus, including the NPS, to "provide leadership by developing timely responses to emerging climate change issues." The secretarial order requires agencies in the DOI to consider potential impacts of climate change in planning, setting priorities for research, and making decisions affecting resources. The order also calls on DOI agencies to review existing programs and policies to identify potential climate change impacts on areas of responsibility and recommend actions in response to potential impacts.

At the agency level, NPS management policies (NPS 2006) refer to potential effects of climate change on resources and call for parks to gather and maintain climate data for reference and to educate visitors about climate change. Future management directives may consider climate change responses across all aspects of park planning and operations. The NPS Pacific West Region, which includes ONP, is developing mitigation strategies in response to a regional directive that calls on all parks in the region to aim to become carbon neutral. Park planning specialists are developing guidance to include climate change in general management plans and other planning documents, as well as draft adaptation concepts for local park units in the Pacific West Region.

Similarities in Management Between Olympic National Forest and Olympic National Park

Although differences in policy exist for management at ONF and ONP, similarities in management objectives exist. Crosscutting statutes such as the ESA (1973), NEPA (1969), Clean Air Act (1970), and Clean Water Act (1977) apply to all management activities for both entities. They also have similar policy goals for preservation of biodiversity and native gene pools. Both ONF and ONP practice ecosystem management focused on maintaining ecosystem process and function and use restoration as a tool to maintain process and function. Policies applied to the wilderness areas of the forest and park are very similar. In addition, recreation and benefit to society are key functions of both ONP and ONF. These similarities in management objectives provide a consistent context for how the forest and park adapt to climate change.

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Chapter 3: Future Climate on the Olympic Peninsula: Forest-Relevant Climate Scenarios

Jeremy S. Littell[1]

Introduction

Adaptation to climate change in forest ecosystems requires a robust estimate (or, in the case of substantial uncertainty, multiple estimates) of future climate to use in planning and scenario development. In this section, I borrow heavily from the Washington Climate Change Impacts Assessment (WACCIA) by the University of Washington Climate Impacts Group (Littell et al. 2010), the chapter on future Pacific Northwest Climate (Mote and Salathé 2010), the chapter on regional dynamic climate modeling (Salathé et al. 2010), and the chapter on future hydrologic regimes (Elsner et al. 2010). I first describe emissions scenarios used to constrain the climate models used in this study, then summarize findings on regional climate in the Pacific Northwest and some of the subregional consequences of those climate changes for variables more closely related to forest ecosystems (see box 3.1 for summary).

Box 3.1—Summary of projected climate change effects in the Pacific Northwest and on the Olympic Peninsula.

- The Washington Climate Change Impacts Assessment, conducted by the University of Washington Climate Impacts Group, provided detailed information on potential climate changes in the Pacific Northwest and on the Olympic Peninsula
- Climate models project increases in annual average temperature of +0.6 °C to +1.9 °C by the 2020s; +0.9 °C to +2.9 °C by the 2040s; and +1.6 °C to +5.4 °C by the 2080s for the Pacific Northwest.
- Warming is expected to occur during all seasons, with most models projecting the largest temperature increases in summer.
- Projected changes in annual precipitation in the Pacific Northwest differ considerably between models, but averaged over all models are small (+1 to +2 percent).
- Ensemble means of models for precipitation suggest wetter winters (+3.3 percent in the 2040s, +7.6 percent in the 2080s) and drier summers (-8.5 percent in the 2040s, -12.8 percent in the 2080s).
- Summer potential evapotranspiration (one component of water balance and closely related to fuel moisture and tree stress) is expected to increase by 5 to 18 mm by the 2040s, with much of the largest increases in lower elevation forests in the northeastern portion of the peninsula.
- Winter precipitation on the Olympic Peninsula is likely to increase by 4.5 to 5 percent, on average and depending on location.
- In addition to increased precipitation quantity, regional climate models show significant increases in the intensity of winter precipitation in the western portion of the Olympic Peninsula.

Emissions Scenarios: A1B (Moderate) and B1 (Low)

To develop plausible estimates of the future climate of the Pacific Northwest, physically based global climate models (GCMs) that incorporate key elements of the climate system (e.g., ocean, atmosphere, cryosphere [snow and ice], and land surface) must be used to project future conditions based on known climate dynamics and changes in the climate forcing factors. The primary forcings likely to affect changes in climate the most in the 21st century are future emissions of greenhouse gases (which increase the heat-trapping capability of the atmosphere, causing warming) and sulfate aerosols (which reflect sunlight and also promote cloud formation, causing local cooling).

Under the direction of the Intergovernmental Panel on Climate Change (IPCC), over 40 emissions scenarios have been published in the Special Report on Emissions Scenarios (SRES) (Nakićenović and Swart 2000). These scenarios have widely varying assumptions about future socioeconomic changes and the resulting changes in greenhouse gas (including carbon dioxide) and aerosol emissions, and represent one constraint on future climate uncertainty. Three

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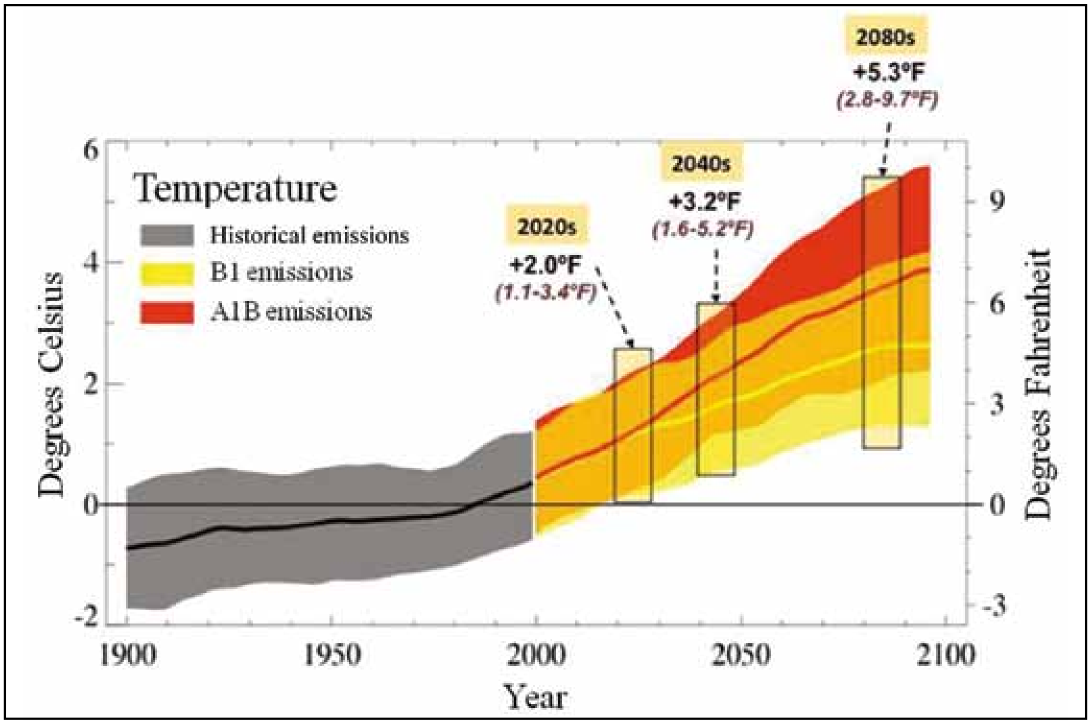

Figure 3.1—Simulated temperature change for the 20th- and 21st-century global climate model simulations for the Pacific Northwest region. The black curve is the weighted average of all models during the 20th century. The colored curves are the weighted average of all models in that emissions scenario ("low" or B1, and "moderate" or A1B) for the 21st century. The colored areas indicate the range (5th to 95th percentile) for each year in the 21st century. All changes are relative to 1970–99 averages.

of these SRES scenarios were commonly chosen for forcing GCMs used in the IPCC Fourth Assessment Report: B1, A1B, and A2. The climate forcing of all scenarios is similar until the 2020s because of a long lifetime of coal-fired electric powerplants and of the major greenhouse gases. Of these three scenarios, A2 produces the highest emissions by the end of the century, but before mid-century, none of the scenarios is consistently the highest. Because more modeling groups use A1B than A2, and because the focus for this study was on mid-century change, A1B was used as the higher emissions scenario and B1 as the low emissions scenario for analysis of 21st-century Pacific Northwest climate. Though B1 is the lowest of the IPCC illustrative scenarios, it still produces changes in climate that many scientists call "dangerous" (Schellnhuber et al. 2006). At the high end, scenario A1FI results in even higher climate forcing by 2100 than A1B. Mid-2000s global emissions of carbon dioxide exceeded even the A1FI scenario (Raupach et al. 2007). Whether these exceedingly high emissions will continue into the future is uncertain, but in any case, the projections described here are potentially conservative.

Pacific Northwest Future Regional Climate

Mote and Salathé (2010) used 20 different climate models to explore the consequences of two different greenhouse gas emissions scenarios for the Pacific Northwest. All of the models indicate that the future climate will be warmer than the past (fig. 3.1) and, together, they suggest that Pacific Northwest warming rates will be greater in the 21st century than those observed in the 20th century. All changes below are relative to the period 1970–1999, and all are regionally averaged changes that apply to the Pacific Northwest. Climate models project increases in annual average temperature of +1.1 °C, range +0.6 °C to +1.9 °C by the 2020s; +1.8 °C, range +0.9 °C to +2.9 °C by the 2040s; and +3.0 °C, range +1.6 °C to +5.4 °C by the 2080s. Climate models are able to match the observed 20th-century warming (0.8 °C since 1920, or +0.1 °C per decade for 1920 to 2000) in the Northwest, and project a warming rate of roughly +0.3 °C per decade in the 21st century. Projected changes in annual precipitation (fig. 3.2) differ considerably between models, but averaged over all models are small (+1 to +2 percent).

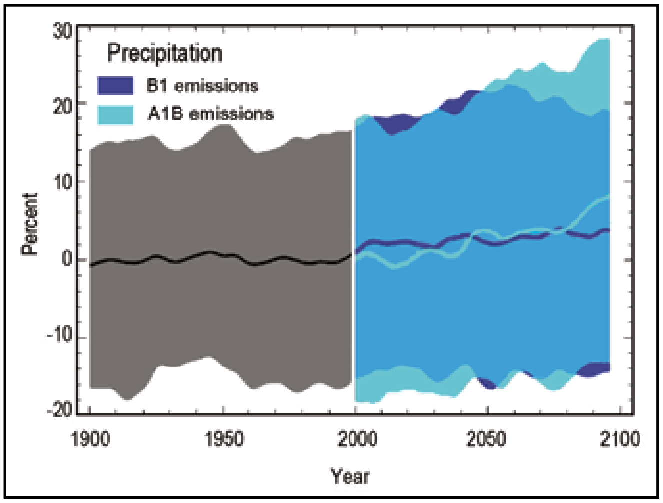

Figure 3.2—Simulated precipitation change for the 20th- and 21st-century global climate model simulations for the Pacific Northwest region. The black curve is the weighted average of all models during the 20th century. The colored curves are the weighted average of all models in that emissions scenario (“low” or B1, and “moderate” or A1B) for the 21st century. The colored areas indicate the range (5th to 95th percentile) for each year in the 21st century. All changes are relative to 1970–99 averages.

Seasonal changes in climate are arguably more important for projecting the impacts of climate change on forests. Warming is expected to occur during all seasons, with most models projecting the largest temperature increases in summer (fig. 3.3). Seasonal changes in precipitation early in the 21st century may not be separable from historical conditions given the large natural variations between wetter and drier years. Some GCMs suggest large seasonal changes (fig. 3.4), but the ensemble means point toward wetter winters (+3.3 percent in the 2040s, +7.6 percent in the 2080s, averaged over all A1B and B1 scenarios) and drier summers (-8.5 percent in the 2040s, -12.8 percent in the 2080s, averaged over all A1B and B1 scenarios).

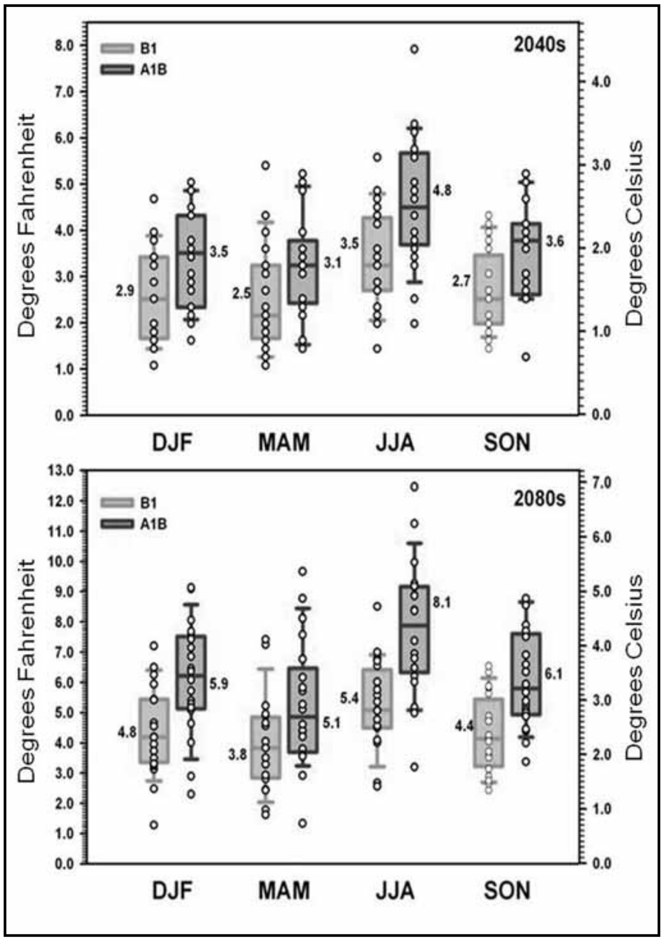

Figure 3.3—Range (lowest to highest) of projected changes in temperature for each season (DJF [December, January, and February] = winter, etc.), relative to the 1970–99 mean, for the Pacific Northwest region. In each pair of box-and-whiskers, the left one is for emission scenario B1 and the right is scenario A1B; circles are individual model values. Box-and-whiskers plots indicate 10th and 90th percentiles (whiskers), 25th and 75th percentiles (box ends), and median (solid middle bar) for each season and scenario. Not all values are visible due to symbol overlap. Printed values are the weighted reliability ensemble average of all global climate models for the season and scenario.

Regional climate modeling (weather models forced with GCMs in the future, Salathé et al. 2010) points out areas and seasons that get drier even as the region gets wetter. The models with the most warming also produce the most summer drying. Regional climate models project some changes that are similar across global models, namely increases in extreme high precipitation in western Washington (including the southwestern Olympics) and reductions in Cascade Range snowpack. Regional climate models project a larger increase in extreme daily heat and precipitation events in some locations than the GCM ensemble suggests, the former being true of the southwestern Olympic Peninsula (Salathé et al. 2010). Regional climate models also suggest

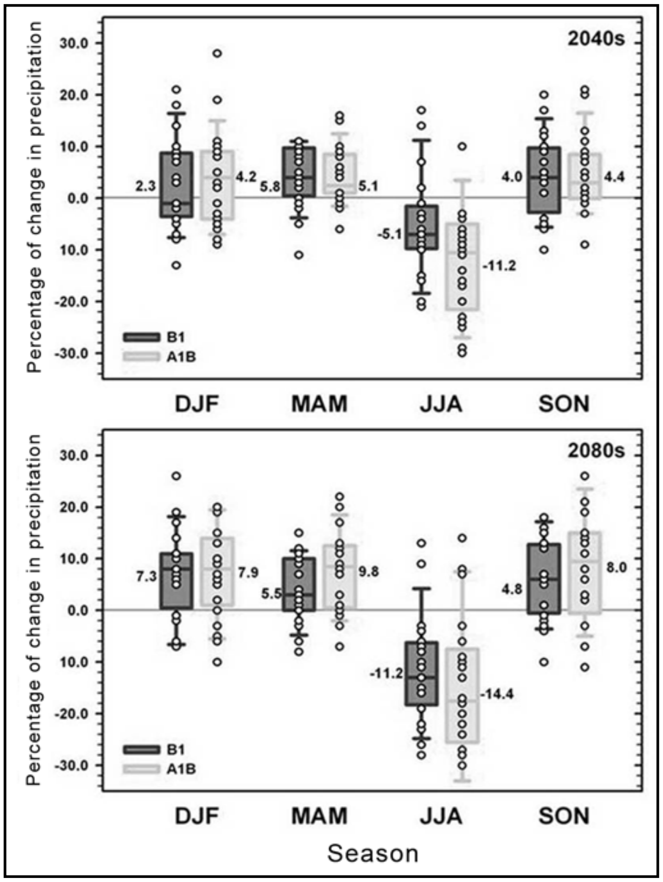

Figure 3.4—Range (lowest to highest) of projected changes in precipitation for each season (DJF [December, January, and February] = winter, MAM [March, April, and May] = spring, JJA [June, July, and August] = summer, SON [September, October, and November] = fall), relative to the 1970–99 mean, for the Pacific Northwest region. In each pair of box-and-whiskers, the left one is for emission scenario B1 and the right is scenario A1B; circles are individual model values. Box-and-whiskers plots indicate 10th and 90th percentiles (whiskers), 25th and 75th percentiles (box ends), and median (solid middle bar) for each season and scenario. Not all values are visible due to symbol overlap. The height of the bars indicates actual water precipitation, but the percentages are calculated with respect to a reference value for that season, so that -11 percent in JJA is much less than -11 percent in DJF. The reference values for the extremes are that model's 20th-century mean for that season (or annual mean), and for the Reliability Ensemble Average, the reference is the all-model 20th-century value. Some models project increases and some project decreases for a season, although the vast majority project decreases for summer and increases for winter by the 2080s.

that some *local* changes in temperature and precipitation may be quite different than average *regional* changes projected by the global models. For example, the two global models examined suggest winter precipitation will increase in many parts of the Pacific Northwest, but potentially decrease in the Cascade Range. Future research is required to understand if this trend is consistent across many global models.

These comparisons between global and regional models are not yet developed to the point that they are a strong basis for decisionmaking; additional models would be needed to characterize the likely seasonal trends expected in the future. Currently, their chief use is as a research tool to better understand where the inferences derived from global models are likely to hold up best, which process may influence rates of change differently within a region, and which changes might be expected to exacerbate extreme events (e.g., prolonged droughts or high-intensity storms). On the Olympic Peninsula, for example, it is possible that decreases in snowpack in spring will lead to higher rates of warming in spring than the regional average owing to the loss of the snow albedo feedback, an effect that the GCMs would not likely capture.

Climatic Downscaling: Winter Precipitation and Water Deficit

The GCMs produce output at relatively coarse scales (100 km or greater) and do not yet operate at scales that provide future climate estimates useful for subregional planning. However, downscaled future climate projections at more local scales are based on the relationship between finer scale historical observations and the GCM during the same historical period. The best way to constrain uncertainty in future regional climate associated with the high number of potential GCM futures is to use the fidelity of each model to the 20th century observed record to gage its usefulness for regional projection (Mote and Salathé 2010). In the WACCIA comparison of GCMs (Mote and Salathé 2010), models were weighted according to their fidelity to construct an ensemble average or an average of all models that gives more weight to models that did well in predicting past climate in the region. However, another approach to this problem (Hamlet et al. 2010, Overland and Wang 2007) is to constrain the average to models that best estimate observed climate (i.e., models that have the smallest bias in temperature and precipitation and that simulate the most realistic annual cycle in these parameters). Hamlet et al. (2010) evaluated a pool of 20 GCMs run for the A1B scenario in IPCC Fourth Assessment Report (Solomon et al. 2007) and selected 10 models, eliminating models that do a poor job of estimating climate change already known to have occurred. In this section on deficit, the average (ensemble) is composed of this subset of the available GCMs: UKMO-HadCM3, CNRM-CM3, ECHAM5/MPI-OM ECHO-G, PCM, CGCM3.1(T47), CCSM3, IPSL-CM4, MIROC3.2(medres), and UKMO-HadGEM.

Elsner et al. (2010) described methods and results for future climatic downscaling and incorporation into hydrologic modeling by using the Variable Infiltration Capacity (VIC) hydrologic model. Littell et al. (2010) showed that Washington forest ecosystem processes such as tree growth and fire are directly associated with potential evapotranspiration, actual evapotranspiration, and their difference (water balance deficit [DEF]), particularly in summer. The DEF is effectively the difference between water demand by the atmosphere and water supply in the soil profile; when demand exceeds supply, there is deficit. These variables are derived from temperature, precipitation, and other physical variables in VIC. Future changes in June to August (JJA) water balance deficit on the Olympic Peninsula (2040s, scenario A1B) are greatest in the northeast, east, and southeast, with increases (effectively drier) of 0.4 in (10 mm) to 2.4 in (60 mm) depending on location, likely because of increased evapotranspiration associated with increased temperature (fig. 3.5). Some of the highest elevations suggest decreases in deficit of similar magnitude, likely owing to increased snowmelt.

Winter (December to February [DJF]) precipitation on the Olympic Peninsula is likely to increase (fig. 3.6) by about 4.5 to 5 percent, on average and depending on location. Precipitation increases suggested by the GCM ensemble should be considered as general estimates of future trends, because the GCMs do not have sufficient topographic detail to describe fine-scale differences in future precipitation. However, Salathé et al. (2010) presented results from regional climate models (weather models forced with GCMs) that show significant increases in the intensity of winter precipitation in the western portion of the Olympic Peninsula. Although there is some uncertainty in this projection because relatively few climate models were used, these results suggest that portions of the Olympic Peninsula will receive not only more precipitation, but that it will come in the form of more intense storms.

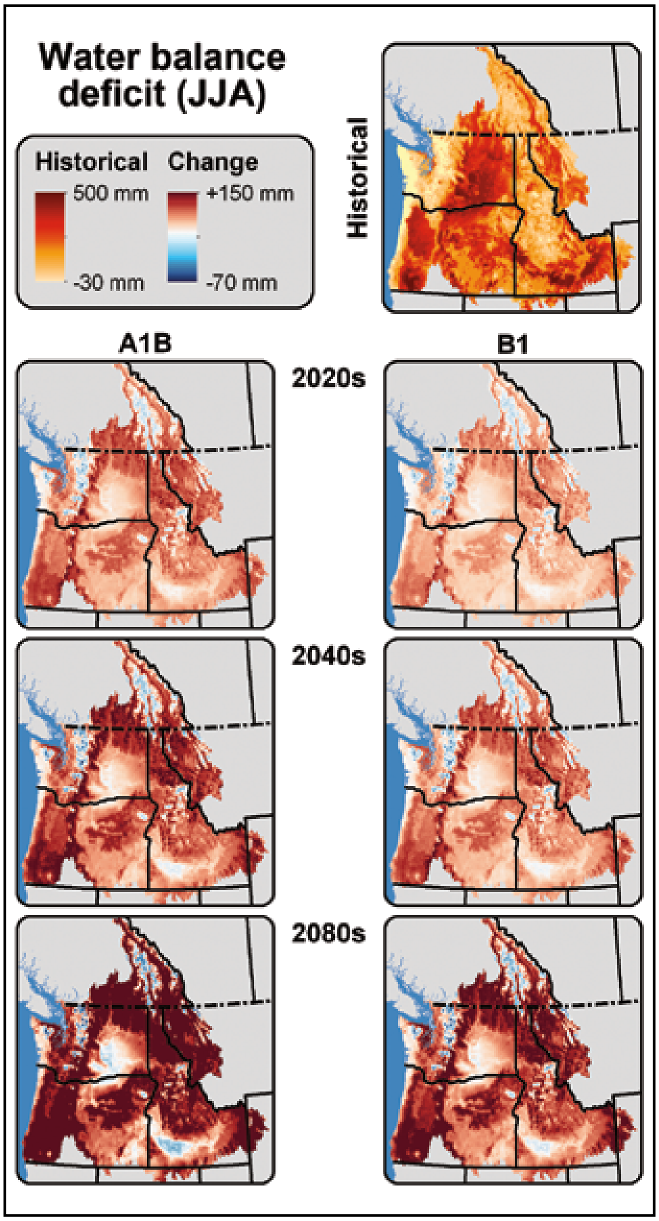

Figure 3.5—Historical June to August (JJA) water balance deficit in the Pacific Northwest and projected changes from historical for the 2020s, 2040s, and 2080s (A1B and B1 emissions scenarios). Deficit increases in most of the drier parts of the Columbia River basin, but on the Olympic Peninsula, most increases are confined to the north, northeast, and southeast.

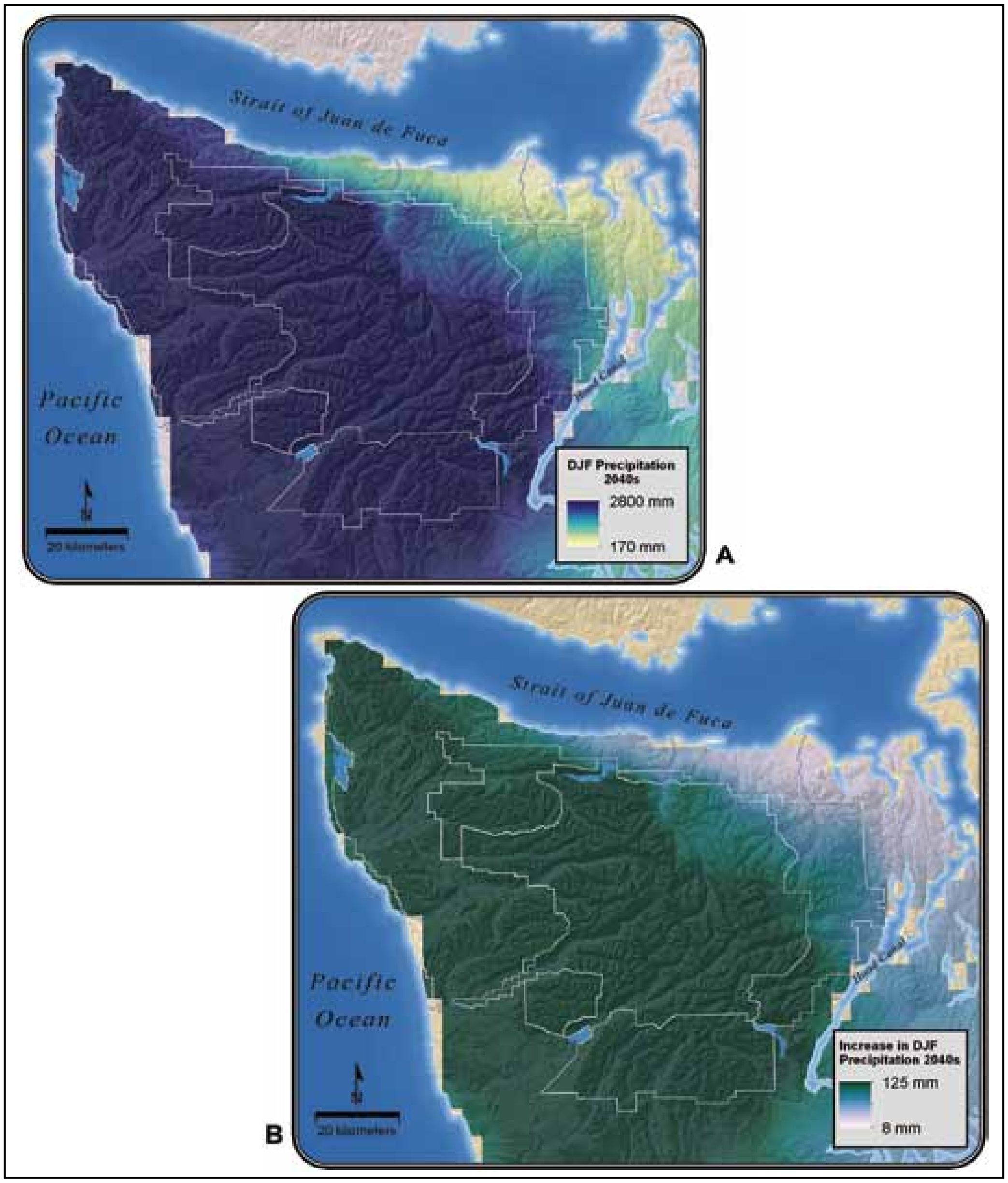

Figure 3.6—(**A**) Future (2040s) December to February (DJF) precipitation and (**B**) change from 1916 to 2006 precipitation for the Olympic peninsula based on statistically down-scaled Global Climate Model (GCM) information for 10 GCM models. Olympic National Park and Olympic National Forest are outlined in white. The largest increases in precipitation are in the southwestern Olympic Peninsula.

Summer (June to August [JJA]) potential evapotranspiration (one component of water balance and closely related to fuel moisture and tree stress) is expected to increase by 5 to 18 mm by the 2040s (fig. 3.7), with most of the largest increases in lower elevation forests in the northeastern portion of the peninsula.

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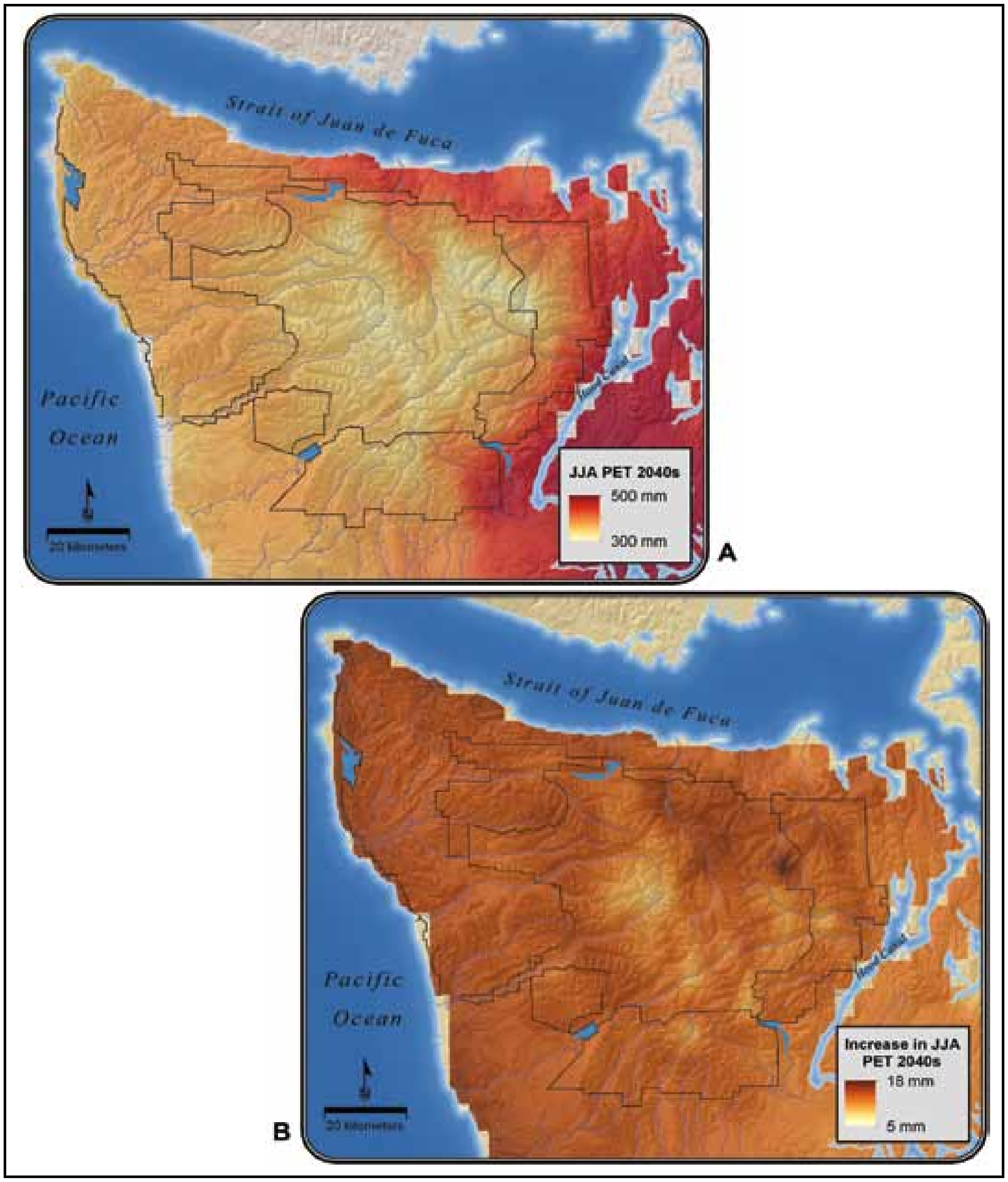

Figure 3.7— (**A**) Future (2040s) June to August (JJA) potential evapotranspiration (PET) and (**B**) change from 1916 to 2006 June to August baseline PET for the Olympic Peninsula based on downscaled climate projections and Variable Infiltration Capacity hydrologic modeling (Elsner et al. 2010). Olympic National Park and Olympic National Forest are outlined in black. Increased PET is related to decreased soil moisture and increased drought stress. The largest increases in PET are in the northeastern Olympic Peninsula.

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Chapter 4: Climate Change, Hydrology, and Road Management at Olympic National Forest and Olympic National Park

Jessica E. Halofsky, William S. Shelmerdine, Robin Stoddard, Robert Metzger, Alan F. Hamlet,
and Catherine Hawkins Hoffman[1]

Potential Effects of Climate Change on Hydrology on the Olympic Peninsula

Temperature, Snowpack, and Timing of Streamflow

Across the Western United States, increasing temperatures over the last 50 years have led to more precipitation falling as rain rather than snow, earlier snowmelt (Hamlet et al. 2007, Stewart et al. 2005), and reduced spring snowpack (Barnett et al. 2008, Hamlet et al. 2005, Mote 2003, Mote et al. 2005). Further reductions in snowpack and shifts in timing of snowmelt are expected with increasing temperatures in the 21st century. April 1 snow water equivalent (a measure of water in snowpack) is projected to decrease by an average of 27 to 29 percent across Washington state by the 2020s, 37 to 44 percent by the 2040s, and 53 to 65 percent by the 2080s (Elsner et al. 2010) (fig. 4.1). The greatest reductions in snowpack are expected for lower elevations (<1000 m) because of warmer midwinter temperatures at these elevations (Elsner et al. 2010, Hamlet et al. 2005).

Changes in snowpack are particularly important for the mountainous regions of the Western United States, including the Pacific Northwest, because snowmelt provides about 70 percent of annual streamflow in these regions (Mote et al. 2008). Warming temperatures affect the timing of snowmelt and associated seasonal streamflow. Both increased winter rain (as opposed to snow) and shifts to earlier spring snowmelt result in higher winter and spring streamflows and lower summer streamflows in snowmelt-dominated and transient (rain/snow mixed) watersheds (Elsner et al. 2010, Stewart et al. 2005). Snowmelt-dominant watersheds store most winter precipitation in snowpack. This snowpack melts in the spring and early summer, resulting in peak

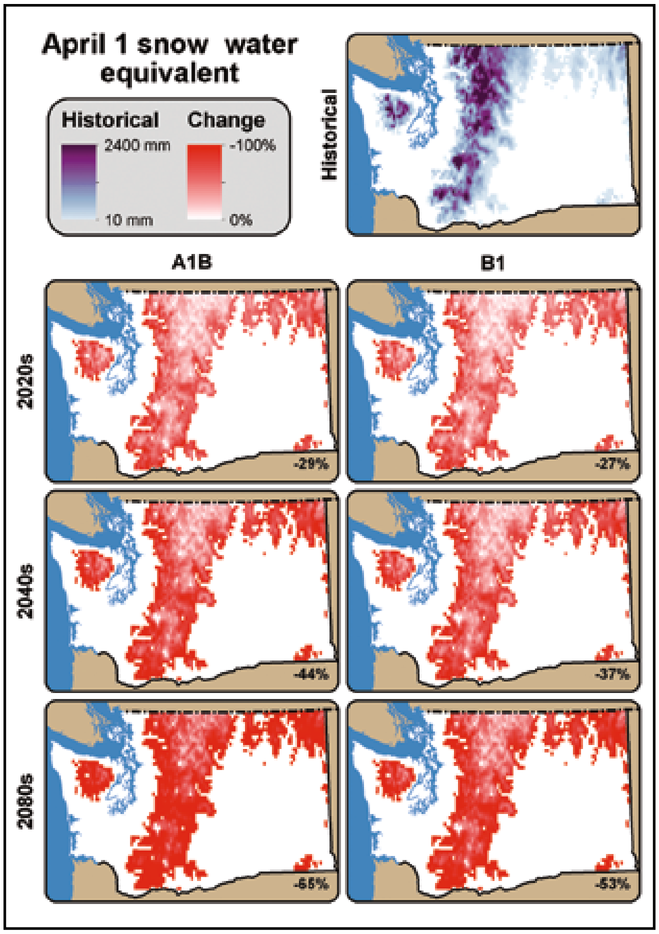

Figure 4.1—Summary of projected changes in April 1 snow water equivalent (SWE), an indication of snow amount, compared to historical for the 2020s, 2040s, and 2080s (A1B and B1 emissions scenarios) by the Variable Infiltration Capacity model. Percentage change values represent spatially averaged April 1 SWE across Washington state (Elsner et al. 2010).

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streamflow in the late spring or early summer and lower streamflow during the winter months (Elsner et al. 2010). Transient watersheds are primarily at mid elevations and receive some snow and some rain. Of the snow that these watersheds receive, some melts in the winter months, and some is stored in the winter months and melts with warming temperatures in the spring (Elsner et al. 2010). Thus, streams and rivers draining transient watersheds often have one streamflow peak in fall or early winter owing to runoff generated by precipitation falling as rain, and another peak in late spring when the snowpack accumulated in midwinter melts (Elsner et al. 2010). Projections for Washington state show that by the 2080s, there will be widespread transformation of transient watersheds to rain-dominant behavior, with essentially no snowmelt-dominant watersheds remaining in Washington by the end of the 21st century (Elsner et al. 2010). In response to these changes in natural storage processes, seasonal streamflow timing will shift significantly in both snowmelt-dominant and transient watersheds, resulting in increased winter and decreased spring and summer streamflows.

Examples of projected shifts in timing of streamflow for river systems on the Olympic Peninsula are shown in figures 4.2 through 4.7. Some river systems on the peninsula, such as the Satsop River (not shown), are rain-dominant watersheds. Warming temperatures will not likely have a significant impact on timing of streamflow in rain-dominant watersheds. Several Olympic Peninsula river systems, such as the Queets, Skokomish, Quinault, and Hoh River basins (figs. 4.2 through 4.5), receive most precipitation as rain but also some as snow at higher elevations, and thus warming will likely have moderate impact on the timing of streamflow in these watersheds. Other river systems, such as the Elwha and Dungeness Rivers, are in transient watersheds. Increasing temperatures in the 21st century will likely lead to significant increases in the winter and early spring peak streamflows and significant decreases in the summer low flows in these transient watersheds (figs.

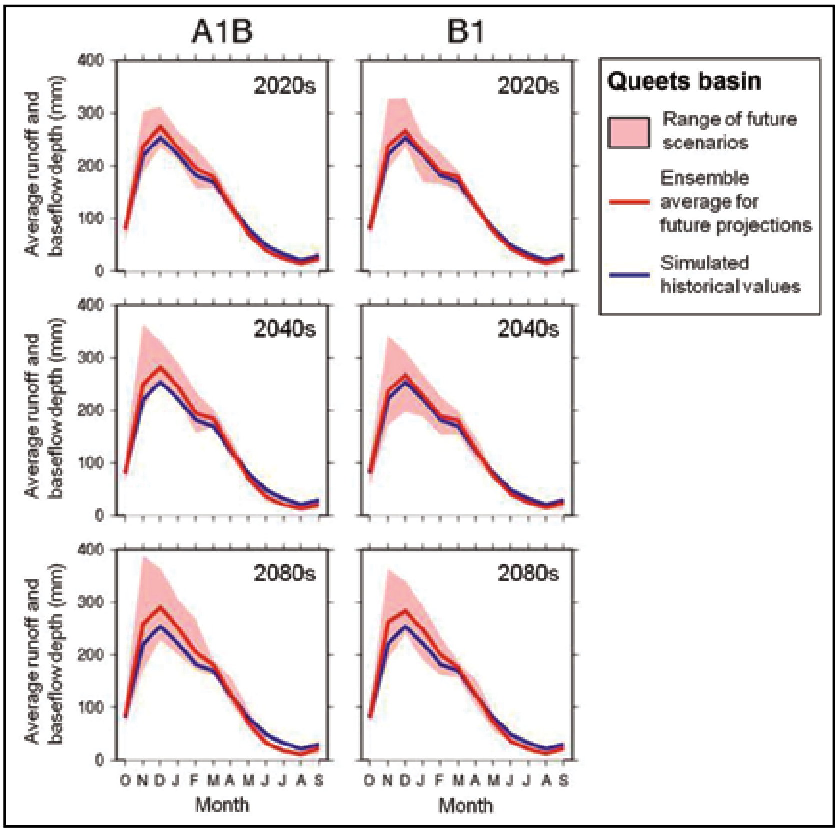

Figure 4.2—Simulated combined monthly average total runoff and baseflow over the entire Queets basin expressed as an average depth (millimeters). This variable is a primary component of the simulated water balance, and is one of the primary determinants of streamflow. The blue line shows the simulated historical values. Light red bands show the range of all future scenarios from 10 global climate models for the A1B (left column) and B1 (right column) emissions scenarios, and the dark red lines show the ensemble average for the future projections. See http://www.hydro.washington.edu/2860 for a detailed description of the methods used to generate these outputs.

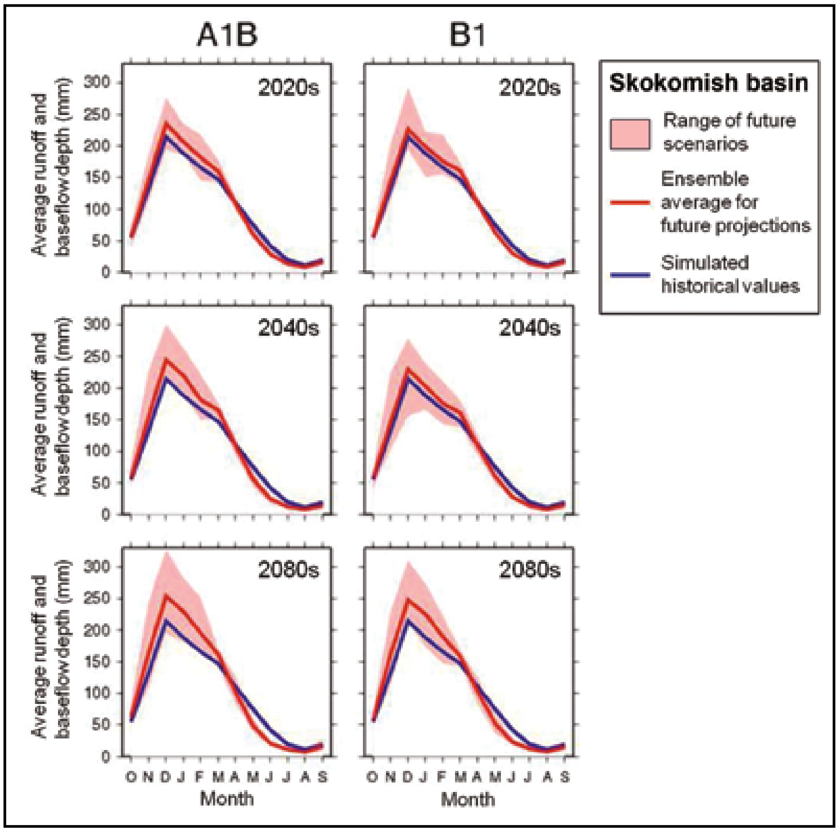

Figure 4.3—Simulated combined monthly average total runoff and baseflow over the entire Skokomish basin expressed as an average depth (millimeters). This variable is a primary component of the simulated water balance, and is one of the primary determinants of streamflow. The blue line shows the simulated historical values. Light red bands show the range of all future scenarios from 10 global climate models for the A1B (left column) and B1 (right column) emissions scenarios, and the red lines show the ensemble average for the future projections. See http://www.hydro.washington.edu/2860 for a detailed description of the methods used to generate these outputs.

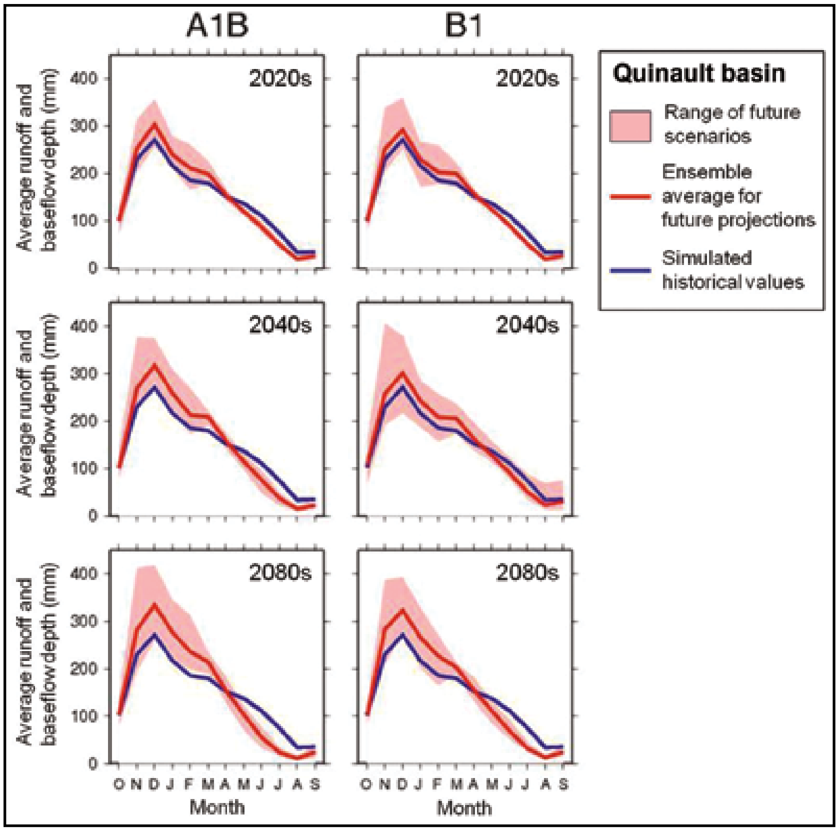

Figure 4.4—Simulated combined monthly average total runoff and baseflow over the entire Quinault basin expressed as an average depth (millimeters). This variable is a primary component of the simulated water balance, and is one of the primary determinants of streamflow. The blue line shows the simulated historical values. Light red bands show the range of all future scenarios from 10 global climate models for the A1B (left column) and B1 (right column) emissions scenarios, and the red lines show the ensemble average for the future projections. See http://www.hydro.washington.edu/2860 for a detailed description of the methods used to generate these outputs.

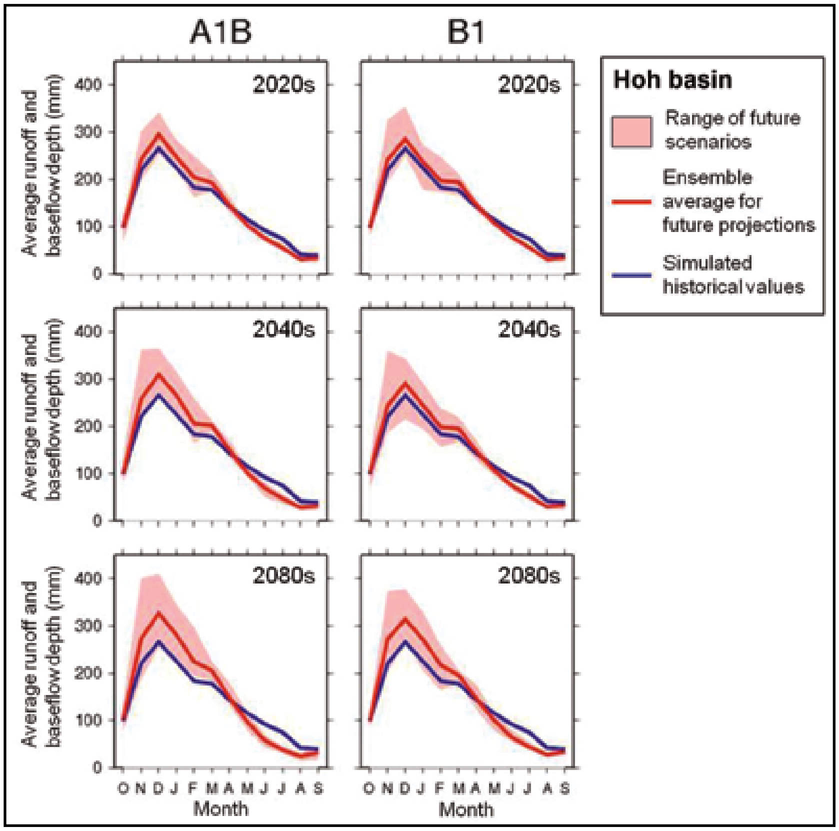

Figure 4.5—Simulated combined monthly average total runoff and baseflow over the entire Hoh basin expressed as an average depth (millimeters). This variable is a primary component of the simulated water balance, and is one of the primary determinants of streamflow. The blue line shows the simulated historical values. Light red bands show the range of all future scenarios from 10 global climate models for the A1B (left column) and B1 (right column) emissions scenarios, and the red lines show the ensemble average for the future projections. See http://www.hydro.washington.edu/2860 for a detailed description of the methods used to generate these outputs.

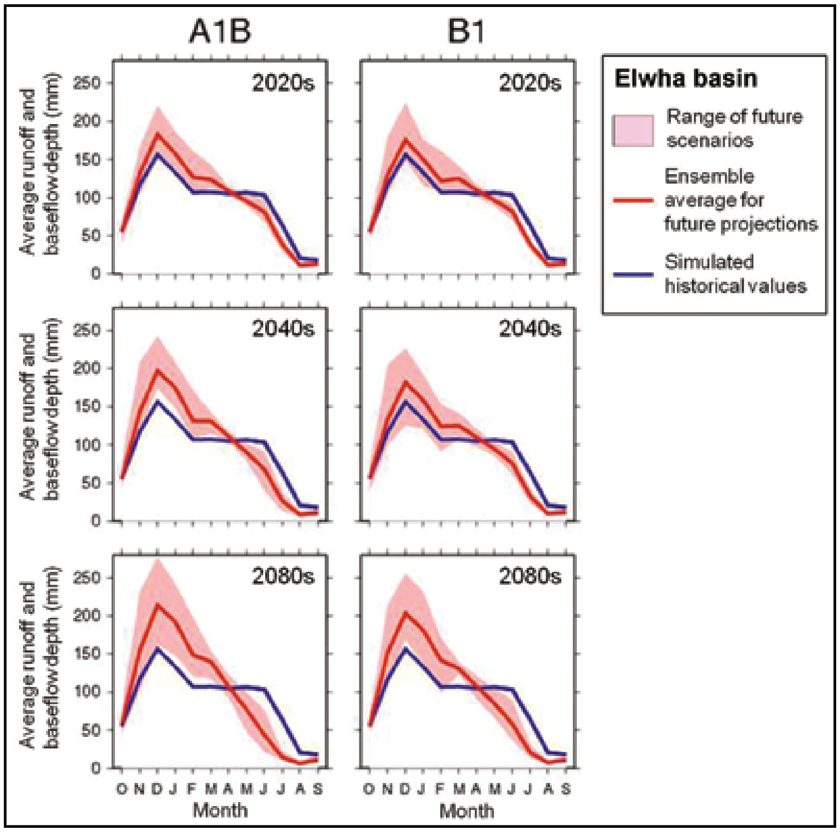

Figure 4.6—Simulated combined monthly average total runoff and baseflow over the entire Elwha basin expressed as an average depth (millimeters). This variable is a primary component of the simulated water balance, and is one of the primary determinants of streamflow. The blue line shows the simulated historical values. Light red bands show the range of all future scenarios from 10 global climate models for the A1B (left column) and B1 (right column) emissions scenarios, and the red lines show the ensemble average for the future projections. See http://www.hydro.washington.edu/2860 for a detailed description of the methods used to generate these outputs.

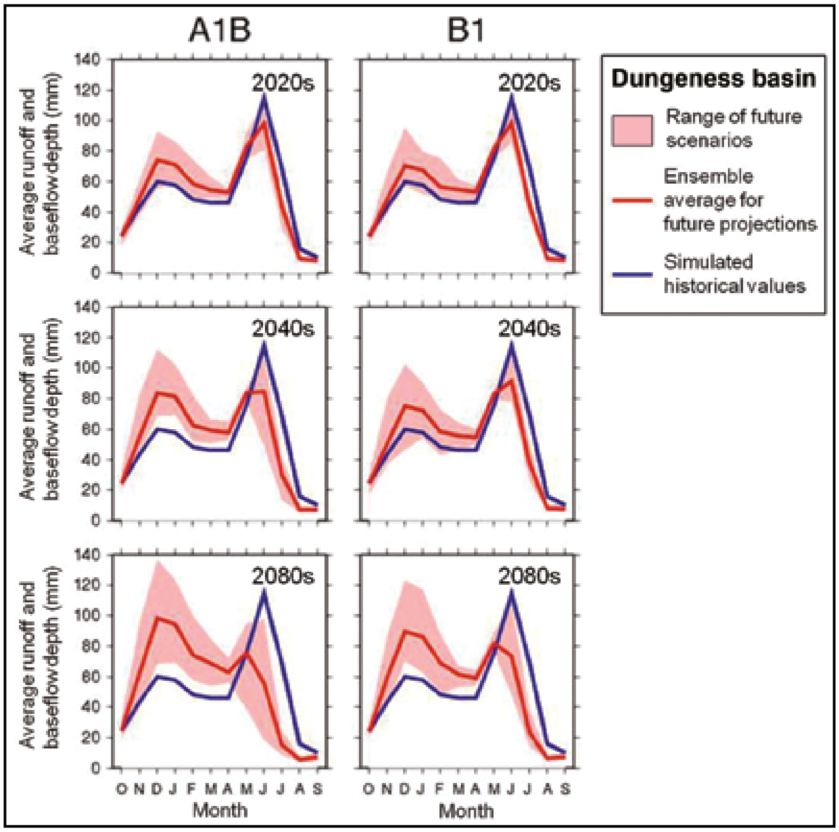

Figure 4.7—Simulated combined monthly average total runoff and baseflow over the entire Dungeness basin expressed as an average depth (millimeters). This variable is a primary component of the simulated water balance, and is one of the primary determinants of streamflow. Blue line shows the simulated historical values. Light red bands show the range of all future scenarios from 10 global climate models for the A1B (left column) and B1 (right column) emissions scenarios, and dark red lines show the ensemble average for the future projections. See http://www.hydro.washington.edu/2860 for a detailed description of the methods used to generate these outputs.

4.6 and 4.7). Decreased summer flow will likely be most evident in the headwaters of watersheds, where flows will likely become increasingly ephemeral or cease altogether in the summer months (fig. 4.8). However, such effects are sometimes strongly linked to changes in groundwater in the basin, which are not included in the projections discussed above (Tague et al. 2008). Locations where deep groundwater may mediate streamflow responses on the Olympic Peninsula could potentially be identified through interpretation of a geological map and locating areas where intense fracturing has occurred. However, groundwater effects are unlikely to be a major influence on hydrologic changes as they are in regions with porous and young volcanic soils, such as central Oregon.

Precipitation, Storm Intensity, and Flooding

Changes in precipitation have a direct influence on streamflow and the frequency and magnitude of flooding events. Model projections for precipitation in the 21st century are much more uncertain than those for temperature. Elsner et al. (2010) analyzed precipitation projections of 20 global climate models and two future carbon dioxide scenarios for the Pacific Northwest, and they found that annual projected precipitation changes range from -9 to +12 percent for the 2020s, -11 to +12 percent for the 2040s, and -10 to +20 percent for the 2080s (Elsner et al. 2010, Mote and Salathé 2010). Projections of seasonal precipitation changes, however, show increases in winter precipitation and decreases in summer precipitation (Elsner et al. 2010, Mote and Salathé 2010). Projections of cool season precipitation (combining both A1B and B1 emission scenarios) range from +2.3 to +3.3 percent for the 2020s, +3.9 to +5.4 percent for the 2040s, and +6.4 to +9.6 percent for the 2080s (Elsner et al. 2010). These increases in cool season precipitation are projected to lead to overall increases in annual runoff across Washington (0 to 2 percent by the 2020s, 2 to 3 percent by the 2040s, and 4 to 6 percent by the 2080s), although the effects differ for individual watersheds (Elsner et al. 2010).

Besides potential increases in winter precipitation, precipitation intensity is projected to increase in some parts of Washington, including the west slopes of the Olympic

Figure 4.8—Projected increases in 20-year floods on the Olympic Peninsula. Numbers indicate the ratio of projected 20-year flood statistics for the 2040s to 20th-century flood statistics at select locations under the A1B carbon dioxide emission scenario. Higher numbers, and larger and darker red dots, indicate higher projected increases in 20-year flood frequency. Olympic National Park and Olympic National Forest are outlined in dark gray. (Adapted from Mantua et al. 2010.)

Peninsula, in the 21st century (Salathé et al. 2010). Increases in winter precipitation, increases in precipitation intensity, and changes in timing of peak streamflow in transient watersheds will contribute to increased flood risk in some of Washington's rivers. Flooding magnitude and frequency are projected to increase most in December and January and in historically transient watersheds in Washington (Mantua et al. 2010). Rain-dominant watersheds will likely see small increases in flood frequency, whereas many snowmelt-dominant watersheds will likely see decreases in flooding owing to decreases in snowpack and corresponding decreases in snowmelt-driven peak flows in the spring (Mantua et al. 2010). On the Olympic Peninsula, increases in flood frequency are projected for many river systems (fig. 4.8), with greater increases in flood frequency projected in historically transient watersheds such as the Elwha. At the opposite extreme, earlier snowmelt and timing of runoff is projected to lead to decreased low flows in the summer in many Olympic Peninsula watersheds (fig. 4.9). As noted above, effects of groundwater on summer streamflows may mitigate these impacts in some watersheds.

Effects of Changing Hydrology on Physical Watershed Processes

Projected hydrologic effects of climate change, including more precipitation falling as rain rather than snow, decreased snowpack, earlier snowmelt, increased winter precipitation and runoff, increased storm intensity, increased winter and spring streamflows, reduced summer streamflows, increased flood frequency and magnitude, and elevation shifts in transition (rain on snow) zones, will likely affect physical watershed processes (table 4.1). Increased precipitation and storm intensity, higher snowlines (increasing effective basin area), and loss of snow

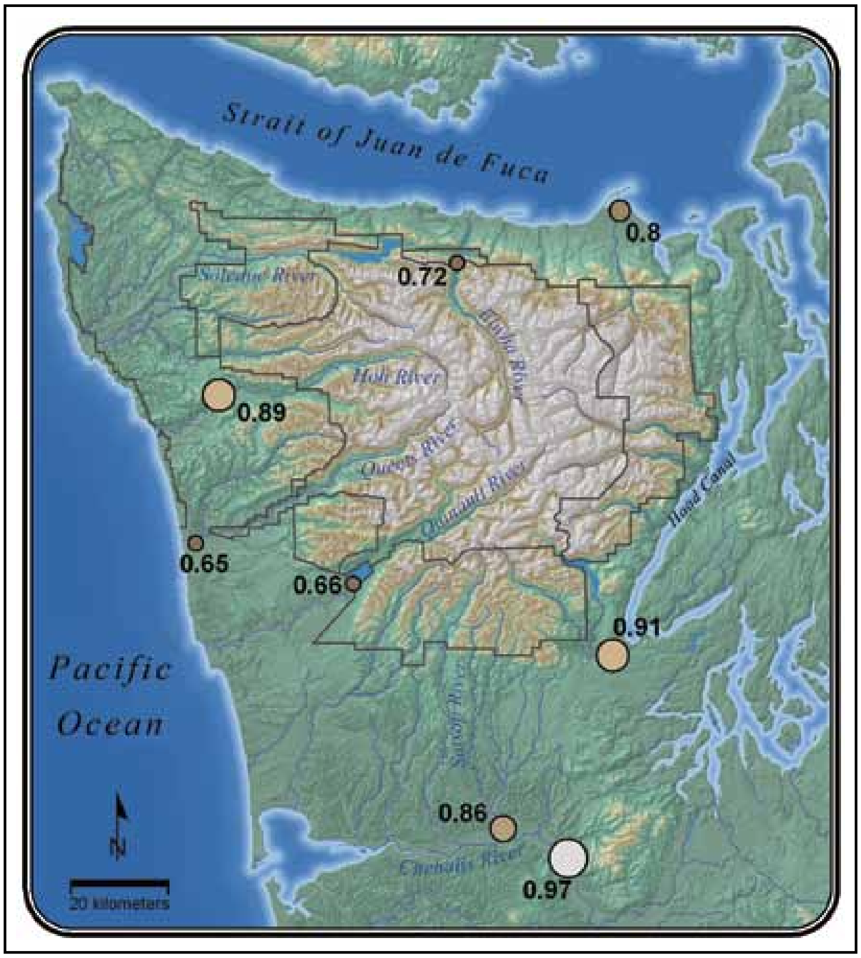

Figure 4.9—Projected decreases in low streamflows on the Olympic Peninsula. Numbers indicate the ratio of projected 20-year low streamflow statistics for the 2040s to 20th-century low flow statistics under the A1B carbon dioxide emission scenario. Lower numbers, and smaller and darker red dots, indicate higher projected decreases in low flow. Olympic National Park and Olympic National Forest are outlined in dark gray. (Adapted from Mantua et al. 2010.)

cover are expected to lead to increased rate and volume of water delivery to channels, increased mass wasting and debris flows, and increased sediment and wood delivery to streams (Benda and Dunne 1997). Increased winter and spring flow volume in streams will lead to increased flood-plain inundation, increased channel migration, and increased channel erosion and scour. Other climate-related stressors, such as fire and tree mortality (see chapter 6), could also exacerbate these hydrologic effects of climate change on physical watershed processes.

Road Management at Olympic National Forest and Olympic National Park

The following section provides information on road management at Olympic National Forest (ONF) and Olympic National Park (ONP) including (1) the context in which ONF and ONP manage roads, (2) the guidance and constraints on road management at ONF and ONP, and (3) the primary issues around and activities currently conducted in road management at ONF and ONP. This information, coupled with the likely impacts of climate change on hydrology on the Olympic Peninsula (described above), provides a basis on which to develop climate change adaptation options for road management at ONF and ONP.

Road Management at Olympic National Forest

Olympic National Forest has 3500 km of roads. Most of these roads were built between 1950 and 1980, primarily for logging purposes, by using practices that are not consistent with today's standards. The high number of roads, heavy rainfall, steep slopes, frequent storm damage, and high recreational demand for well-maintained forest roads all lead to high road maintenance costs at ONF. However, funding allocated for road maintenance, upgrading, and decommissioning at ONF is limited.

Table 4.1—Projected climate change effects and adaptation options in the context of road management at Olympic National Forest (ONF) and Olympic National Park (ONP)

Program	Project	Projected climate change effects[a]	Projected effects on physical watershed processes	Current and expected sensitivities	Adaptation management options and strategies	Barriers and information needed
Road maintenance[b]	Planning	2, 6–10	• Increased flow volume • Increased mass wasting and avalanches • Increased sediment delivery • Increased flood-plain inundation • Increased channel migration	• Culvert capacity • Water diversion • Fill-slope failures • Stream-adjacent road failure	• Prioritize road treatment by watershed risk and road risk (the roads with the most sensitivities and that are most connected to streams)	• National Highway Safety Act fund requirements (ONF) • Maintenance funding limitations • Need assessments to refine links to physical process and response
	Implementation	1, 5–9	• Increased flow volume • Increased mass wasting/debris flows • Increased sediment delivery to culvert inlets and ditches • Increased rate and volume of water delivery to channels • Increased transport of wood in channels	• Culvert capacity • Culvert plugging • Water diversion • Fill-slope failures • Extension of channel network (development of first-order channels)	• Increased maintenance (preparation and response), including: Culvert cleaning Armoring outlets and ditches Installing water bars and drivable dips	• National Highway Safety Act fund requirements (ONF) • Maintenance funding limitations • Physical barriers to road access in winter
Road operations	Planning	2, 5–10	• Increased flow volume • Increased mass wasting and avalanches • Increased sediment delivery • Increased flood-plain inundation • Increased channel migration	• Culvert capacity • Water diversion • Fill-slope failures • Stream-adjacent road failure • Encroachment from stream-adjacent road segments	• Prioritize road treatment by watershed risk and road risk (the roads with the most sensitivities and that are most connected to streams) • Assess possibilities to design more sustainable road types for the future	• National Highway Safety Act fund requirements (ONF) • Road funding limitations • Need assessments to refine links to physical process and response • Need feasibility studies for mass transit options (ONP)

Table 4.1—Projected climate change effects and adaptation options in the context of road management at Olympic National Forest (ONF) and Olympic National Park (ONP) (continued)

Program	Project	Projected climate change effects[a]	Projected effects on physical watershed processes	Current and expected sensitivities	Adaptation management options and strategies	Barriers and information needed
	Design: Water crossing Fish passage	2, 5–10	• Increased flow volume • Increased sediment and wood transport • Increased channel migration	• Culvert capacity • Foundation scour • Lateral channel adjustments	• Design more resilient structures (design resilient bridges and larger structures, and incorporate channel geomorphic attributes in structure design)	• Need method to calculate Q_{100} (historical or recent data?) or an alternative
	Design: Bank protection	7–10	• Increased flow volume • Increased erosion and scour • Increased channel migration • Increased mass wasting and avalanches	• Stream-adjacent road failure • Cut-bank failures on montane and subalpine roads	• Relocate road segment, decommission road segment, or accept higher maintenance costs (ONF) • In a scenario-planning context, analyze roads and road segments (ONP) • Install retaining walls or other cut-bank stabilization (ONP)	• Revisit access and travel management plan and develop better resolution in identifying sensitive stream-adjacent roads • Need geomorphic analyses of other (park) rivers bordered by roads (ONP) • No funding source for proactive, sustainable bank protection • Emergency Relief for Federally Owned Roads funding policies limit or preclude sustainable road restoration options
	Design: New construction	7–10	• Potential increase in capture and concentration of water • Potential decrease in slope stability	• Increased potential for ditch or culvert plugging and diversion • Increased potential for erosion and scour at pipe outlets	• Decrease reliance on drainage structures • Increase frequency of drainage discharge points • Increase redundancy or backup features • Limit consequence of failure • Adjust alignment, roll with topography	• May have to adjust thinking regarding design life and therefore life cycle costs in alternative comparisons

Table 4.1—Projected climate change effects and adaptation options in the context of road management at Olympic National Forest (ONF) and Olympic National Park (ONP) (continued)

Program	Project	Projected climate change effects[a]	Projected effects on physical watershed processes	Current and expected sensitivities	Adaptation management options and strategies	Barriers and information needed
	Design Reconstruction Drainage upgrades Stabilization Storm-proofing	7–10	• Increased flow volume • Increased rate and volume of water delivery to channels • Increased sediment and wood transport • Increased mass wasting/debris flows • Increased sediment delivery to culvert inlets and ditches	• Culvert capacity • Culvert plugging; water diversion • Fill-slope failures • Extension of channel network (development of first-order channels)	• Implement more conservative design elements (more intensive treatments such as larger diameter culverts, closer spacing between ditch relief culverts and waterbars) • Increase maintenance-frequency of drainage features	• Revisit access and travel management plan and develop better resolution for identifying road vulnerability (consider rain-on-snow and increased storm intensity) (ONF) • Region 6 is currently developing a road storm-damage risk reduction guide (ONF)
	Design: Decommissioning (ONF)	7–10	• Increased runoff • Increased flow volume; increased channel migration • Increased sediment transport • Increased mass wasting and debris flows • Increased **floodplain** inundation	• Increased erosion with sediment delivery to channels	• Implement more conservative design elements (bigger channels, more drainage, more outsloping, increased armoring of outlets)	
Road operations	Implementation	1, 5–9	• Increased flow volume • Increased mass wasting/debris flows • Increased sediment delivery to culvert inlets and ditches	• Increasing number of projects needed to reduce resource risk and road failures • Limited funding • Changes in project work periods	• Continue efforts to improve, stabilize, and reduce existing road system • Focus road improvements in priority areas	• National Highway Safety Act requirements (ONF) • Funding limitations • Physical barriers to road access owing to storm damage

Table 4.1—Projected climate change effects and adaptation options in the context of road management at Olympic National Forest (ONF) and Olympic National Park (ONP) (continued)

Program	Project	Projected climate change effects[a]	Projected effects on physical watershed processes	Current and expected sensitivities	Adaptation management options and strategies	Barriers and information needed
			• Increased rate and volume of water delivery to channels • Increased wood transport		• Seek out additional funding to implement improvements	

[a] Projected climate change effects relevant to road management:
(1) Increased winter air temperatures/fluctuation above and below freezing
(2) More precipitation falling as rain rather than snow
(3) Decreased snowpack
(4) Earlier snowmelt
(5) Increased winter and spring streamflows in some types of watersheds
(6) Decreased summer streamflows in some types of watersheds
(7) Increased winter precipitation and runoff
(8) Increased storm intensity
(9) Increased flood frequency and magnitude in some types of watersheds
(10) Elevation shifts in transition (rain-on-snow) zones

[b] Road maintenance activities ensure that existing roads function correctly (defined by policy).

To help prioritize road management activities at ONF, a road management strategy (RMS) was developed in 2000 that assessed the risks that individual road segments posed to various resources, especially aquatic resources, against the need for access that the road provided. The RMS was developed at least partly in response to the aquatic restoration mandate of the Northwest Forest Plan (USDA and USDI 1994). The RMS is used for setting priorities for road maintenance, upgrading, and decommissioning (see box 4.1 for specific activities in these categories) and considers five factors, each of which incorporates particular indicators. These five factors include aquatic risk, access needs, wildlife concerns, high-value watersheds, and silvicultural opportunities (box 4.2). In general, roads that present high risk to aquatic systems, are needed for access (by the public or for activities such as restoration thinning), impact threatened or endangered species, and are located in high-value watersheds are prioritized for maintenance, stabilization, and upgrading. Roads that meet the above criteria but are not necessary for access are prioritized for decommissioning (e.g., fig. 4.10).

In addition to being guided by the RMS, road management at ONF is guided by the access and travel management (ATM) plan, which is a strategic management tool that describes the proposed future road system. The ATM was updated by forest managers in 2003. By using RMS information as a starting point, managers conducted a road-by-road evaluation on about 3300 km of road, during which RMS data were supplemented by the site-specific knowledge of interdisciplinary ONF District ATM teams to generate draft proposals for the long-term management of forest roads. Public and tribal involvement was also a critical component of the ATM plan update. The updated ATM plan proposes substantial reductions in road mileage throughout many watersheds at ONF owing to declining road maintenance funding, reduced need for access, and high risk to aquatic habitat. Nearly one-third of the forest's roads are proposed for decommissioning.

Road Management at Olympic National Park

There are more than 225 km of paved and unpaved visitor use roads at Olympic National Park (ONP). There are no

Box 4.1—Common road management activities at Olympic National Forest (ONF) and Olympic National Park (ONP). Many of these activities will likely be influenced, in frequency or nature, by climate change.

Road maintenance activities—

- Culvert cleaning, replacement, and installation
- Grading
- Slide removal
- Erosion control
- Brushing
- Hazard and downed tree removal (developed areas only at ONP)
- Pavement repair
- Bridge maintenance
- Gate installation and maintenance
- Painting
- Shoulder maintenance
- Ditch cleaning and drainage maintenance
- Water bar and dip installation

Storm-proofing and road drainage upgrading activities—

- Correcting stream-diversion potentials at stream crossings
- Removing unstable fill (ONF)
- Rerouting road drainage to stable areas
- Adding new culverts
- Installing proper-sized culverts
- Lowering fills (ONF)
- Hardening stream crossings (ONF)
- Lowering inlets
- Out-sloping
- Installing waterbars (ONF)

Road decommissioning activities (ONF)—

- Removing culverts
- Ripping or decompacting road surfaces
- Out-sloping
- Removing unstable fills
- Removing bridges or converting road bridges to trail bridges
- Constructing waterbars
- Seeding/planting
- Installing erosion-control measures
- Placing travel barriers

cross-park roads; however, roads do penetrate the park's perimeter and front-country areas, often along major river drainages. Roads and other infrastructure located within flood plains of the Olympic Peninsula have a high risk of being damaged during storm events. Coastal rivers located in the temperate rain forest exhibit a broad range of flows. For example, the summer low flow in the Queets River for the 2007 water year was about 10 m^3/s, while the peak flow for the year was 1190 m^3/s, or two orders of magnitude higher (USGS 2008). The record flow for the Queets River is 4080 m^3/s, which approximates the mean annual flow of the Columbia River (USGS 2008).

The ONP General Management Plan (GMP) (NPS 2008) calls for all existing roads to be maintained in a sustainable manner and for improving mass-transit opportunities. Objectives and desired conditions described in the plan relevant to the road system include the following:

- Park managers will use the most current and feasible engineering methods and techniques that minimize adverse effects on natural river processes to protect park roads and facilities located in flood plains.
- Park managers will inventory flood-prone areas near facilities and roads, and develop a program to proactively protect or relocate these facilities by using the most current techniques that minimize adverse effects on aquatic and riparian habitats and fluvial processes.
- Park managers will work with area partners, including tribes, federal, state, and county agencies, and others, to develop restoration plans for at-risk river systems, and for incorporating current technologies, over time, to restore or improve flood-plain and riparian functions altered in the past by bank-hardening techniques.

If park facilities are damaged or destroyed by a hazardous natural event, park managers will thoroughly evaluate options for relocation or replacement by new construction at a different location. If a decision is made to relocate or replace a severely damaged or destroyed facility, it will be placed, if practicable, in an area believed to be free from natural hazards.

The GMP specifically calls for road management plans to be developed in cooperation with federal, state,

Box 4.2—Critical factors and associated indicators considered in road work prioritization under the Olympic National Forest road management strategy.

Aquatic risk:

Geologic hazard—This factor identifies those roads located within potentially unstable terrain or within areas with high sensitivity to erosion. In this context, it is used as an aquatic habitat and water quality risk factor. It evaluates the terrain that the road is located on, not the terrain above the road. It is intended to be a reflection of the potential to initiate erosion or mass wasting from roads themselves rather than the potential for impacts to roads from processes initiated upslope.

Proximity (delivery) to fish habitat—This factor uses a combination of sediment delivery efficiency and physical distance from the fish-bearing portions of the stream network. It provides an estimate of how direct any road effects would be on fish and fish habitat.

Stream crossing density—The stream crossing density factor determines the relative hazard associated with stream crossing(s) within the road segment, defined as the frequency.

Riparian zone/stream proximity—The riparian zone factor determines the relative degree of connectivity between the road system and the stream system. This factor considers the portion of the road segment within the riparian zone or near a stream. Riparian zones are defined as a 100-m buffer width, which spans both sides of the channel, as measured from the center of the channel.

Upslope hazard—The upslope hazard factor identifies those roads located downslope of steep converging topography or terrain designated to have a high potential for landslides. These hazard elements may initiate new hill slope failures or increase the magnitude of initial mass wasting events. This factor differs from the geologic hazard factor in that the road itself may not be on the terrain that is considered hazardous, and the problems or disturbances affecting the road or the aquatic system may not be initiated from the road itself.

Access:

Private access—This factor identifies roads that provide access to non-National Forest System lands or special use permit sites.

Public access—This factor identifies roads that provide access to national forest-developed recreation sites.

Administrative access—This factor identifies roads that provide access to administrative sites (facilities, rock sources, and communication sites).

Wildlife:

Threatened and endangered species—The wildlife factor identifies roads that lie within or intersect a 0.40-km radius of a known northern spotted owl activity center, a marbled murrelet occupied site, or a bald eagle activity center.

High-value watersheds:

These factors are used to determine whether the road segment lies within or is within areas contributing to:
Northwest Forest Plan key watersheds
Municipal watersheds
Clean Water Act 303(d) listed water bodies
Habitat for listed fish stocks

Silvicultural:

Terrestrial habitat development (commercial thinning)—This factor considers whether the road provides access to stands with potential for terrestrial habitat development through commercial thinning.

Terrestrial habitat development (precommercial thinning)—This factor considers whether the road provides access to stands with potential for terrestrial habitat development through precommercial thinning.

Figure 4.10—A decommissioned road at Olympic National Forest. (Photo courtesy of USDA Forest Service, Olympic National Forest.)

and tribal partners for at-risk roads near rivers and within the flood plains of the Hoh, Queets, and Quinault Rivers. These plans may include geomorphic investigations (such as that prepared for a section of the Quinault River) (see Bountry et al. 2005), restoration, feasibility studies, and as appropriate, recommendations for road relocations and potential wilderness boundary changes that may be needed as rivers respond to changing hydrology associated with climate change. The plan includes development of a North Shore Road/Finley Creek management plan (Quinault) to address the hydrologic and geomorphic issues associated with maintaining year-round vehicle access in this unstable environment, and to return Finley Creek to a more naturally functioning and stable condition. Finally, related to rising sea levels associated with climate change, the GMP calls for a risk-assessment study for Highway 101 along the coastal portion of the park to be conducted in cooperation with the Washington State Department of Transportation. This study will identify at-risk portions of the highway and determine suitable areas for reroutes or road relocations.

Specific road management goals for ONP, including considerations for potential effects of climate change, include:

- Hurricane Ridge—Road access to Hurricane Ridge will continue to be provided year round, and alternative methods of transportation (transit) will be provided if studies indicate it is feasible. The unpaved road to Obstruction Point will be maintained seasonally.
- Staircase—The Staircase road will be maintained by using methods that minimize adverse effects on river processes and aquatic and riparian habitats to the extent possible (NPS 2008).
- Elwha—Road access will be retained to the Boulder Creek and Whiskey Bend trailheads; methods will minimize adverse effects on river processes and aquatic and riparian habitats to the extent possible (NPS 2008).
- Sol Duc—Seasonal road access will be provided by using methods that minimize adverse effects on river processes and aquatic and riparian habitats to the extent possible (NPS 2008).
- Mora—The last 0.8 km of road will be retained unless lost to a catastrophic event and reconstruction is infeasible because of topography. This section of the road lies within a tsunami zone in an area of very high sensitivity to future sea level rise. Access to the Rialto Beach area will be by trail should this section of road be lost (Pendleton et al. 2004).
- Hoh—Year-round road access will be provided by using methods that minimize adverse effects on river processes and aquatic and riparian habitats to the extent possible (NPS 2008). In the event of a flood with associated road loss or damage, if road relocation away from river meander areas is feasible, wilderness boundary changes that result in no net loss of ONP wilderness acreage will be sought as necessary (NPS 2008). Alternative methods of transportation (transit) would be provided if studies indicate it is feasible.
- Kalaloch—The ONP will work with the Washington Department of Transportation to determine options to relocate all or portions of Highway 101 outside the active coastal erosion zone as needed to maintain access, and for the protection of the coastal portion of the park. Kalaloch is also in an area of very high sensitivity to future sea level rise (Pendleton et al. 2004).
- Queets—Vehicular access will be retained, but the road or portions of the road may be moved or closed as needed in response to river meandering and changing

conditions, by using methods that minimize adverse effects on river processes and aquatic and riparian habitats to the extent possible (NPS 2008). The ONP will develop a plan to address long-term access options, and existing facilities may be removed or relocated in response to changing river and road conditions.

- Quinault—The loop drive will be retained and will provide access to the North Fork and Graves Creek areas. ONP will seek options to redesign or relocate the Finley Creek bridge, including moving and possibly redesigning the North Shore Road. The North Fork and Graves Creek roads will be retained; relocations may be necessary because of river movement and river restoration goals. Year-round road access would be retained by using methods that minimize adverse effects on river processes and aquatic and riparian habitats to the extent possible (NPS 2008). If road relocation away from river meander areas is feasible, wilderness boundary changes that result in no net loss of ONP wilderness acreage would be sought as necessary.
- Dosewallips—Road access will be provided by using methods that minimize adverse effects on river processes, aquatic and riparian habitats, and old-growth forests, to the extent possible.
- Deer Park—No change is expected for Deer Park Road; the road will remain unpaved and opened seasonally as weather conditions permit.

Climate Change Adaptation Strategies and Action Items for Road Management at Olympic National Forest and Olympic National Park

Process Used to Develop Adaptation Strategies for Road Management

In January 2009, ONF and ONP natural resources and engineering staff, and scientists from the Forest Service Pacific Northwest Research Station (PNW) and University of Washington Climate Impacts Group (CIG) convened to discuss adapting road management activities to climate change and related hydrologic changes on the Olympic Peninsula. Objectives of the workshop were to (1) learn about the latest climate and hydrology model projections, and (2) use an interactive dialogue between scientists and managers to explore options to incorporate climate change information into road management at ONF and ONP. The workshop began with a presentation from Alan Hamlet on climate and hydrologic model projections, and a presentation from ONF engineer William Shelmerdine on current road management at ONF. A facilitated discussion on potential adaptation strategies for road management at ONF and ONP followed. Table 4.2 and the "General Adaptation Strategies for Road Management" section below describe key points from the discussion.

Building on the January workshop, ONF natural resources and engineering staff and PNW scientists further examined the ideas brought forth in the workshop and developed a strategy to use climate change information in road management at ONF, in particular, and to further inform road management activities at ONP. Participants concluded that climate change predictions could affect all aspects of road management, including (1) planning and prioritization, (2) operations and maintenance, and (3) design. A discussion of adaptation strategies developed for each of these areas is below, after a description of more general adaptation strategies for road management in the forest and park. See box 4.3 for a summary of projected climate change effects on hydrology on the peninsula and related adaptation strategies for road management at ONF and ONP.

General Adaptation Strategies for Road Management

The goal of road management at ONF and ONP is to provide a safe and economical transportation system to meet the access needs of various users while minimizing potential adverse impacts to other resources. Recent road management actions at ONF have focused on reducing potential risk to aquatic resources by removing unstable roads, relocating roads and infrastructure out of valley bottom areas, and at both ONF and ONP, correcting culvert fish passage barriers (fig. 4.11), and increasing the size and number of drainage structures, or replacing culverts with bridges where appropriate. Anticipated climate change effects tend to validate the current road management efforts. In many ways, climate change will not necessitate large modifications of road management at ONF and ONP because the majority of current practices are focused on increasing the resilience of infrastructure and ecosystems. However, potential climate change effects underscore the need to increase activity and be proactive in priority areas to avoid impacts associated with infrastructure failure.

To deal with the uncertainty associated with climate change, strategic planning and efforts to increase flexibility in road management policies will be critical. Strategic approaches to resource allocation and utilizing no-regrets strategies will likely reduce vulnerability to future climate change and also help to better meet current objectives. Increasing flexibility in forest road management policies will allow management actions to shift more rapidly in response to new information on climatic changes and ecosystem response.

Managers will likely need to evaluate the density, location, design, and maintenance intensity of roads and related structures in the context of climate change to avoid escalating road maintenance costs associated with impacts discussed above. For example, roads in valley bottoms are particularly susceptible to flood damage, and moving these roads to other locations, when possible, may be desirable. Roads within or downslope of transient snow zones or snow-dominated areas will likely be subjected to increased flood damage because of more precipitation in the form of rain and increased storm intensity. These roads may require more intense treatments or more frequent maintenance. Also, current methods to size culverts and guidelines to determine design life may no longer be appropriate under changing climate.

The concept of Q_{100} (the peak flow anticipated in a 100-year flood event) is a key factor currently used for road

Box 4.3—Summary of projected climate change effects on hydrology on the Olympic Peninsula and related adaptation strategies for road management at Olympic National Forest and Olympic National Park.

- Reductions in snowpack and shifts in timing of snowmelt and streamflow are expected across the Western United States with increasing temperatures in the 21st century.
- Shifts in timing of streamflow, mainly increased winter and early spring peak flows and lower summer low flows, are expected for many Olympic Peninsula rivers, particularly for those in transient (mixed rain and snow) basins, such as the Elwha and Dungeness Rivers.
- Increases in cool season precipitation are projected to lead to overall increases in annual runoff across Washington state.
- Increases in precipitation intensity are also expected for the west slope of the Olympic Peninsula.
- Increases in winter precipitation, increases in precipitation intensity, and changes in timing of peak streamflow will contribute to increased flood risk in some of the Olympic Peninsula's rivers, particularly in December and January and in historically transient watersheds.
- Potential climate change effects underscore the need to increase activity and be proactive in priority areas to avoid impacts associated with increased infrastructure failure.
- Managers will likely need to evaluate the density, location, design, and maintenance intensity of roads and related structures in the context of climate change to avoid escalating road maintenance costs associated with impacts discussed above. For example, roads in valley bottoms are particularly susceptible to flood damage, and moving these roads to other locations, when possible, may be desirable to reduce maintenance costs and impacts on aquatic systems.
- Roads within, or downslope of, transition or snow-dominated areas will likely be subjected to increased flood damage because of more precipitation in the form of rain and increased storm intensity. Identifying these roads may be useful as they will likely require more intense treatments or more frequent maintenance.
- Also, current methods to size culverts and guidelines to determine design life may no longer be appropriate under changing climate. There are several alternatives, including using only the last 30 years of record (as opposed to the entire period of record), or using physically based model simulations to determine design discharge.

Table 4.2—Methods to incorporate climate change into road management at Olympic National Forest and Olympic National Park

Adaptation principle	Example adaptation strategies and actions
Be strategic and flexible	• Use selectivity in allocating resources. • Identify no-regrets strategies that do not require an accurate design standard but meet multiple criteria (e.g., for fish and streamflow). For example, with culvert design, bigger culverts could be put in every location to accommodate higher flows and fish passage, thus avoiding the development of new engineering design standards every decade. A standard design that works most of the time does not require constant updating and the large cost associated with the updating process. • Work under a new climate change paradigm in road management that is less prescriptive and more flexible. • Develop strategies and actions that are adaptable over time. • Focus on management actions that are robust to multiple future scenarios. • Broaden options and consider which option is more prudent for time and cost: new design, relocation, or increased maintenance. • Conduct management experiments on national forests to learn valuable lessons and contribute to the broader interest of all land and resource managing agencies. • Consider potential alterations to desired future conditions and alternative management pathways to achieve those conditions.
Reexamine road locations and entire design	• Rethink the design-life guidelines (usually <50 years) for roads and other structures. • Redo culvert size analysis based on peak flow data from only the last 30 years (as opposed to the period of record) or by using a physically based hydrology model (such as Variable Infiltration Capacity). • Consider whether existing roads are in the right locations (e.g., valley bottom roads). • Consider sediment problems in glacier-fed rivers that can make some valley bottom roads at risk or unsafe (such as in Mount Rainier National Park, or potentially the Hoh and Quinault valleys). • Consider future repair and maintenance needs in evaluating relocation options.
Use information selectively	• Use empirical data first and models second in analysis and planning. Assess sensitivities and trends in failures over the last 30 years and determine whether the sensitivities/failures were due to increased precipitation intensity or snowpack. Use the causes and consequences of past failures to determine where future failures will be and where actions should be focused. Consider new information and model predictions for the future only after that analysis. • Use expert knowledge when reliable quantitative data are not available. For example, instead of quantitative calculations of expected peak flow based on historical data, look at actual channel size on the ground and base culvert size on expert judgment.
Manage risk	• Expect that there will be some road failures. For example, failure can be expected in debris-prone areas. Without proactive action to manage risk, the anticipated failure rate will increase in response to climate change. • Conduct more up-front analysis and have plans in place to protect the most at-risk resources. • Use "What if it fails?" scenarios to address risk and uncertainty in evaluating road management alternatives. Failures that will result in the most severe impacts are the ones to be avoided
Increase communication and foster partnerships	• Foster science-management partnerships. • Engage scientists in communicating new science for management. • Communicate with the Federal Highway Administration about projected climate change effects and associated needs to widen programmatic capability and resources to respond.

management and stream crossing design. Calculation of this metric may need to shift under a changing climate. For example, instead of quantitative calculations of expected peak flow based on historical data, culvert size could be based on a qualitative ground-based assessment within an expert systems framework. Alternatively, physically based hydrologic models that incorporate changes in climate could provide quantitative estimates of changes in Q_{100} or other factors affecting design decisions. Assessing changing sensitivities and trends over the last 30 years (and their relationship to projected 21st century impacts) may also give a more accurate picture of future sensitivities and trends than the entire period of record. Looking for evidence of precession of peak flows or of the temporal centroid of the hydrograph, and determining the rate at which any change is occurring, may be useful to managers in determining how rapidly hydrologic effects of climate change are being realized. Observed trends may also provide important information needed to augment and validate model predictions (further discussion below).

Regardless of forward-thinking design or restoration methods used for roads, uncertainties associated with rainfall, steep slopes, and the transport of water, sediment, and wood in stream channels make some level of road failure inevitable. Climate change will exacerbate these uncertainties and associated risks. However, several strategies can minimize risk and failure. For example, inventorying and analyzing high-risk areas, such as debris-prone sites, can support development of plans to prevent or manage issues in these areas. In addition, “what if it fails?” scenario analyses can identify likely failures that will result in the most adverse consequences. This information can help to target sensitive areas in strategic planning to emphasize specific actions to avoid these impacts (e.g., specifying more robust design criteria for these areas).

Communication and partnerships are needed for adapting road management to climate change on the peninsula. Topography constrains potential road-access options; roads can affect important resource values such as fish and riparian resources; and forest management, recreation, tourism, and residential access are essential. The present case study serves as an example of the utility of science-management partnerships that facilitate communication and help to address challenges and barriers to climate change adaptation.

Figure 4.11—Fish passage culvert at Olympic National Forest. (Photo courtesy of USDA Forest Service, Olympic National Forest.)

Adaptation Strategies for Road Management Planning and Prioritization at Olympic National Forest

The RMS at ONF is a tool to evaluate the use or need for all of the roads in the transportation system against the potential risks the roads pose to other resources. Identified through analysis with RMS criteria, priority roads for decommissioning are those determined to be of low use volume or need, and high environmental impact. A major category in evaluating road risk is risk to aquatic resources. The RMS applies five rating factors to assess aquatic risk: (1) geologic hazard, (2) proximity (delivery) to fish habitat, (3) stream crossing density, (4) riparian zone proximity, and (5) upslope hazard. Climate change will likely influence all of these aquatic risk factors. The ONF engineering and natural resources staff identified three of the aquatic risk factors to focus discussion of adaptive strategies for road management planning and prioritization: proximity (delivery) to fish habitat, riparian zone proximity, and upslope hazard.

The upslope hazard factor developed in the RMS incorporates geologic hazard and delivery conditions within the hill slope immediately upslope of the road segment being evaluated. It identifies roads located downslope of either steep converging topography or terrain designated as having a high potential for landslides. These hazard elements may initiate new hill slope failures or increase the magnitude of initial mass wasting events. To incorporate climate change predictions, ONF proposes to modify the upslope hazard factor to consider the amount of area upslope that is in the transient snow zone or rain-on-snow (ROS) zone. With increasing temperatures, there will be shifts in the location and extent of ROS zones. High rates of water delivery to soils in ROS zones can be associated with mass wasting of hill slopes, and thus hill slopes with increasing area of ROS are potentially more susceptible to slope failure (Swanson and Dyrness 1975, Swanson et al. 1998, Wemple et al. 2001), which will affect use and maintenance of the adjacent road.

Scientists and engineers can predict future locations of ROS zones by using a model that accounts for factors such as climate, snow cover, and elevation. The ONF proposes to model the area within the ROS zone in hill slope areas above and connected to road segments, and evaluate road segments for ROS under current conditions and future projected conditions (e.g., 2040). Assessment of current and future hazard evaluations will flag areas with a higher hazard rating under projected future conditions as priorities for maintenance, upgrading, or decommissioning. This comparative evaluation will support recommendations for increased frequency and intensity of road treatments for some roads, as well as recommendations to decommission other road segments rather than continue efforts to maintain them.

Riparian area and stream proximity are also used to evaluate the risks that roads present to aquatic systems under the 2000 RMS. Managers consider stream-adjacent or riparian area roads to be risky owing to their often direct and deleterious effects on aquatic habitats. Stream-adjacent roads also have high potential for frequent damage from floods and stream channel changes, resulting in higher maintenance costs. To incorporate climate change predictions, ONF proposes to modify the riparian area/stream proximity factor in the RMS by manually validating the locations of stream-adjacent roads and degree of connectivity of these roads to streams. Olympic National Forest engineers will assess roads under current and future projected conditions, and assign a higher (riparian zone proximity) hazard rating to those that are determined to be within a projected flood hazard corridor (in a potential area of inundation or channel migration zone, or in a geotechnical setback buffer). Highest priorities for maintenance, upgrading, or decommissioning will focus on roads with higher hazard ratings under future projected conditions (e.g., roads at higher risk owing to increased flood risk).

Adaptation Strategies for Road Operations and Maintenance at Olympic National Forest and Olympic National Park

Assessing current road maintenance and operations tasks conducted at ONF and ONP in the context of climate change can inform managers of necessary changes. For example, climate change will likely influence watershed processes, resulting in increased flow volume, increased mass wasting and debris flows, increased sediment delivery to culvert inlets and ditches, increased rate and volume of water delivery to stream channels, and increased transport of wood. These changes will likely increase the incidences of culvert capacity being exceeded, fill slope failures, and development of first-order channels that can affect roads and related structures (e.g., fig. 4.12). A response to these potential changes could involve prioritizing maintenance preparation and response, including increased frequency of culvert cleaning, installing more and larger culverts where appropriate, and installing water bars and drivable dips. Table 4.1 lists potential climate change effects and affected watershed processes and sensitivities associated with major road maintenance and operations tasks, along with potential strategies to address climate change issues.

Adaptation Strategies for Road Design

Anticipating the effects from changes in watershed processes also informs the design of roads and related structures. Design of water crossing structures in the context of climate change, specifically culvert design, is an area of particular interest to both the forest and the park because of the increased potential for higher fall and winter flow volumes to exceed culvert capacity. Stream simulation is a method used to design culverts on fish-bearing streams that applies attributes of streams (geometry and geomorphology) to size and select water crossing structures. This method leads to designs that are relatively resilient to a range of conditions. Consequently, no changes to this method are proposed at this time.

Culverts on non-fish-bearing streams are designed principally by analyzing predicted runoff and flow capacity. Standard methods applied at ONF and elsewhere include sizing culverts for the predicted 100-year flood and associated debris (Q_{100} + debris). The Northwest Forest Plan aquatic conservation strategy (ACS) established this standard in 1994. The standard requires that an understanding of watershed process and channel functions be incorporated in culvert design, and thus, culverts designed by using this standard are considerably more resilient than those designed under pre-ACS standards. However, there is a question as to whether the methods used to predict Q_{100} should be altered according to expected hydrologic effects of climate change.

Engineers currently use the period of record to predict the Q_{100}. However, flood magnitude will likely increase in the transient snow zone with warming temperatures. Predictions based on the period of record may be even less accurate for predicting large flows if future precipitation or runoff patterns change. In many Olympic Peninsula streams, the largest flows on record at gauged sites are clustered in the later part of the record (i.e., the last 20 years). For example, at the Duckabush River gauge, the five largest flows in the 70-year record occurred in the past 12 years. Deriving the same predictive equations based on the late, early, or entire record gives entirely different predictions of Q_{100}.

There are several possible ways to modify the current method used for prediction of design discharge (Q_{100} flow). Suggested alternatives include calculations based on the later part of the record, such as the past 30 years. Alternatively, the Variable Infiltration Capacity (VIC) hydrologic model can provide future runoff estimates under different scenarios of climate change, which could be used to supplement information from the period of record. The VIC model uses a physically based simulation of runoff processes combined with a unit hydrograph approach that would provide a more physically based analysis than the current Q_{100} calculation method. The VIC model has predictive capabilities related to temperature and snowpack changes, which the current method does not. In considering climate change, ONF proposes to conduct an analysis of both the current method and the proposed VIC-based method and compare results, selecting the most appropriate option based on hazard and consequence for a particular site.

These analyses would not address several potential issues with culvert design based on predictions of Q_{100}. Predictions of Q_{100} have been and likely will continue to be associated with much uncertainty, regardless of the method used for prediction. Predictions of Q_{100} also do not address sediment and wood, which are most frequently the cause of culvert failures (not excessive water) (Furniss et al. 1998). Thus, continued and potentially increased focus on geomorphic culvert design on non-fish-bearing streams will be important with climate change. Besides an increase in magnitude, the frequency of moderate floods will likely increase with climate change; five 20-year flood events may in fact cause more damage to road infrastructure than one 100-year flood event. As noted above, increased focus on design of resilient structures will help avoid adverse effects of climate change on road systems.

Challenges and Opportunities in Climate Change Adaptation in Road Management

There are many potential challenges in the implementation of adaptation strategies and actions in road management on the Olympic Peninsula (table 4.2). For example, the National Highway Safety Act sets specific requirements for heavily used roads, arterials and collectors (maintenance level 3 and above), and most appropriated road operations and maintenance funds focus on these higher standard roads. Valley bottom and stream-adjacent roads are well represented, but other roads are not. In general, lower standard roads at the head of the transportation and drainage network have higher hazards when it comes to slope and runoff processes, but

Figure 4.12—Ditch scour along an Olympic National Forest road. Changes in hydrology and physical watershed processes with climate change will likely increase the incidences of culvert capacity being exceeded, fill slope failures, and development of first-order channels that can affect roads and related structures. (Photo courtesy of USDA Forest Service, Olympic National Forest.)

funding generally does not target operations and maintenance on these lower standard and higher hazard roads.

Another potential policy challenge is the Federal Highway Administration Emergency Relief for Federally Owned Roads (ERFO) Program. This program is the principal source for storm damage repair funds. However, at present, use of these funds is generally limited to in-kind replacement (although there have been some recent exceptions). For example, if storm damage occurs owing to culvert failure, ERFO funds will cover replacement of the same size culvert but not a larger one that could accommodate higher flows and be more resilient to future floods. Such policies limit the ability to design replacement structures that accommodate changing conditions with climate change or other factors. Further collaboration with the Federal Highway Administration may help to alleviate these limitations.

Budgets and the need for economic efficiency present further challenges in climate change adaptation in road management. Competing with the need to implement resilient designs is the objective to be economically efficient. Although long-term costs may be reduced by implementing more resilient designs for a changing climate, costs at the time of construction will likely be higher than current designs (especially in the case of in-kind replacement guidelines discussed above). Thus, strategic planning and prioritization efforts to identify areas where more robust designs would be most advantageous will make the best use of limited financial resources for climate change adaptation.

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Chapter 5: Climate Change, Fish, and Fish Habitat Management at Olympic National Forest and Olympic National Park

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Potential Climate Change Effects on Hydrology, Summer Stream Temperatures, and Fish on the Olympic Peninsula

Climate plays a crucial role in aquatic ecology, but the relative importance of climatic factors is quite different for different species, and even different populations of the same species. For example, key limiting factors for freshwater salmon productivity include thermal and hydrologic regimes that depend on species, their life history, watershed characteristics, and to a great extent, stock-specific adaptations to local environmental factors (e.g., Beechie et al. 2008, Crozier and Zabel 2006, Farrell et al. 2008, Richter and Kolmes 2005). Those stocks that typically spend extended rearing periods in freshwater (steelhead, stream-type chinook salmon, sockeye salmon, and coho salmon) are likely to have a greater sensitivity to freshwater habitat changes than those that migrate to sea at an earlier age (ocean-type chinook salmon, pink salmon, and chum salmon). Because they spend almost all of their life cycle in freshwater, resident rainbow trout, cutthroat trout, and bull trout are also likely to be sensitive to freshwater habitat changes. Effects of changes in marine conditions with climate change could interact with effects of changes in freshwater conditions to further affect fish populations that spend part of their life cycle in the marine environment.

Mantua et al. (2010) reported on a few direct, well-understood mechanisms whereby more easily predicted physical properties of the freshwater habitat for salmon directly influence salmon reproductive success (or overall fitness) at certain stages of their life cycle. Those physical properties are warm season stream temperature and the volume and time distribution of streamflow. They did not, however, assess the impacts of climate change on cold season water temperatures and related impacts on salmon, and this choice directed their focus on negative, rather than positive, impacts of climate change on the freshwater habitat for Washington's salmon.

We describe in a report by Mantua et al. (2010) qualitatively assessed the potential effects of climate change on the reproductive success for salmon in Washington's watersheds by combining salmon sensitivities described in the scientific literature with future scenarios for changes in the statistics of stream temperature and streamflows. Climate also influences estuarine and marine habitat for salmon. See reviews of climate effects on marine habitat for Pacific Northwest salmon in ISAB (2007), Loggerwell et al. (2003), and Pearcy (1992).

Summertime Stream Temperature Projections

Maximum weekly water temperatures in Washington are typically observed from late July through late August, similar to the period of climatologically warmest air temperatures. Figure 5.1 shows downscaled historical averages for August surface air temperatures and simulated annual maximum weekly water temperatures (T_W) for the 1970–99 (1980s) period (left panel) and for a multimodel ensemble average under A1B greenhouse gas emissions for 2030–2049 (2040s) (right panel). Although air temperatures are not the only influence on water temperatures, air temperature can provide an accurate indicator of water temperature in many cases (Mohseni et al. 1998; see Mantua et al. [2010] for detailed modeling methods). Under historical conditions, August mean surface air temperatures on the Olympic Peninsula are below 17 °C everywhere except a narrow corridor in the lowlands along Hood Canal. Two of

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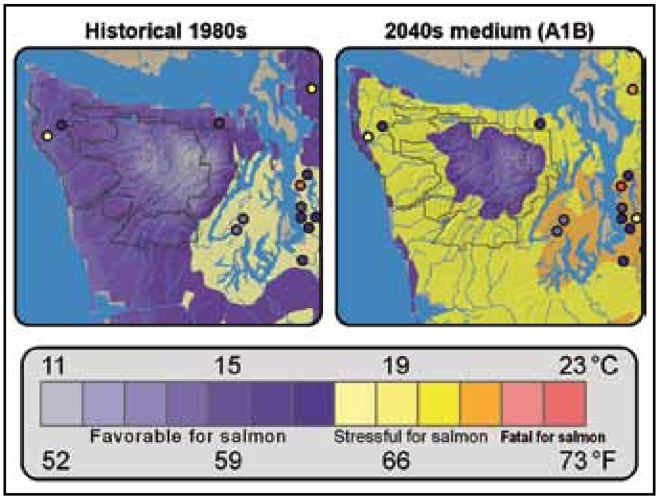

Figure 5.1—August mean surface air temperature and maximum stream temperature for the Olympic Peninsula. Color shading shows mean surface air temperatures for August, and shaded circles show the simulated mean of the annual maximum for weekly water temperatures for select locations. Historical air temperature and simulated water temperature for the 1980s (1970–99) are in the left panel, while a future scenario derived from a multimodel average under A1B medium level emissions is shown in the right panel. Olympic National Park and Olympic National Forest are outlined in dark gray. (Adapted from Mantua et al. 2010.)

the three water temperature sites on the Olympic Peninsula have T_w <17 °C, while one has T_w approximately 20 °C. For the 2040s scenario, the encroachment of summertime air temperatures with T_a >20 °C becomes the norm for western Washington's lowlands, and for this period only, the higher elevations of the Cascades and Olympics have temperatures like those characteristic of the western Washington lowlands in the 1980s.

For A1B emissions scenarios in the 2020s, annual maximum T_w at most stations on the Olympic Peninsula is projected to rise less than 1 °C, but by the 2080s, several stations on the Olympic Peninsula warm by 1 to 2 °C (not shown). Water temperatures projected under the A1B emissions scenarios become progressively warmer than those projected under the B1 emissions, and by the 2080s the differences are approximately 1 °C (projected summertime air temperatures under A1B emissions are, on average, 1.8 °C warmer than those under B1 emissions for the 2080s).

Increases in stream temperature with climate change are likely to differ across landscapes. Locations that currently experience high summer air temperatures are likely to have the largest increases in water temperature (ISAB 2007). A study by Daly et al. (2009) suggests that complex patterns of temperature change may occur in locations with complex terrain; locations with cold air drainage and pooling will likely experience the lowest temperature increases, whereas exposed hill slope and ridge top locations will likely experience the highest temperature increases. In the John Day River basin in northeastern Oregon, Torgersen et al. (1999) found water temperatures to be warmest in downstream (low-elevation) stream reaches and in locations where the cooling effects of subsurface flow are less apparent. These and locations with channel conditions prone to heating (wide, shallow, lack of riparian vegetation) (Crozier and Zabel 2006) are likely to experience further warming with climate change. Changes in water temperature will also differ with hydrologic changes. Decreases in summer low flows will make streams more susceptible to increased air temperature, and earlier snowmelt will result in warming beginning earlier in the year in basins affected by snowmelt (ISAB 2007).

Climate Change Effects on Snowpack and Streamflow

Figure 5.2 classifies runoff in Washington's watersheds (at the level 4 hydrologic unit code) for historic and future periods as either snowmelt dominant, transient, or rain dominant based on their basin-averaged ratio of simulated April 1st snowpack to their October to March total precipitation (Elsner et al. 2010). Rain-dominant basins (where the ratio is <0.1) are the most common type on the Olympic Peninsula (for the 1980s). There is one transient basin (mixed rain and snow basin where the ratio lies between 0.1 and 0.4) in the northeastern portion of the Olympic Peninsula, and there are no snowmelt basins (where this ratio >0.4 for the 1980s). As projected climate warms, the historically transient basin on the Olympic Peninsula is projected to become rain dominant by the 2040s under the A1B emissions scenario, and by the 2080s under the B1 emissions scenarios.

The recently completed *Hydrologic Climate Change Scenarios for the Pacific Northwest Columbia River Basin and Coastal Drainages* project (project homepage http://

www.hydro.washington.edu/2860) includes future snowpack and streamflow scenarios from 10 global climate models under two greenhouse gas emission scenarios for the 21st century. A sample of hydrologic model output for select watersheds on the Olympic Peninsula is provided in figures 4.2 to 4.7 in chapter 4. The magnitude and frequency of flooding are predicted to increase for watersheds on the Olympic Peninsula, most dramatically in the months of December and January, and most dramatically for the coldest basins that in the late 20th century typically collected significant amounts of snow in their upper reaches. Hydrologic models indicate that warming trends will substantially reduce seasonal snowpack on the Olympic Peninsula (Elsner et al. 2010), thereby decreasing the risk of springtime snowmelt-driven floods.

The shifts in flood risk in each basin tend to monotonically increase or decrease through time. In other words, the increases or decreases in flooding magnitude of each basin generally become larger, with the same sign from the 2020s to the 2080s, with the greatest impacts occurring at the end of the 21st century. Emissions scenarios also play a strong role in the rate of change in flooding magnitudes, with the changes for A1B emissions in the 2040s being similar to those for the B1 emissions in the 2080s.

Reductions in the magnitude of summer low flows are projected to be widespread for the Olympic Peninsula's rain-dominant and transient runoff river basins (not shown). Future estimates of the annual average low flow magnitude (7Q10, which is the 7-day average low flow magnitude with a 10-year return interval) are projected to perhaps increase by a few percentage points or decline by up to 50 percent, with most climate model scenarios leading to declines by the 2080s under both the A1B and B1 emissions scenarios. As indicated by the simulated runoff graphs shown in figures 4.2 through 4.7, the duration of the summer low flow period is also projected to increase significantly in all but the most rain-dominant watersheds, which include the Skokomish, Queets, and Hoh watersheds.

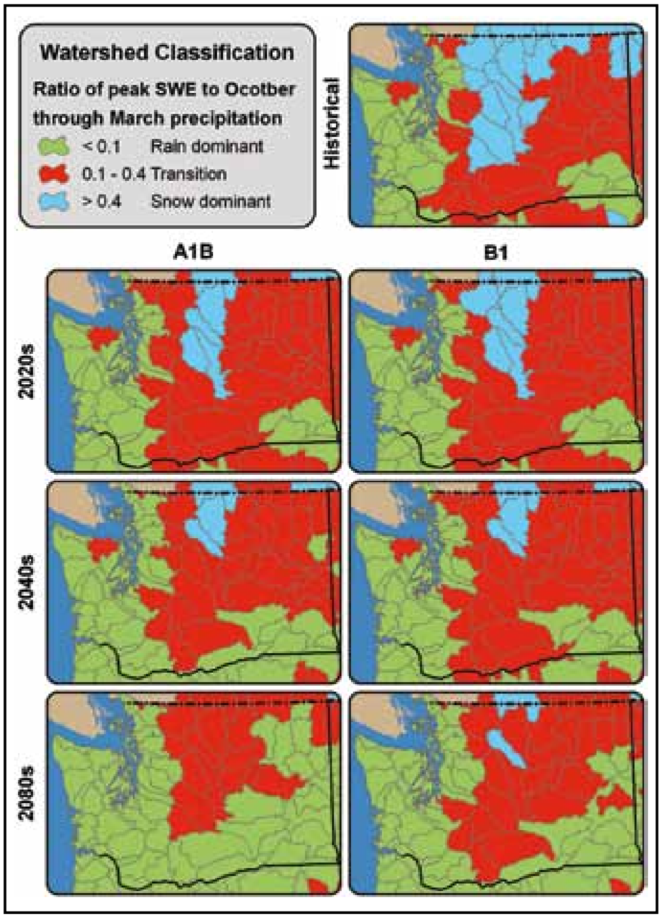

Figure 5.2—Watershed classification in Washington state for simulated runoff in the historic period (1970–99) and future periods (2020s, 2040s, and 2080s). Simulations that use A1B emissions are in the lower three rows of the left column, and those that use B1 emissions scenarios are in the lower three rows of the right column. [SWE = snow water equivalent.] (Adapted from Elsner et al. 2010.)

Projected Effects of Altered Hydrology on Olympic Peninsula Salmon, Steelhead, and Bull Trout

Waples et al. (2008) noted that existing salmon populations should have the capacity for responding to habitat changes that fall within the bounds of historical disturbance regimes, specifically episodic disturbances that most often impact relatively small habitat patches relative to the spatial extent of evolutionarily significant population groups that are typically influenced by regional physiographic features. It remains an open question whether present-day salmonid fish populations on the Olympic Peninsula can adapt (either through phenological, phenotypic, or evolutionary responses) at rates required to deal with the combination of anthropogenic climate change and other habitat and ecosystem changes that will come in the next century (Crozier et al. 2008).

Our assessment of future stream temperature, streamflow changes, and limiting factors indicates widespread declines in the quality and quantity of freshwater habitat for many Olympic Peninsula salmon, steelhead, bull trout, and resident fish populations, unless they are able to quickly adapt to changing habitat conditions. Increases in stream temperature alone point to significant increases in thermal stress (fig. 5.1) for Washington's salmonid fish populations having a stream-type life history that puts them in freshwater during summer for spawning migrations, spawning, rearing, or seaward smolt migrations. Temperature impacts on adult spawning migrations are projected to be most severe for stocks having summertime migrations. These include summer-run coho salmon in the Sol Duc watershed, and summer run chum salmon in several Hood Canal streams. Increased stream temperatures pose risks to the quality and quantity of favorable rearing habitat for stream-type chinook and coho salmon and steelhead (summer and winter run) because these stocks spend at least one summer (and for steelhead typically two summers) rearing in freshwater.

Increased stream temperatures on the Olympic Peninsula will also affect bull trout. This species, which is listed as threatened under the federal Endangered Species Act (ESA) (ESA 1973), is highly sensitive to stream temperature, generally requiring stream temperatures below 15 °C (USFWS 2004). There are six core areas of spawning bull trout on the peninsula (USFWS 2004). Unlike other areas of their range, bull trout on the peninsula are found only within the anadromous portion of watersheds, below anadromous migration barriers. Increased stream temperatures and reduced summer streamflows could particularly affect bull trout by reducing the quantity and quality of rearing habitat.

In addition to increased stream temperatures, reductions in the volume of summer/fall low flows in transient and rain-dominated basins might also affect summer-run steelhead migration and reduce the availability of spawning habitat for bull trout and salmon populations that spawn early in the fall (e.g., Healey 1991). Predicted increases in the intensity and frequency of winter flooding will likely negatively impact the egg-to-fry survival rates (table 5.1) for pink, chum, sockeye, chinook, and coho salmon and bull trout owing to an increased intensity and frequency of redd and egg scouring. However, the effects of scour will differ, in part, by channel type and location in the stream network. Confined streams that are high in the network will likely be most susceptible to scour, which will likely impact the steelhead and bull trout that inhabit them. Lower gradient streams in unconfined settings, such as those typically inhabited by chinook, will likely be least vulnerable to scour. In addition, the impact of increasing winter flooding will likely differ across species or populations because redd depth is a function of fish size (deeper redds will be less vulnerable to scouring and the deposition of fine sediments).

Parr-to-smolt survival rates may be reduced for coho and stream-type chinook salmon and steelhead with climate change because increases in peak flows can reduce the availability of slow-water habitats and cause increases in the displacement of rearing juveniles downstream of preferred habitats (table 5.1). However, the effects of increased peak flows will depend on the particular geomorphic setting and on whether the fry will have emerged before or at the time of the high flows. The effects of increased peak flows will be more pronounced in constrained reaches (i.e., narrow valleys and higher gradient streams), which are used by steelhead and bull trout for spawning, than in unconstrained reaches (i.e., wide valleys and lower gradient streams), which are used by coho and chinook. In the latter, the fish may be able to move to off-channel areas that would not be available at normal flows. Displacement could be a problem in the former situation. Displacement could be exacerbated if fish emerge earlier because of elevated winter water temperatures. The effects of high flows may be minimal for some fish, such as winter steelhead that spawn after peak flow events. However, for some species, reductions in springtime snowmelt may negatively impact the success of smolt migrations from snowmelt-dominant streams where seaward migration timing has evolved to match the timing of peak snowmelt flows.

Summer chum salmon stocks in Hood Canal are listed as threatened under the ESA. These populations have a unique life history that makes them especially vulnerable to the impacts of climate change. Adults return to spawn in

Table 5.1—Salmon life cycle stages and climate change effects that will likely impact each salmon life cycle stage

Salmon life cycle stage	Climate change effects that will likely impact salmon life cycle stage
Eggs in stream gravel; hatch in 1 to 3 months	Increased winter flooding and mean flows; warmer water
Alevins in stream gravel; 1 to 5 months	Increased winter flooding and mean flows; warmer water
Fry emerge in spring or summer	Increased winter flooding and mean flows; warmer water
Juvenile fish in freshwater; a few days to 4 years depending on species and locality	Warmer water and lower streamflows in summer; increased winter flooding in transient basins
Smolt migration to ocean; usually in spring and early summer	Warmer water and lower streamflows in summer; increased winter flooding in transient basins
Fish in ocean; 1 to 4 years	Sea level rise; altered river discharge
Migration to spawning grounds; timing depends on species and race	Warmer water and lower streamflow
Fish spawning in freshwater stream	Warmer water and lower streamflow

small shallow streams in late summer, and eggs incubate in the fall and early winter before fry migrate to sea in late winter. The predicted climate change effects for the low-elevation Hood Canal streams used by summer chum include multiple negative impacts stemming from warmer water temperatures and reduced streamflow in summer.

It is possible that climate-induced warming in winter and spring will lead to earlier and perhaps longer growing seasons, increased aquatic food web productivity, and more rapid juvenile salmon growth and development rates that benefit parts of the freshwater life cycle of the Olympic Peninsula's salmon and steelhead (Schindler and Rogers 2009). This could potentially increase the full life cycle productivity for salmon populations if the positive impacts outweigh the negative impacts described above. For example, in watersheds that are currently minimally affected by snowmelt (rain-dominant basins), the changes in the timing of streamflow with climate change will likely be minimal. Thus, without substantial increases in winter flooding and reductions in summer low flows, increased winter stream temperatures could have a net positive impact on salmon in these watershed types, depending on the magnitude of late-spring through fall stream temperature changes.

Potential benefits of warmer stream temperatures for coho salmon were shown in studies of clearcut logging impacts in the Carnation Creek watershed of Vancouver Island, British Columbia (Holtby 1988). Logging in this watershed led to stream warming of 0.7 °C in December and over 3 °C in August, which in turn contributed to positive growth responses in juvenile coho salmon, accelerations in the freshwater component of coho salmon life histories, and increases in overwinter survival rates for rearing juveniles. However, these changes in freshwater development appear to have been offset by reduced marine survival rates associated with earlier smolt migrations to the ocean (because of warmer spring stream temperatures) that may have been mismatched to the optimal timing for ocean prey availability and predator avoidance. Holtby (1988) estimated that warmer stream temperatures increased the full life cycle coho production in this system by about 9 percent. Modeling from the same study system suggested that effects of warmer stream temperatures as a result of logging may be greater on chum than coho salmon (Holtby and Scrivener 1989).

Because of the earlier timing of snowmelt and increased evaporation, some of the Olympic Peninsula's river basins (including the Elwha and Dungeness) are projected to experience reduced streamflow in summer and early fall that results in an extended period of summer low flows, and many basins are also projected to have substantially lower base flows. In combination with increased summertime stream temperatures, reduced summertime flow is likely to limit rearing habitat for salmon with stream-type life histories (wherein juveniles rear in freshwater for 1 or more years) and increase mortality rates during spawning migrations for summer-run adults (table 5.1).

Fish Habitat Management at Olympic National Forest and Olympic National Park

This section provides information on the biogeographic context, guiding policies and legislation, and primary activities in fish habitat management at Olympic National Forest (ONF) and Olympic National Park (ONP), including (1) the context in which ONF and ONP manage fish habitat, (2) the guidance and constraints on fish habitat management at ONF and ONP, and (3) the primary issues around and activities currently conducted in fish habitat management at ONF and ONP. This information, coupled with the likely impacts of climate change on fish on the Olympic Peninsula, provides a basis on which to develop climate change adaptation options for fish habitat management at ONF and ONP.

Biogeographic Context

The ONF contains portions of 17 major drainages on the Olympic Peninsula and manages about 560 km of anadromous fish streams and another 685 km of streams that provide habitat for resident fish populations. At least 40 small alpine lakes and two reservoirs exist on the forest.

The streams, rivers, and lakes at ONF provide habitat for seven anadromous fish species including chinook, coho, chum, and pink salmon; steelhead trout; sea-run cutthroat trout; and bull trout. Resident salmonids include cutthroat trout and rainbow trout. Four of the fish stocks on the forest are listed as threatened under the ESA: Puget Sound chinook, Puget Sound steelhead, Hood Canal summer chum, and bull trout.

Rainfall, geology, and management legacies present some challenges for fish habitat management at ONF. Some parts of the Olympic Peninsula receive more than 5 m of rain per year. Long, steep slopes, underlying geology, and heavy rainfall result in unstable ground on some parts of ONF. The ONF also has an extensive legacy of timber harvest. About 50 percent of the suitable land base was harvested between the 1960s and the mid 1990s. Over 3500 km of forest roads initially built for timber harvest remain on the forest road network. Unstable slopes combined with an extensive road network can result in sedimentation and aquatic habitat degradation.

The ONP contains over 5600 km of rivers and streams that support 70 unique salmonid stocks as well as numerous nonsalmonid species. The park also includes two large natural lakes and over 300 smaller alpine lakes and lower elevation ponds. In addition to the federally listed fish stocks at ONF, ONP also has the Lake Ozette sockeye fish stock, which is listed as threatened under the ESA.

There are 225 km of roads located in the park, along with many visitor facilities (visitors' centers, campgrounds, and way points). With the exception of the Hurricane Ridge Road and Deer Park Roads that access alpine areas, the park's road system and many visitor facilities occur within the flood plains of the park's major river systems (Elwha, Sol Duc, Hoh, Queets, Quinault, and North Fork Skokomish); segments of these roads lie immediately adjacent to the rivers. Maintenance and repair activities associated with these road systems constitute (historically) a major impact to fish and aquatic communities.

Guiding Policies and Legislation

The ONF Land and Resource Management Plan (LRMP) (USFS 1990) as amended by the 1994 Northwest Forest Plan (USDA and USDI 1994) guides current management activities at ONF. A key component of the plan is the Aquatic Conservation Strategy (ACS), which includes nine objectives for maintaining and restoring watershed processes and functions. To be consistent with the LRMP and the ACS, all management activities at ONF must maintain or help restore watershed conditions. In line with these broader mandates, the goal of fish habitat management at ONF is to maintain or restore watershed processes and functions and provide diverse, resilient fish habitats capable of supporting populations of native fishes over the long term.

At ONP, fish habitat management programs and decisions are guided by the National Park Service Management Policies (NPS 2006), as well as the ONP General Management Plan (GMP) (NPS 2008), the ONP Backcountry Management Plan (NPS 1980), and the ONP Superintendant's Compendium. The park's planning and compliance process guides preservation of fish habitat within ONP by prescribing measures to prevent or minimize the impact of all park management activities. Usually, particularly within wilderness areas, limiting the construction of new facilities within flood plains avoids impacts to fish habitat. The park's GMP (NPS 2008) calls for potential relocation of existing roads, campgrounds, or other visitor facilities out of flood plains as feasible, or when a road or facility cannot be relocated, directs that measures to protect and maintain the facility must be designed to minimize the effect on fish habitat to the extent possible. The ONP recently evaluated a variety of road and facility hazards within the park, and will evaluate protection measures designed to be more environmentally sensitive than traditional engineered designs.

Primary Fish Habitat Management Issues and Activities

Olympic National Forest—

The primary management issues for fish and fish habitat at ONF include:

Sedimentation from forest roads

Road-related landslides can cause sedimentation in streams (Fredriksen 1970, Harr and Nichols 1993) and influence fish habitat (Harr and Nichols 1993). Road-related sedimentation is a major issue impacting fish habitat at ONF. In response, ONF decommissions unneeded roads, and removes sidecast material and improves drainage on the remaining roads.

In 2000, the forest completed a Road Management Strategy (RMS). This geographic information system based analysis evaluated the risk each road segment presented to fish habitat and water quality based on its location, geomorphic factors, distance to stream channels, and number of stream crossings. About 34 percent of the roads on the forest are rated as "high" or "very high" risk to aquatic resources.

In 2003, the forest used the new aquatic risk information, coupled with an assessment of the access needs and anticipated future funding levels, to revise the Access and Travel Management (ATM) Plan. The plan proposes decommissioning of over 1270 km of forest roads, or about one-third of the road system. The ATM and aquatic risk information helps to prioritize road treatment locations as funding becomes available. In previous actions and following the new ATM plan, ONF decommissioned about 700 km of road since 1990.

Fish passage and culverts

Currently, 77 culverts block fish passage on the forest including five anadromous sites blocking a total of 13 km of anadromous fish habitat, 16 high-priority resident sites blocking more than 1.6 km of resident fish habitat each, 14 moderate-priority resident sites blocking between 0.8 and 1.6 km of resident fish habitat each, and 42 low-priority resident sites that block less than 0.8 km of resident fish habitat each. Since 2002, forest managers completed 18 fish passage barrier correction projects, restoring access to 39 km of fish habitat. Anadromous barriers are the top priority for correction. Biologists prioritize resident barriers based on the amount of fish habitat that would be reconnected.

Instream large wood

Past stream clearing and splash damming activities at ONF removed large wood from many stream channels. Placing large wood in key stream reaches restores watershed processes and functions and improves fish habitat by providing structure, creating cover, scouring pools, and trapping spawning gravels. The forest completed numerous small-scale large-wood placement projects in the past and is planning an extensive logjam construction project on the South Fork Skokomish River in 2010. Increasing landslides with climate change (see chapter 4) could also potentially increase upslope sources of wood to streams.

Riparian vegetation

Logging activities in the past removed conifers from many streambanks at ONF. Conifers regenerated in some riparian areas, but many riparian corridors have few conifers to provide large wood to streams. In these areas, reestablishment of conifers will help to provide a long-term source of large wood in channels. However, these projects require long commitments over time, are costly, and are consequently not a high priority for forest managers.

Nutrient supplementation

Marine-derived nutrients carried back into anadromous streams by returning adult salmon carcasses are a key element in the productivity of many streams (Helfield and Naiman 2001, Naiman et al. 2002). Extirpation of salmon stocks and extremely low escapements of anadromous fish have likely reduced potential productivity in forest streams. Supplementing nutrient supplies, either by distributing salmon carcasses or adding slow-release fertilizers, has the potential to increase the numbers and condition of juvenile salmon, steelhead, and bull trout in forest streams. Although carcass supplementation has not yet been demonstrated to improve salmonid productivity or riparian vegetation growth on the Olympic Peninsula, Cederholm et al. (1989) showed that carcasses are utilized by a large number of wildlife species. The forest has been distributing surplus chum salmon carcasses throughout the upper South Fork Skokomish watershed. The Pacific Salmon Coalition distributes salmon carcasses throughout the Quileute system.

Invasive species

Some exotic species such as Japanese knotweed are considered invasive owing to their potential to outcompete native vegetation. Invasive infestations in riparian areas reduce future sources of large wood by outcompeting tree species and change the terrestrial food inputs into streams. Removal and control of priority invasive weed species helps to maintain riparian function. There are also public education efforts for aquatic invasive species. However, ONF has not identified aquatic species on the forest that warrant intensive control or monitoring efforts.

Olympic National Park—

At ONP, fish habitat management activities fall into three general categories: (1) habitat preservation, (2) habitat restoration, and (3) management planning. Within the past 5 years, the park has conducted several restoration projects, including removal or replacement of numerous undersized culverts that were partial or complete barriers to fish migration. A significant habitat restoration project is the upcoming removal of two dams from the Elwha River. However, with the exception of the Elwha project, habitat restoration within ONP is opportunistic as opposed to strategic, and has no sustained funding source. Park biologists work to rectify this through numerous activities, including participation in various salmon recovery forums, interagency planning for watershed water use strategies, cooperation with the National Oceanic and Atmospheric Administration National Marine Fisheries Service and local tribes to develop and implement ESA recovery plans, and development of a prioritized list of culverts targeted for replacement.

It will be critical for ONP to consider climate change in the future management of fish habitat. Whether management activities involve protection, restoration, or unknown and undecided manipulative actions, the changing climate will dictate measures needed to preserve "unimpaired" the fisheries resources of the park. Although today's conditions will change, through careful consideration and evaluation of the effects of climate change on the aquatic environment, adaptation strategies may help to sustain processes that shape and maintain viable aquatic ecosystems.

Climate Change Adaptation in Fish and Fish Habitat Management at Olympic National Forest and Olympic National Park

Process Used in Development of Adaptation Strategies for Fish Management

To develop adaptation strategies and action items for fish management on federal lands on the Olympic Peninsula, scientists, managers, and other stakeholders collaborated and shared information and perspectives at two workshops. In November 2009, a workshop on "Climate Change Impacts on Olympic Peninsula Salmon" provided scientific information to a broad audience of stakeholders regarding vulnerabilities of aquatic habitats and salmonids on the Olympic Peninsula under a changing climate. Twelve scientists spoke on a variety of topics, including scenarios for the Olympic Peninsula's climate and landscape in the 21st century, climate change effects on freshwater aquatic ecosystems, climate change effects on coastal marine systems, and planning for climate change (presentations are available online at: http://www.fs.fed.us/ccrc/video/olympic_climate_change.shtml). Panel discussions followed the presentations in each topic area, and the workshop concluded with an open discussion focused on key vulnerabilities and adaptation strategies for aquatic ecosystems on the peninsula. The nearly 100 participants included representatives from ONF, ONP, and a variety of state and federal natural resource agencies, watershed organizations, and tribes.

A subsequent, smaller workshop focused on developing adaptation strategies and action items for fish management at ONF and ONP. Participants in this second workshop included ONF and ONP natural resources staff and scientists from the Forest Service Pacific Northwest Research Station (PNW) and the University of Washington Climate Impacts Group. Objectives of the workshop were to (1) use the latest scientific information on climate change and effects on fish to identify adaptation actions for fish management that should be taken by ONF and ONP in the short term (over 1 to 5 years), (2) identify priorities and priority areas (e.g., key watersheds, stream reaches, and species) for climate change adaptation on the forest and park, and (3) identify policy issues and regulatory barriers to climate change adaptation in fisheries and fish habitat management. The workshop began with a presentation from Nathan Mantua on key aquatic vulnerabilities with climate change on the Olympic Peninsula. Fish biologists Patrick Crain (ONP) and Robert Metzger (ONF) provided presentations on fish habitat management at ONP and ONF, respectively. Gordon Reeves (PNW) also gave a presentation on the potential utility of the NetMap tool (Benda et al. 2009; http://www.netmaptools.org) in adapting fish habitat management to climate change. A facilitated discussion on adaptation options for fisheries and fish habitat management with climate change followed. A description of potential adaptation strategies and action items appears in the section below, with a summary in table 5.2. See box 5.1 for a general summary of projected climate change effects on fish on the peninsula and related adaptation strategies for fish habitat management at ONF and ONP.

Adaptation Strategies and Actions for Hatcheries and Harvest

Olympic National Park has exclusive federal jurisdiction with the authority to determine regulations for sport fishing and recreational shellfish harvest in the park, and thus can consider resilience to climate change among other factors used to set regulations. For example, it is anticipated that Sol Duc summer coho will be affected by climate change. Although the summer coho in the Sol Duc River is not a federally listed population, the population is known by the park to be depressed. Current park regulations for the Sol Duc River allow for a catch-and-release fishery from June 1 to October 31, with a minor area closure associated with a summer coho prespawning staging area below the Salmon Cascades. However, minor but measurable mortality occurs with all catch-and-release fisheries. Therefore, in the face of climate change, it may be appropriate for the park to consider a complete closure of fisheries in the Sol Duc River when summer coho are present to eliminate all harvest mortality and thus help the population remain viable.

As warranted by climate change and associated stressors, the park will foster fish population protection through recreational harvest management, considering potential area or time closures for fish or shellfish as necessary, and protecting any identified cold water refugia (using stream temperature information or modeling tools such as NetMap; Benda et al. 2009; http://www.netmaptools.org; and G. Reeves[2]). Biologists will consider fish life history in determining when and where these management actions would be most effective. As it does currently, the setting of fishing regulations within the park in the future will occur in consultation with the state of Washington and the affected Olympic Peninsula tribes to ensure that the park's regulations are consistent with, or not in opposition to, fishing regulations set by the state or federal government.

Besides the authority to manage recreational fisheries within the park's boundaries, there is also National Park Service guidance (NPS 2006) for the use of hatcheries within the park. National Park Service 2006 Management Policies require that, whenever possible, native plants and animals should be relied upon to maintain their own populations, although management intervention is allowed to protect rare, threatened, or endangered species. In these

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[2] **Reeves, G.** 2009. Personal communication. Research fisheries biologist. USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331.

Table 5.2—Current and expected sensitivities of fish to climate change on the Olympic Peninsula, associated adaptation strategies and actions for fisheries and fish habitat management at Olympic National Forest (ONF) and Olympic National Park (ONP)[a]

Current and expected sensitivities	Adaptation strategies and actions
Novel ecosystem response to shifting climate and hydrology	• Shift to a new paradigm in fish habitat management that recognizes that pre-existing channel conditions may no longer be an accurate representation of the potential state. • Incorporate climate change into the ONF Strategic Plan.
Changes in fish distribution, population size, and viability	• Implement strategic monitoring; build from existing monitoring programs.
Changes in timing of fish life history events	• Use tools such as NetMap to identify areas most likely to exhibit a climate change signal. • Monitor restoration projects to determine strengths and weaknesses of existing projects, and improve design of future restoration projects. • Look for early indications of change to determine how quickly some of the climate-related changes are occurring, and use that information to adjust management priorities.
Changes in habitat quantity and quality	• Implement habitat restoration projects that focus on re-creating watershed processes and functions and that create diverse, resilient habitat.
Increase in culvert failures, fill-slope failures, stream adjacent road failures, and encroachment from stream-adjacent road segments	• Decommission unneeded roads. • Remove sidecast, improve drainage, and increase culvert sizing on remaining roads. • Relocate stream-adjacent roads.
Greater difficulty disconnecting roads from stream channels	• Design more resilient stream crossing structures.
Major changes in quantity and timing of streamflow in transitional watersheds	• Make road and culvert designs more conservative in transitional watersheds to accommodate expected changes.
Increased erosion and sediment delivery to channels.	• Consider adding large wood to small headwater channels to restore natural sediment routing (ONF lands). • Consider thinning in steep landslide-prone areas to accelerate development of large wood inputs to streams (ONF lands).
Increased thermal stress on cold-water-adapted fish species Decreased fish numbers owing to reductions in suitable habitat and productivity	• Limit mortality associated with recreational fishing through time and area closures as necessary.
Increased risk of disease introduction from hatchery fish Increased disease virulence with warmer stream temperatures	• Encourage implementation of Hatchery Scientific Review Group recommendations for hatchery reforms. • Follow 2006 National Park Service policies regarding the planting of hatchery fish within parks. • Control spread of exotic species.

Table 5.2—Current and expected sensitivities of fish to climate change on the Olympic Peninsula, associated adaptation strategies and actions for fisheries and fish habitat management at Olympic National Forest (ONF) and Olympic National Park (ONP)[a] (continued)

Current and expected sensitivities	Adaptation strategies and actions
Decline in native fish populations owing to increased competition from exotic species Increased spread of aquatic invasive species	• Monitor to detect increases in invasive populations; initiate control measures aggressively. • Educate the public about measures to prevent the spread of invasive species. • Focus habitat protection and restoration efforts on existing wild fish strongholds and streams that are less influenced by hatcheries.
Loss of cold water refugia for cold-water-adapted fish species	• Identify and protect cold water refugia.
Decrease in area of headwater streams.	• Continue to correct culvert fish passage barriers. • Consider re-prioritizing culvert fish barrier correction projects.
Decrease in habitat quantity and connectivity for species that use headwater streams.	• Restore habitat in degraded headwater streams that are expected to retain adequate summer streamflow (ONF).
Increased sensitivity for species that spawn in late summer (e.g., summer chum, summer coho, spring chinook)	• Limit mortality associated with recreational fishing through time and area closures as necessary.

[a] Sensitivities are based on projected climate change effects on the Olympic Peninsula, including increased winter precipitation and runoff, more precipitation falling as rain rather than snow, increased storm intensity, greater winter and spring streamflows in some types of watersheds, increased flood frequency and magnitude in some types of watersheds, elevation shifts in transition (rain-on-snow) zones, reduced summer streamflows, and increased stream temperatures.

cases, animals (including fish) can be subjected to a captive breeding program (hatchery) to maintain or increase their abundance. However, the park must follow all planning procedures and provide for public comment and review before initiating such a program. In the future, this review will include an analysis of the appropriateness of management intervention in the face of climate change.

Olympic National Forest does not have jurisdiction over fishing regulations, seasons, or closures on national forest lands, nor do they control hatchery supplementation in streams and rivers that flow through the national forest. Authority for these activities resides solely with the state of Washington and the Olympic Peninsula tribes as co-managers. As in the past, ONF will continue to work with the state of Washington and the tribes to help identify and promote regulations needed to limit harvest mortality on high-priority species in key areas. The ONF will also continue to work with the co-managers and the National Marine Fisheries Service to help evaluate and implement hatchery supplementation programs, where necessary, to maintain viable populations of high-priority fish species on ONF lands.

Both the forest and park can continue to encourage the state, tribes, and U.S. Fish and Wildlife Service to implement the Hatchery Scientific Review Group recommendations (HSRG 2004) for hatchery reforms on the peninsula. The intent of these science-based recommendations is to redesign hatchery programs to help conserve wild salmon and steelhead populations and support sustainable fisheries. Implementation of these reforms will likely help salmon on the Olympic Peninsula remain viable in the face of climate change.

Adaptation Strategies and Actions for Fish Habitat Management

The goal of fish habitat management on ONF and ONP is to maintain or restore diverse, resilient habitat capable of supporting native fish populations over the long term.

Box 5.1—Summary of projected climate change effects on fish on the Olympic Peninsula and related adaptation strategies for fish habitat management at Olympic National Forest and Olympic National Park.

- Projected increases in winter peak flows, increases in summer stream temperatures, and lower summer streamflows suggest there will be declines in freshwater habitat quality and quantity for salmon, steelhead, bull trout, and resident fish on the Olympic Peninsula.
- Climate-induced warming in winter and spring could lead to earlier and perhaps longer growing seasons, increased aquatic food web productivity, and more rapid juvenile salmon growth and development rates that benefit parts of the freshwater life cycle of the Olympic Peninsula's salmon and steelhead.
- Climate plays a crucial role in aquatic ecology, but the relative importance of climatic factors is quite different for different species, and even different populations of the same species. For example, those stocks that typically spend extended rearing periods in freshwater are likely to have a greater sensitivity to freshwater habitat changes than those that migrate to sea at an earlier age. Effects of climate change will also differ within and across watersheds.
- In the face of climate change, it may be appropriate for the park to consider a complete closure of fisheries in some locations when vulnerable fish populations are present to eliminate harvest mortality and thus help the population to remain viable.
- Increased restoration efforts, focused on maintaining, reconnecting, and reestablishing ecosystem processes and functions, and proactive management in priority areas will likely increase ecosystem resilience to climate change at Olympic. National Forest and Olympic National Park.
- On the Olympic National Forest, maintaining and restoring connectivity and fish passage in headwater areas that are likely to go dry, and restoring damaged habitat in headwater streams that are expected to retain adequate stream flows will help maintain viable resident fish populations in as many areas as possible.
- The park and forest will control, to the extent possible, exotic aquatic species, invasive riparian plants, and fish diseases.
- Protection of cold-water refugia will be critical for many species as summer water temperatures increase. Streams with cold-water refugia could be prioritized over streams that are currently warm or are likely to become too warm with changing climate.
- Monitoring will also be critical to document current status and detect changes that are occurring with warming temperatures, and thus, implementation of strategic monitoring will be important for the forest and park in adapting fish habitat management to climate change. Existing monitoring programs can be used as a base to develop more extensive programs.

Recent habitat restoration efforts have typically attempted to maintain or re-create key watershed processes and functions, assuming that doing so would eventually re-create the historical river morphology and habitat conditions. Current restoration efforts are generally consistent with actions that will lead to increased ecosystem resilience under changing climate. However, increased restoration efforts and proactive management in priority areas will likely increase ecosystem resilience to climate change. Further effort will be required to reevaluate priorities in light of climate change.

Preexisting channel conditions and locations may no longer be an accurate representation of the potential future state of fish habitat. To increase ecosystem resilience to climate change, ONF and ONP will emphasize maintaining and reestablishing ecosystem processes and functions, considering how past and current management practices contribute to current and future habitat conditions. Olympic National Forest and ONP will also consider how the magnitude of potential changes in climate and streamflow regimes will differ both between and within watersheds and assess how anticipated changes in climate will alter future stream characteristics. For example, increased frequency and magnitude of high-intensity rainfall events will likely increase the number of landslides and debris torrents, thus increasing sediment loading and subsequent stream aggradation.

Numerous management actions can be taken to reduce the incidence of human-induced landslides, such as decommissioning unstable roads, removing sidecast material, and increasing the size and number of culverts to reduce the potential for plugging or flow diversion. At ONF, erosion on hill slopes and in steep headwater stream areas once intensively managed for timber production could potentially be reduced by adding large wood to channels to reestablish the sediment storage and routing function that large wood provides in streams. In addition, if trees are left along debris flow channels, they will cause the debris flow to behave differently and have much different effects on the channel. However, because an increased rain:snow ratio will likely amplify both natural and human-induced landslides, and associated higher runoff will alter the stream channel morphology, management actions are unlikely to fully offset climate change effects on erosion and stream morphology.

Consideration of synergisms among changing processes with climate change will also be important. For example, summer flows are anticipated to decrease, but increased porous sediment deposition associated with winter flooding may exacerbate low summer surface flows. Understanding and preparing for these potential synergisms will be important in adapting to changing conditions associated with climate change.

Roads and associated channel crossings are a major issue for fish habitat quality. Many adaptation actions for road management discussed in chapter 4 are also relevant to adaptation in fish habitat management. For example, roads adjacent to streams or the marine environment are particularly susceptible to flood and storm damage and are more likely to alter natural ecosystem function through restrictions in channel meanders, acceleration of flow velocity, and alteration of large wood recruitment. Thus, whenever possible, managers will consider moving roads out of flood plains (ONF and ONP) and marine coastal zones (ONP). Similarly, undersized channel crossings (either bridges or culverts) affect the natural function of stream channels through increased channel velocity and associated channel degradation, disruption of downstream transport of sediment and large wood, and increased potential for plugging and initiating landslides or debris torrents. Therefore, to the extent practicable, ONF and ONP will attempt to construct any new stream crossings with structures sized to meet the needs for natural channel function under flows anticipated with climate change. This may require larger structures than have been used in the past. Olympic National Forest and ONP will continue to remove or replace existing undersized stream crossings with appropriately-sized structures as opportunities arise and funding is available (see chapter 4 for further detail).

Reduced summer streamflows in headwater tributaries will likely reduce the amount of resident fish habitat available in many upper stream reaches during dry periods. The magnitude of stream habitat reductions will differ from watershed to watershed. Intermittent streamflows may increase the importance of providing barrier-free migration corridors in the upper watersheds so that resident fish can reoccupy intermittent stream reaches when flow returns. The ONF currently prioritizes resident fish culvert barrier correction projects based on the total amount of habitat that would be reconnected. Culvert barrier corrections tend to focus on the larger, longer streams first and then up into the headwaters. The ONF will continue to correct culvert fish passage barriers as funds are available. Considering potential streamflow reductions in small high-gradient resident fish streams associated with climate change, ONF may need to reconsider how to prioritize removal of culvert barriers to facilitate passage of resident fish.

Increased cooperation and strong partnerships can help natural resource agencies and other groups address ecosystem stressors and climate change more effectively through a shared vision and pooling of resources. Olympic National Forest and ONP will increase communication and coordination on fisheries research, habitat restoration, and monitoring between the park and forest. They will also work to increase communication with neighboring tribes, the state of Washington, other government entities, and local watershed groups on restoration priorities and climate change issues, seeking opportunities to collaborate with other landowners and managers in priority watersheds.

Reduced summer streamflows will create challenges in meeting adequate instream flows for fish in some watersheds. The city of Port Townsend has already experienced problems in meeting their required instream flows for summer chum as specified in the Biological Opinion for their special use permit. The forest will work with the city to encourage them to adopt adequate water conservation measures and increase efficiency of their delivery systems so that the Big Quilcene River water levels do not fall below specified levels. The ONF could also review existing water withdrawal permits and review how users are withdrawing water from the streams across the forest to provide an early warning for fish habitat issues as summer streamflows decline.

Owing to resource limitations and differences in anticipated climate change effects between watersheds, a strategic focus of efforts and use of resources is essential to most effectively deal with fish habitat issues related to climate change. The ONF and ONP identified some general priority actions for adaptation, as well as some preliminary priorities for species protection, habitat protection, and monitoring. One general priority for ONF and ONP is to control, to the extent possible, exotic aquatic species, invasive riparian plants, and fish diseases. Many exotic fish species introduced to the Pacific Northwest are well-suited to warmer water temperatures (e.g., American shad, bass, perch, channel catfish, etc.). American shad is an Atlantic Ocean species that prefers slightly warmer waters than salmon. Populations of American shad in the Columbia River have increased substantially in the last several decades and are likely competing with native fishes for habitat and food resources during the summer and fall (Petersen et al. 2003). Invasive New Zealand mud snails and zebra mussels occur in other parts of Washington. Several knotweed species (especially Japanese knotweed) currently thrive in some watersheds on the peninsula. Detecting the presence of, or increases in, invasive species populations requires monitoring and prompt action to effectively control or eliminate them. Preventing the spread of exotic fish and shellfish and keeping stream temperatures as low as possible through shading will help to keep the potential spread of fish disease to a minimum, because exotic species may spread diseases to native fish and diseases become more virulent with increasing stream temperatures. Ensuring that stocked fish meet health guidelines will also help to control disease spread. Finally, educating the public about invasive species and disease will further minimize the spread of those factors.

Olympic National Forest will explore ways to incorporate climate change in the Forest Strategic Plan. The Forest Strategic Plan identifies focus areas for restoration and areas where projects, such as commercial thinning, may achieve multiple objectives. In prioritizing thinning activities, increased attention could be given to the positive impacts that thinning activities can have on riparian and aquatic habitat quality. For example, thinning in high-risk landslide-prone areas may help to accelerate the establishment of large trees that provide wood to streams.

Several fish species, including spring chinook salmon, Ozette Lake sockeye salmon, resident trout, bull trout, Olympic mudminnow, summer coho salmon, and summer chum salmon, are proposed as potential priorities for protection because of their sensitivity to changes in stream temperature and hydrology expected with climate change. Climate change effects will differ between watersheds, and a variety of habitat types and locations will be particularly sensitive. These areas can be prioritized for restoration and protection. For example, transitional watersheds (which receive some precipitation as rain and some precipitation as snow) are likely to have the greatest increases in winter streamflow with climate change. Thus, road and culvert designs on both ONF and ONP could be modified to accommodate expected changes in transitional watersheds. Extent of headwater streams will likely be reduced with climate change-related changes in hydrology. On ONF, maintaining and restoring connectivity and fish passage in headwater areas that are likely to go dry, and restoring damaged habitat in headwater streams that are expected to retain adequate streamflows, will help maintain viable resident fish populations in as many areas as possible. Protection of cold water refugia will be critical for many species as summer water temperatures increase. Streams with cold water refugia could be prioritized over streams that are currently warm and are likely to become too warm with changing climate. Wild fish strongholds, such as the Sol Duc, Calawah, and Hoh River watersheds, and streams that are less influenced by hatcheries could be prioritized over other watersheds for a wide range of actions to help ensure continued viability of wild fish populations in the face of climate change.

Monitoring will be critical to document current status and detect changes that are occurring with warming temperatures, and thus, implementation of strategic monitoring will be important for ONF and ONP in adapting to climate change. Olympic National Park has a long-term ecological monitoring program that can be used as a foundation for a more extensive monitoring program designed to interpret effects of climate change on fish populations in both fresh and salt water areas of the Olympic Peninsula. Tools such as NetMap (Benda et al. 2009; http://www.netmaptools.org) can also be used to identify areas that are most likely to exhibit a climate change signal. Finally, monitoring of restoration projects (e.g., culvert fish passage corrections, road decommissioning, engineered logjams, and the Elwha dam removal) will continue to be key in determining strengths and weaknesses of existing projects, and improving design of future restoration projects.

Priorities for monitoring at ONF and ONP include effects of changing climate on fish life history (e.g., emergence timing, and fitness of juvenile fish over the course of a growing season), which will be important in determining how climate change is influencing fish on the peninsula. Collection of otoliths could help identify changes in life history patterns. Monitoring of habitat loss, particularly in headwaters and at higher elevations, will also help to determine what types and how fast habitat is being lost so that management activities can be tailored accordingly.

Challenges and Future Directions in Adaptation in Fish and Fish Habitat Management

Clear actions can be taken by ONF and ONP to adapt to climate change. However, implementation of adaptation in fish and fish habitat management also faces some challenges. As noted in chapter 4, the predominant Emergency Relief for Federally Owned Roads Program policy of replacing existing infrastructure with the same infrastructure after a failure makes it difficult for ONF and ONP to improve infrastructure to meet current standards and accommodate effects of climate change. Similarly, restrictions on activities in wilderness areas sometimes prevent both agencies from being able to move high-risk roads out of flood plains without Congressional action. Both ONF and ONP have limited funding for activities that would contribute to adaptation. Other state and federal policies may become limiting in the future. For example, the state of Washington has historically overallocated water, although the full allocated rights have not yet been used. New water rights may be allocated based on existing summer flows and channel conditions, which are likely to change in the future. At the federal level, there is no clear pathway to bring climate change information into Endangered Species Act [ESA 1973] consultations, National Environmental Policy Act (1969) analyses, or Clean Water Act (1977) degraded waterbody designations. Olympic National Forest and ONP will communicate these challenges to state and federal decisionmakers and seek solutions that will help overcome these challenges and facilitate climate change adaptation.

Olympic National Forest and ONP may also need to initiate research and explore new types of actions to adapt fisheries and fish habitat management to climate change. For example, more information will be needed on how the effects of climate change differ across the landscape, and an understanding of this variation will be a key factor in the development and implementation of new adaptive actions. It is possible that forest structure and composition could be managed to reduce evapotranspiration and maximize water retention and summer base flow. Stand structure could be manipulated to retain snow, and it is possible that forest structural conditions could be managed to promote increased fog drip. Determining whether these and other potential actions could help ONF and ONP adapt to climate change will require experimentation, monitoring, and feedback to management.

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Chapter 6: Climate Change and Vegetation Management at Olympic National Forest and Olympic National Park

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Vegetation on the Olympic Peninsula

The Olympic Peninsula has steep and dissected topography, which results in temperature and precipitation gradients and varied climatic environments (Peterson et al. 1997). The western, coastal side of the peninsula is characterized by a wet and humid maritime climate. Higher elevations on the western side of the peninsula receive as much as 5 m of precipitation per year (Henderson et al. 1989). The northeastern portion of the peninsula, in contrast, is characterized by a drier, more continental climate owing to the rain-shadow effect of the Olympic Mountains (and prevailing winds from the southwest during the winter), and rainfall in this area is as low as 0.5 m per year at lower elevations (Henderson et al. 1989). Most precipitation falls between October and March, resulting in low summer soil moisture, particularly in the northeastern portion of the peninsula.

Dominant forest species differ with climatic conditions found on the peninsula (Buckingham et al. 1995) (fig. 6.1). Lower elevation forests on the western side of the peninsula are dominated by Sitka spruce, with western hemlock and western redcedar as common associates (Sitka spruce zone in fig. 6.1) (See a "Common and Scientific Names"). Red alder and bigleaf maple are also abundant in some locations. At lower to middle elevations, western hemlock and Douglas-fir are the dominant overstory species (western hemlock zone in fig. 6.1). Pacific silver fir dominates mid to upper slope forests, except in very dry locations, sometimes sharing dominance with Douglas-fir and western hemlock (Pacific silver fir zone in fig. 6.1). Mountain hemlock is dominant at higher elevations (mountain hemlock zone in fig. 6.1) in all but the driest locations, where subalpine fir is dominant (subalpine fir zone in fig. 6.1) (Henderson et al. 1989).

In the northeastern portion of the peninsula, distributions with elevation differ. Lower elevation forests are dominated by western hemlock and Douglas-fir (western hemlock zone in fig. 6.1). Grand fir, western redcedar, and Pacific silver fir share dominance with Douglas-fir and western hemlock at many mid-elevation sites on the east side of the peninsula (western hemlock and Pacific silver fir zones in fig. 6.1), but Douglas-fir is dominant on south-facing slopes in dry areas (Douglas-fir zone in fig. 6.1). Subalpine fir is a major overstory species at higher elevations, with lodgepole pine dominant in some areas (subalpine fir zone in fig. 6.1). Mountain hemlock and subalpine fir give way to subalpine meadows at the highest elevations (parkland mountain hemlock zone in fig. 6.1).

Potential Climate Change Effects on Vegetation on the Olympic Peninsula

Climate, in concert with landscape and local-scale variables, dictates vegetation distribution across landscapes by placing both thermal and water constraints on plant regeneration, establishment, and growth. Past species response to changing climate observed in the paleoecological (pollen and fossil) record shows that the abundance and distribution of plant species shift individualistically in response to climate fluctuations (Davis and Shaw 2001, Delcourt and Delcourt 1991, Whitlock 1992); different species respond in varied ways to changing climate, leading to new species assemblages and communities. Increasing temperatures associated with climate change, and corresponding increases in summer drought stress and fire frequency in

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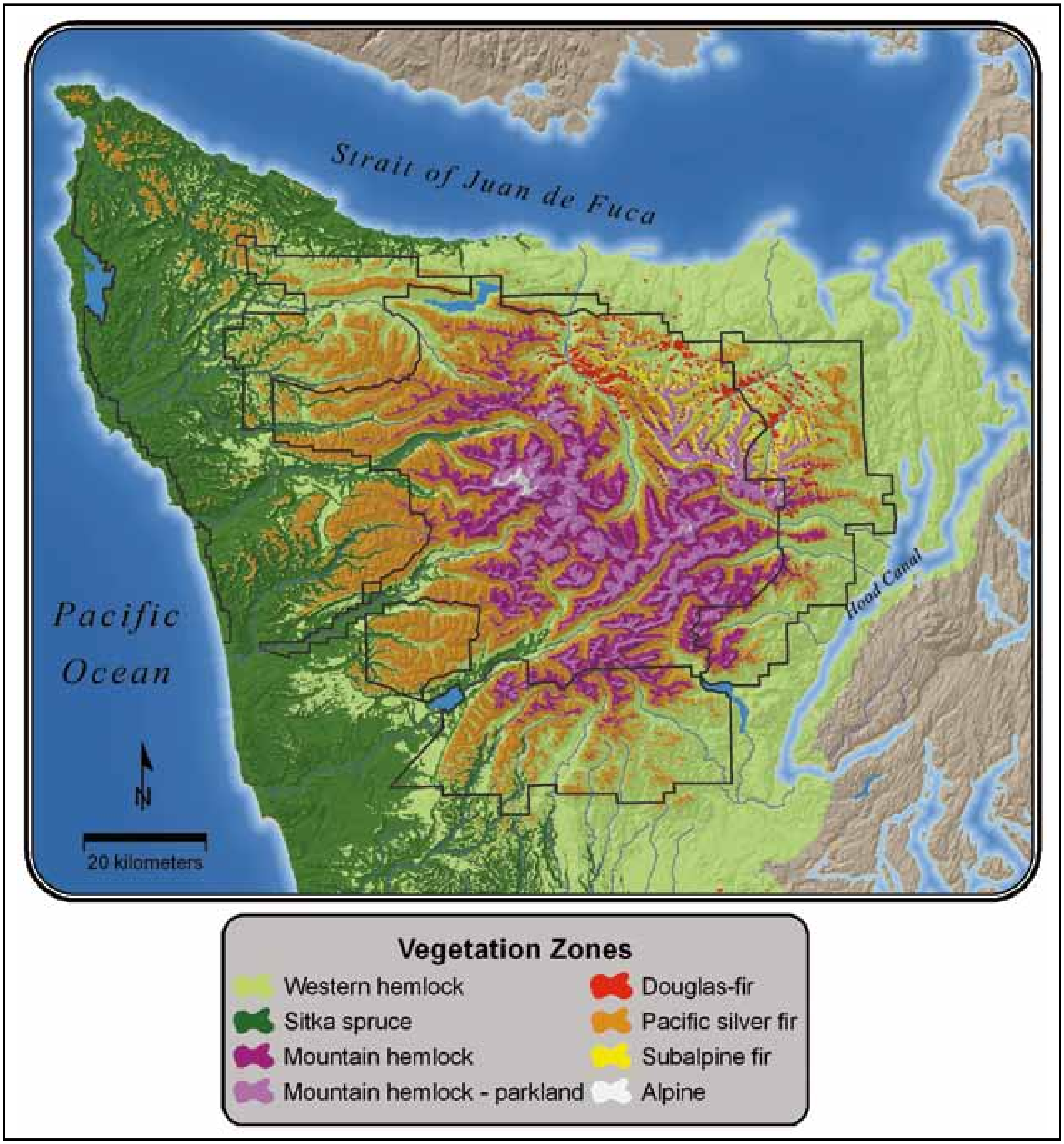

Figure 6.1—Vegetation zones (based on climate zones and potential climax or dominant species within climate zones) on the Olympic Peninsula.

the Pacific Northwest, will probably lead to changing species distribution in the region, resulting in forest types different from those we see today (Zolbrod and Peterson 1999). There are several information sources useful for predicting potential climate change impacts on vegetation and future forest composition and structure, including long-term paleoecological records, modern tree ring records of tree growth and establishment, current trends with recent warming, and model predictions for the future. The following section reviews these information sources for the Olympic Peninsula.

Paleoecological Records of Climate and Species Distribution

Paleoecological records from the Pacific Northwest and elsewhere show that during historical warm periods, many tree species moved poleward and upward in elevation. Poleward and upward shifts in elevation of species distributions involve changes in species abundance, rather than a species extirpation in areas where it was formerly dominant; shifting distributions represent leading edge dynamics rather than trailing edge contraction. For example, during a warmer period in the 19th century, western hemlock became dominant in areas where Pacific silver fir and mountain hemlock were dominant on Mount Rainier in the Washington Cascade Range (Dunwiddie 1986), suggesting that western hemlock will move up in elevation in a warmer climate (Zolbrod and Peterson 1999). Several studies have shown the range expansion of subalpine fir into alpine tundra at higher elevations in the northeastern portion of the Olympic Peninsula during historical warm periods (Brubaker and McLachlan 1996, Gavin et al. 2001, McLachlan and Brubaker 1995). The range expansion of subalpine fir around Moose Lake in the northeastern portion of the peninsula during a warm period around 11,000 BP was also associated with increased charcoal content in lake sediments, suggesting fire size and frequency increased near the lake (Gavin et al. 2001).

During the warm and dry Holocene period circa 10,000 to 6,000 BP, red alder, Douglas-fir, and lodgepole pine were abundant in forests of primarily western hemlock and spruce at lower elevations on the Olympic Peninsula (Henderson et al. 1989, Heusser 1977, Peterson et al. 1997, Whitlock 1992). The abundance of these species in the Pacific Northwest has been associated with higher fire frequency (Cwynar 1987, Prichard et al. 2009). A study in the nearby north Cascade Range also found increased abundance of lodgepole pine, in association with high fire frequency, circa 10,500–8,000 BP (Prichard et al. 2009). In addition, western white pine became locally important in the Pacific Northwest during this period (Cwynar 1987), and Oregon white oak, a species usually associated with drier climates, was very common during this period in the northeastern Olympics (Petersen et al. 1983, Peterson et al. 1997). The range expansion of western redcedar, and further range expansion of western hemlock and Sitka spruce, occurred only after a period of lower temperatures and higher precipitation during the Holocene warm period, suggesting that the range of these species on the peninsula was limited by drought during that warm period (Whitlock 1992).

The paleoecological record from the Pacific Northwest shows that species with life history traits that allow survival during periods of frequent disturbance and in stressed environments have persisted during past periods of rapid climate change (Brubaker 1988, Whitlock 1992). For the Pacific Northwest, these species include red alder, Douglas-fir, and lodgepole pine, suggesting that these species will be successful in a rapidly warming climate (Whitlock 1992). Other examples of species that have persisted over millions of years of climatic change on the Olympic Peninsula include Oregon white oak, giant chinquapin, bigleaf maple, and Pacific madrone (Henderson et al. 1989).

Warmer and drier conditions at lower elevations on the Olympic Peninsula would likely result in expansion of the range of Douglas-fir and lodgepole pine. Other species that may expand their ranges under these conditions include western white pine, Oregon white oak, giant chinquapin, and Pacific madrone. Increased disturbance frequency may lead to the range expansion of red alder. The paleoecological record for the Pacific Northwest also suggests that many species, including western hemlock and subalpine fir, will become more abundant at higher elevations with warming on the peninsula.

Modern Records of Climate, Tree Growth, and Fire

Before climate-induced changes in species distribution become apparent, changes in patterns of species establishment, growth, and mortality occur that eventually lead to broader range shifts (Littell et al. 2008). Dendroecological (tree ring) records from the past several hundred years allow observation of changes in growth of tree species with climate variation. Tree ring records show that individual tree growth and net primary productivity are sensitive to annual changes in climate in the Pacific Northwest

(Brubaker 1980, Ettl and Peterson 1995, Graumlich et al. 1989, Hessl and Peterson 2004, Holman and Peterson 2006, Littell et al. 2008, Nakawatase and Peterson 2006, Peterson and Peterson 2001). Effects of future climate change on both tree growth and establishment will differ by species (owing to varied physiologies and allocation patterns) and with elevation and topography (Ettl and Peterson 1995, Holman and Peterson 2006).

At higher elevations on the Olympic Peninsula, tree growth and establishment are limited by snowpack amount and duration and associated growing-season length; greater snowpack amount and duration lead to a shorter growing season and decreased growth in high-elevation trees. For example, tree growth at the mid- and high-elevation subalpine fir-mountain hemlock and Pacific silver fir-western hemlock forests of the Hoh watershed on the western Olympic Peninsula is limited by snowpack and associated growing-season length (Holman and Peterson 2006, Nakawatase and Peterson 2006). Mountain hemlock growth in the Pacific Northwest is limited by spring snowpack depth and low summer temperatures (Peterson and Peterson 2001). Similarly, subalpine fir at high-elevation, wetter sites on the Olympic Peninsula grows more slowly during years with lower summer temperature (Ettl and Peterson 1995), and regionally, growth of subalpine fir in the wetter portions of its range is negatively correlated with winter precipitation and spring snowpack depth (Peterson et al. 2002). Increasing temperatures with climate change will lead to more precipitation falling as rain rather than snow, earlier snowmelt, and thus lower snowpacks and longer growing seasons on the peninsula (Elsner et al. 2010). Longer growing seasons on the peninsula will alleviate growth-limiting factors and likely result in increased growth and productivity in high-elevation forests. Longer growing seasons will likely also lead to higher tree establishment at higher elevations.

In the dry northeastern Olympics, tree growth and establishment are limited by low summer soil moisture. For example, tree growth in the Dungeness watershed in the northeastern portion of the Olympic Peninsula has been shown to be limited by summer soil moisture, although less so at higher elevations (Nakawatase and Peterson 2006). Douglas-fir, although more drought tolerant than other major Olympic Peninsula tree species such as western hemlock, is limited by water supply at lower elevations in the Pacific Northwest (Littell et al. 2008).

Increasing temperatures, lower winter snowpack, and early snowmelt with climate change will likely result in decreased soil moisture in parts of the Pacific Northwest, including many areas west of the Cascade Range in Washington state (Elsner et al. 2010). For the state of Washington, soil moisture content on July 1st is projected to decrease through the 21st century; for mean historical values (from the 1915 to 2006 period), July 1st soil moisture content is defined as 50 percent and is projected to be in the 38th to 43rd percentile by the 2020s, 35th to 40th percentile by the 2040s, and 32nd to 35th percentile by the 2080s (Elsner et al. 2010) (fig. 6.2). These decreases in summer soil moisture will likely lead to increased stress to tree species in some portions of the Pacific Northwest.

Increased drought stress will likely result in decreased tree growth and forest productivity in the northeastern forests of the Olympic Peninsula. In the Sitka spruce forests on the west side of the peninsula, carbon dioxide fertilization could lead to increases in productivity (Norby et al. 2005), if other factors, such as nutrient availability, do not limit growth. However, growth may also decrease in these Sitka spruce forests if summer soil moisture becomes sufficiently limiting with warming (Holman and Peterson 2006, Nakawatase and Peterson 2006).

Tree ring and modern fire records both show that years with widespread fire and fire extent are associated with warmer and drier spring and summer conditions in the Western United States (Heyerdahl et al. 2008, Littell et al. 2009, McKenzie et al. 2004, Taylor et al. 2008, Westerling et al. 2006). Warmer spring and summer conditions in the Western United States lead to relatively early snowmelt, and lower summer soil and fuel moisture, and thus longer fire seasons (Westerling et al. 2006). Wildfire area burned in mountainous areas in the Western United States was positively related to low precipitation, drought, and high temperatures in the 20th century (Littell et al. 2009). Increased temperatures and drought occurrence in the Pacific Northwest from climate change will likely lead to increased fire frequency and extent. In addition, the intensity and severity

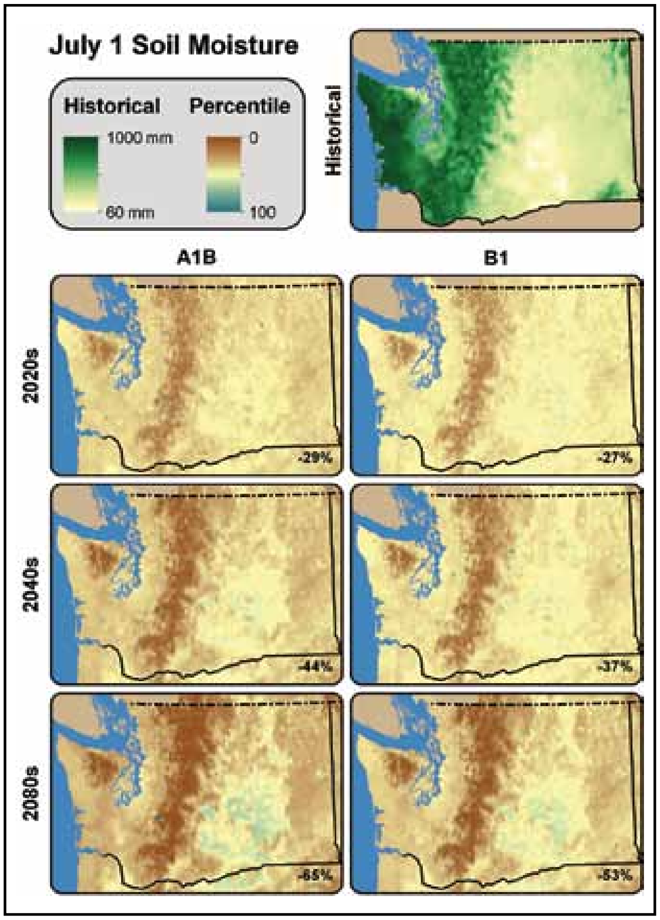

Figure 6.2—Summary of projected July 1 soil moisture (volumetric soil water content) for the 2020s, 2040s, and 2080s (A1B and B1 Intergovernmental Panel on Climate Change emissions scenarios) as a percentile of simulated historical mean from 1916 to 2006 (by using the Variabile Infiltration Capacity model). For future projections, percentiles less than 50 (browns) represent a decrease in soil moisture, and percentiles greater than 50 (blues) show an increase in soil moisture. Percentage change values represent spatially averaged July 1 soil moisture across Washington state. (Adapted from Elsner et al. 2010.)

of fires may increase in some areas if higher temperatures exacerbate low moisture content in fine fuels.

Climate and fire on the Olympic Peninsula have been closely related in the past (Henderson et al. 1989). Warmer and drier periods of the past were likely characterized by increased fire frequency, particularly on the east side of the Olympic Peninsula (Gavin et al. 2001, Henderson et al. 1989). Historical fires have been most frequent in the drier western hemlock, subalpine fir, and Douglas-fir vegetation types in the eastern half of the Olympic Peninsula (Henderson et al. 1989, Pickford et al. 1980). Henderson et al. (1989) calculated the average fire-return period for the last 800 years in these vegetation types on the peninsula and found that the Douglas-fir zone had a fire-return period of 138 years, the subalpine fir zone had a fire-return period of 208 years, and the western hemlock zone had a fire-return period of 234 years. Decreases in fire-return intervals in these forest types would likely favor tree species that can survive fires or regenerate after fires, such as Douglas-fir and lodgepole pine, at the expense of less fire-tolerant species, such as western hemlock. Individual trees can withstand climatic variation, but disturbance events that result in mortality of mature trees could trigger changes in distribution and abundance of forest species on the peninsula.

Trends With Recent Warming

Plant and animal species in different ecosystems across the world have begun to respond to recent warming over the last few decades (Parmesan 2006, Parmesan and Yohe 2003, Root et al. 2003). Most plant responses to recent warming have involved alteration of species' phenologies, or timing of life history stages (Bradley et al. 1999, Menzel 2000, Menzel et al. 2001, Parmesan 2006). Advances in timing of flowering, for example, have been reported for plant species in Great Britain (Fitter and Fitter 2002), and evidence exists that the growing season has lengthened in the Northern Hemisphere in the last 50 years (Menzel and Fabian 1999, Parmesan 2006). Shifts in timing of flowering and the abundance of insect pollinators could lead to the decline of some plant species if pollinators are absent during times of peak flowering.

Shifts in species' distribution with warming in recent decades have been documented at several locations, including mountain ranges in western Europe (Grabherr et al. 1994, Lenoir et al. 2008) and southern California (Kelly and Goulden 2008). Consistent with paleoecological records, these shifts have generally involved movement upward in elevation or poleward (Parmesan 2006). Upward movement of tree lines has been documented in numerous mountainous locations across the world, including locations in Canada (Lescop-Sinclair and Payette 1995, Luckman and Kavanagh 2000), Sweden (Kullman 2001), Bulgaria (Meshinev et al. 2000), Russia (Moiseev and Shiyatov 2003), and New Zealand (Wardle and Coleman 1992). However, tree-line dynamics are complex and dependent on precipitation and microsite patterns in addition to temperature (Malanson et al. 2007, Parmesan 2006). A meta-analysis of response of tree lines at 166 sites (from around the world, but mostly in North America and Europe) to recent warming found that tree lines at sites with more winter warming were more likely to have advanced than tree lines at sites with less warming. In addition, tree lines with a diffuse form, characterized by decreasing tree density with increasing altitude or latitude, were more likely to have advanced than those with an abrupt form, characterized by a continuous canopy with no decline in density right up to tree line (Harsch et al. 2009). It is possible that diffuse tree lines are more responsive to warming because tree growth, but not survival, is limited by climatic factors. In contrast, winter stress factors that cause plant damage and limit survival may have a stronger influence on abrupt tree lines (Harsch et al. 2009).

The frequency of some drought-related disturbance events has increased with recent warming. Tree mortality events in the Southwestern United States have been attributed to late 20th-century warming and related drought (Breshears et al. 2005, 2009). Increased temperatures have led to drier fuel levels, longer fire seasons, and an increase in years with widespread fire across the Western United States (Littell et al. 2010, Westerling et al. 2006).

Insect outbreaks, such as that of the mountain pine beetle, have been recorded across a broad spectrum of latitude and temperature regimes in the past in western North America. However, the severity and distribution of some recent outbreaks differ from what can be inferred from historical records, and higher temperature associated with climate change is believed to be a significant factor in these differences (Aukema et al. 2008, Carroll et al. 2004, Logan and Powell 2001). For example, the expansive mountain pine beetle outbreak in British Columbia has expanded into northern areas and into areas east of the Rocky Mountains in Alberta, where mountain pine beetles were not successful in the past because of cold winter temperatures (Carroll et al. 2004). Current conditions on the Olympic Peninsula do not preclude mountain pine beetles from infesting and killing hosts, and the suitability for mountain pine beetle outbreaks at higher elevations in the Olympics is expected to increase under moderate warming (Littell et al. 2010). Besides the effects of changing climate on insect reproductive cycles, timing and severity of outbreaks will depend on availability of susceptible ages and sizes of lodgepole pine, western white pine, and whitebark pine and the stand conditions within which they reside.

The exotic balsam woolly adelgid can infest both Pacific silver fir and subalpine fir on the Olympic Peninsula. This insect generally does not kill trees quickly, but will result in the slow demise of infested trees. Mitchell and Buffam (2001) observed that 3 to 4 years of warmer than average summers resulted in increased adelgid damage in subalpine fir at higher elevations in Oregon and Washington. They stated that, "If there was a permanent or long-term (decades) increase in summer temperatures, it is likely we would see an expanded range for the balsam woolly adelgid within the subalpine fir ecotypes—upward in elevation and to other new environments." This suggests that, with warmer temperatures, balsam woolly adelgid will have greater effect on subalpine fir than is now being experienced on the Olympic Peninsula.

Besides the increased fire risk in drought-stressed forests, increased moisture stress may leave forests in the Western United States more susceptible to insect attack (Allen and Breshears 1998, Breshears et al. 2005, Hicke et al. 2006, Shaw et al. 2005). As temperature increases, any increase in moisture stress will increase the susceptibility of Douglas-fir on the peninsula to attack by Douglas-fir beetle. On the Olympic Peninsula, Douglas-fir beetle outbreaks are generated by wind events, which result in significant amounts of blowdown. Beetle populations build up in the downed trees, and then can attack and kill standing green Douglas-firs. These outbreaks will subside within 3 years if no subsequent blowdowns occur, and the numbers of standing trees that are killed will depend on the relative moisture stress of these trees. Historically, after blowdowns, mortality has been higher in the drier, eastern habitats of the peninsula than in the wetter, western habitats. Any changes in moisture regimes would affect the distribution of Douglas-fir beetle-caused mortality from a wind event on the peninsula. Recently burned forests may also lead to increases in Douglas-fir beetle populations, and subsequent mortalilty of additional green trees. In turn, these insect outbreaks can alter fuel and forest stand conditions which, at certain points after infestation, could result in increased risk of high-severity fire (Jenkins et al. 2008). All of these disturbances may increase opportunities for establishment by exotic species (Joyce et al. 2008). In this way, disturbances could act synergistically to drive ecosystem change on the Olympic Peninsula (McKenzie et al. 2009).

Tree disease could also potentially increase with warming on the peninsula. The effects of climate change on host physiology, adaptation or maladaptation, and population genetics that affect host-pathogen interactions is uncertain (Kliejunas et al. 2009). However, based on existing knowledge of tree disease in western North America, it can be inferred that climate change will result in reductions in tree health and advantageous conditions for some pathogens (Kliejunas et al. 2009). Any drought stress that is realized owing to changing conditions will exacerbate the impacts of many pathogens (Kliejunas et al. 2009).

Model Predictions for Future Vegetation Patterns With Climate Change

Along with past records, models can be used to project future ecosystem response to changing climate. Output from three different types of climate change impact models—gap, climate envelope, and mechanistic dynamic

Box 6.1—Model types that assess potential effects of climate change on vegetation. Adapted from Robinson et al. (2008)

Gap models

- Gap models simulate forest interactions and dynamics on a small, gap-sized patch of land (usually 0.01 ha and larger).
- The geographic extent of analysis ranges from forest stands to regions.
- Ingrowth, growth, and death of individuals of one or more species on the patch are simulated over time.
- Dynamics in gap models are based on species-specific parameters, competition (e.g., relative height), light, temperature, and soil moisture.
- Output includes density, basal area, biomass, and leaf area index by species and by stand. Information on each live tree is also available (e.g., species and diameter).
- Gap models use monthly temperature and precipitation, and so can respond to novel climate.
- Some gap models have recently been adapted to be sensitive to changes in soil moisture and carbon dioxide concentrations.

Climate envelope models

- Climate envelope models (CEMs) are statistical models that predict future species distribution based on the relationship between current species distribution and climate variables (and sometimes other variables).
- CEMs use basic climate information as input.
- The geographic extent of analysis is variable, but regional analyses are typical. Modeling unit differs with input information.
- CEMs represent a snapshot in time and do not show variability in species distribution over time.
- These models assume that climate is the primary determinant of a species distribution and that the current relationship between a species and climate will hold under changing climate.
- CEMs do not account for competition, dispersal, or evolutionary change in vegetation communities.
- CEMs do not account for increases in carbon dioxide ($CO_{2)}$ and changes in disturbance regimes.

Dynamic global vegetation models

- Dynamic global vegetation models (DGVMs) simulate key physiological processes in plant communities to infer vegetation type over time.
- DGVMs use soil and climatic information (hourly to yearly).
- DGVMs can respond to novel climate and are sensitive to changes in CO_2 and fire regimes.
- The geographic extent of analysis ranges from landscape to global, with modeling unit ranging from a 30 m^2 to several-square kilometer pixel.
- Output shows distribution of broad vegetation functional types over time but not individual species.
- DGVMs can identify limiting factors in different regions.
- DGVMs do not consider complex topography, land use change, management, pests, or herbivores.

global vegetation models (box 6.1)—has been produced for the Olympic Peninsula. All of these model types have strengths and limitations but can be conceptually useful in assessing potential climate change effects on vegetation. Output from these different model types for the Olympic Peninsula is described below.

Gap model results for the Olympic Peninsula—
A gap modeling study for the subalpine and upper montane zones of the Olympic Mountains under a warming climate (Zolbrod and Peterson 1999) suggested that in the wetter southwest areas, dominant tree species will shift upwards 300 to 600 m; gap model study results predict that Pacific silver fir will increase in subalpine meadows and mountain hemlock forests and western hemlock will increase in Pacific silver fir forests. In the drier northeast, study results suggest that drought-tolerant species will become dominant at lower elevations. At higher elevations, subalpine fir will dominate north aspects, and lodgepole pine will dominate south aspects. In general, productivity will increase in the southwest owing to longer growing seasons (and lack of moisture limitations), and productivity will decrease in the northeast owing to increased evapotranspiration and lower soil moisture content during the summer.

Climate envelope model results for the Olympic Peninsula—
Statistical ecological models, also known as climate envelope models, were developed for the state of Washington by Littell et al. (2010 with data from Rehfeldt et al. 2006) to determine the potential for climate change to alter distribution of important tree species, including Douglas-fir, lodgepole pine, ponderosa pine, and whitebark pine. Under a moderate carbon dioxide-emission scenario (1 percent per year increase in greenhouse gases after 1990) (Rehfeldt et al. 2006), the envelope models suggested that there will be a significant decline in the area of suitable climate for Douglas-fir at lower elevations and in the southern portion of the Olympic Peninsula. A decrease in area of suitable climate for pine species, which could include whitebark pine and lodgepole pine, is also projected to occur at higher elevations on the Olympic Peninsula.

As noted in box 6.1, several assumptions and limitations are associated with climate envelope models. First, climate envelope models assume that climate is the primary determinant of a species distribution and that the current relationship between a species and climate will hold under changing climate. In addition, these models do not account for several important determinants of plant species distribution, including competition, dispersal, evolutionary change in vegetation communities, and changes in disturbance regimes.

Dynamic global vegetation model results for the Olympic Peninsula—
The MC1 (Bachelet et al. 2001) dynamic global vegetation model (DGVM) is based on fundamental ecological processes and provides projections of future change in broad vegetation types with changing climate. Vegetation types in MC1 are based on life form (e.g., tree, shrub, or grass; evergreen or deciduous; broadleaf or needleleaf) and biome physiognomy (e.g., forest, savanna, or shrub-steppe) (see Neilson 1995). Species-level information is not included in MC1 output but can be inferred at coarse scales based on modeled vegetation type and local vegetation information. Additional limitations of MC1 are that it does not include complex topography, which may be important with changing climate in mountainous regions such as the Olympic Peninsula, or the effects of land use change, management, insects, or herbivores (see box 6.1).

MC1 model projections are based on future climate projections from global climate models (GCMs). The Mapped Atmosphere-Plant-Soil System (MAPSS) Team (Forest Service, Pacific Northwest Research Station, Corvallis, Oregon) ran the MC1 model for the Pacific Northwest region, at a scale of 800 m, with inputs from three GCMs under three future carbon dioxide emissions scenarios. The three GCMs used in the analysis included the CSIRO-MK3.0 model from Australia (Dix et al. 2009, Gordon et al. 2002), the Hadley CM3 model from the United Kingdom (Gordon et al. 2000, Pope et al. 2000), and the MIROC 3.2 medium-resolution model from Japan (Hasumi and Emori 2004). These three GCMs were chosen to bracket the range of scenarios available for the Western United States. In general, the Commonwealth Scientific and Industrial Research

Organization (CSIRO) model projections show a relatively cool and wet Pacific Northwest, whereas the Model for Interdisciplinary Research on Climate (MIROC) model projections show a hot and wet Pacific Northwest, and the Hadley projections show a hot and dry Pacific Northwest. The carbon dioxide emissions scenarios used in the analysis included the Intergovernmental Panel on Climate Change (IPCC) special report on emissions scenarios (Nakićenović and Swart 2000) B1 (relatively low future carbon dioxide emissions), A1B (moderate future carbon dioxide emissions), and A2 (relatively high future carbon dioxide emissions) scenarios.

Here we present MC1 output on vegetation shifts and fire dynamics on the Olympic Peninsula through the end of the century for the three GCMs described above and the B1 and A2 emissions scenarios (relatively low and high emissions scenarios, respectively) (figs. 6.3 through 6.8). The MC1 output is based on model runs that included a relatively high carbon dioxide fertilization effect (Norby et al. 2005) and potential nitrogen limitation. Changes in vegetation type in figures 6.3 through 6.5 indicate that the climate will no longer be suitable for the former vegetation type and that changes in species composition and abundance are likely. However, changes in species composition and abundance will likely be gradual because of

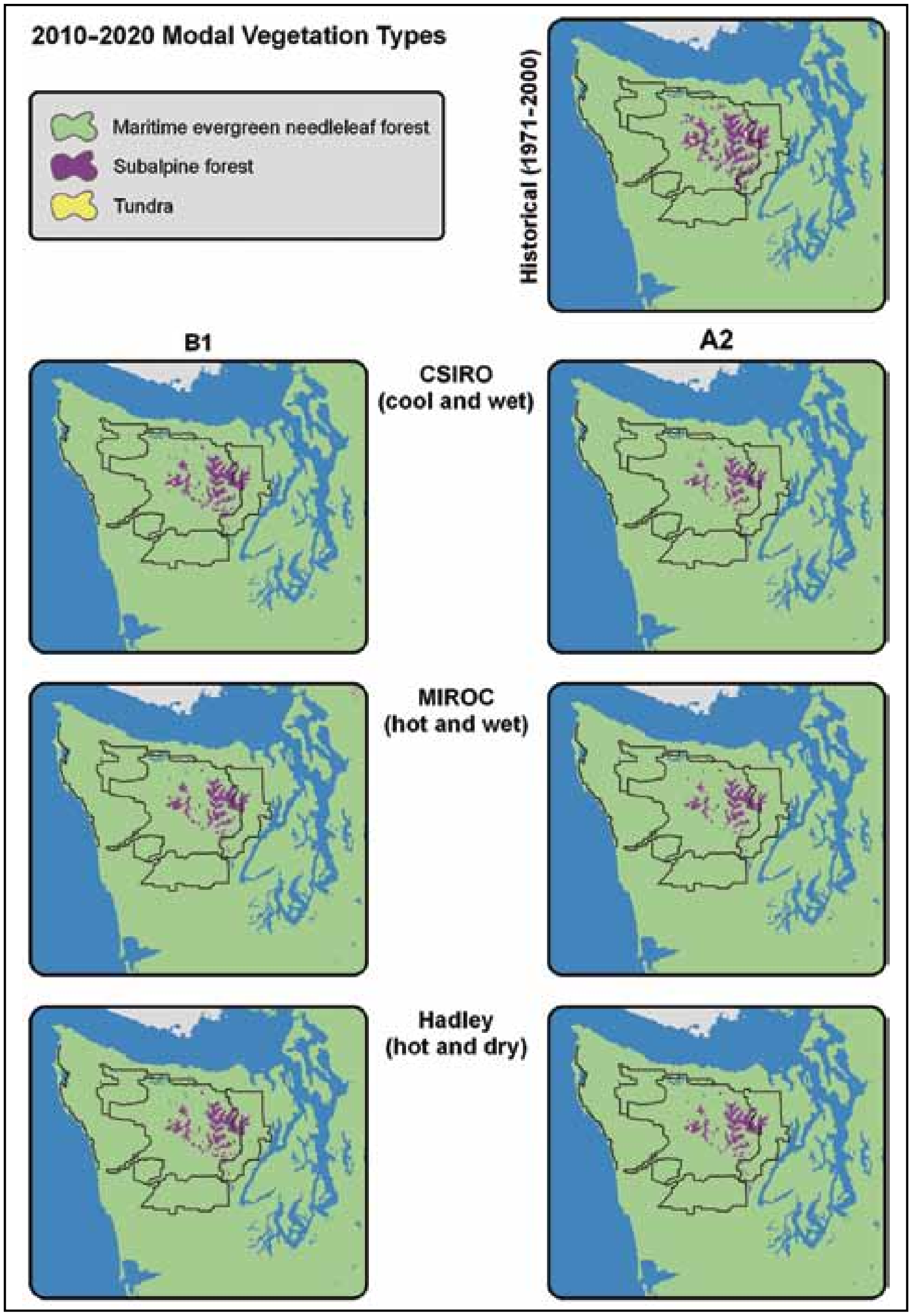

Figure 6.3—Projected modal vegetation types on the Olympic Peninsula for the 2010–20 period compared to modeled historical vegetation types. Projections are from the MC1 model for three global climate models (GCMs) (rows) and two Intergovernmental Panel on Climate Change (IPCC) carbon dioxide emissions scenarios (columns). The Commonwealth Scientific and Industrial Research Organization's (CSIRO) GCM projects a relatively cool and wet Pacific Northwest, whereas the Model for Interdisciplinary Research on Climate (MIROC) projects a hot and wet Pacific Northwest, and the Hadley model projects a hot and dry Pacific Northwest. The B1 emissions scenario is characterized by relatively low future emissions, and the A2 scenario is characterized by relatively high future emissions. Olympic National Park and Olympic National Forest are outlined in black. (Data from R. Neilson and the MAPSS Team, USDA Forest Service and Oregon State University, Corvallis, Oregon.)

Table 6.1—Dominant and associated species for current vegetation (elevation/moisture) zones on the Olympic Peninsula with potential dominant species in 2100[a b]

Current vegetation zones	Current dominant species	Current associates	Potential dominant species in 2100
Sitka spruce	Sitka spruce (-), western hemlock (-), western redcedar (+)	Douglas-fir (+), red alder (+), Pacific silver fir (+), bigleaf maple (+)	Douglas-fir, western redcedar, red alder
Western hemlock	Western hemlock (-), Douglas-fir (+)	Western redcedar (-), lodgepole pine (+), western white pine (+), grand fir (-), bigleaf maple (-)	Douglas-fir, lodgepole pine, western white pine
Douglas-fir	Douglas-fir (+), lodgepole pine (+)	Western hemlock (-), western redcedar (-), madrone (+), western white pine (+), Rocky Mountain juniper (+), golden chinquapin (+)	Douglas-fir, lodgepole pine, western white pine
Pacific silver fir	Pacific silver fir (-), western hemlock (+)	Alaska yellowcedar (-), western redcedar (+), Douglas-fir (+), mountain hemlock (-), western white pine (+)	Western hemlock, western redcedar, Douglas-fir, western white pine
Mountain hemlock	Mountain hemlock (-), Pacific silver fir (+)	Subalpine fir (+), Alaska yellowcedar (+), western white pine (+), western hemlock (+), Douglas-fir (+)	Pacific silver fir, western hemlock, western white pine
Subalpine fir	Subalpine fir (-), lodgepole pine (+)	Whitebark pine (-), Alaska yellowcedar (-), Pacific silver fir (-), Douglas-fir (+), western hemlock (+)	Lodgepole pine, Douglas-fir
Alpine	—	—	Subalpine fir, mountain hemlock, Alaska yellowcedar, whitebark pine

— = no tree species present.

[a] Potential dominant species were determined assuming that the next century will be hotter, with increasing summer drought stress, and that disturbance frequency (either fire on the east side of the peninsula or windstorms on the west side of the peninsula) will increase over the next century to facilitate species transition. It was also assumed that species dispersal would not be a limiting factor for movement in response to changing climate. Expected increases or decreases in abundance of current dominant and associate species are indicated with a (+) or (-), respectively.

[b] Henderson, J.A.et al (1989).

the high tolerance of mature trees to climatic variation; disturbances such as fire will likely be the main triggers for major compositional change. To interpret the MC1 output for the Olympic Peninsula, we focused on coarse-scale changes in vegetation type and disturbance, and the factors that led to those changes, and related them to likely changes in species composition and abundance (table 6.1).

In many of the future scenarios in MC1, there is a decline in the extent of the high-elevation tundra and subalpine vegetation types on the Olympic Peninsula by 2040–2060 (fig. 6.4), and there is also an almost complete loss of the tundra and subalpine vegetation types under most scenarios by 2070–2099 (fig. 6.5). This suggests that suitable conditions for tundra and subalpine vegetation will decline substantially or disappear by the end of the 21st century with warming on the peninsula. Large-scale dispersal of plant species to the Olympic Peninsula will likely be limited because of isolation from mainland areas by water and lower elevation zones (Peterson et al. 1997, Zolbrod and Peterson 1999). Thus, changes in distribution and abundance of plant species must occur within the existing populations and communities on the peninsula, and species adjustments to changing climate are expected to be mainly altitudinal or between aspects (Zolbrod and

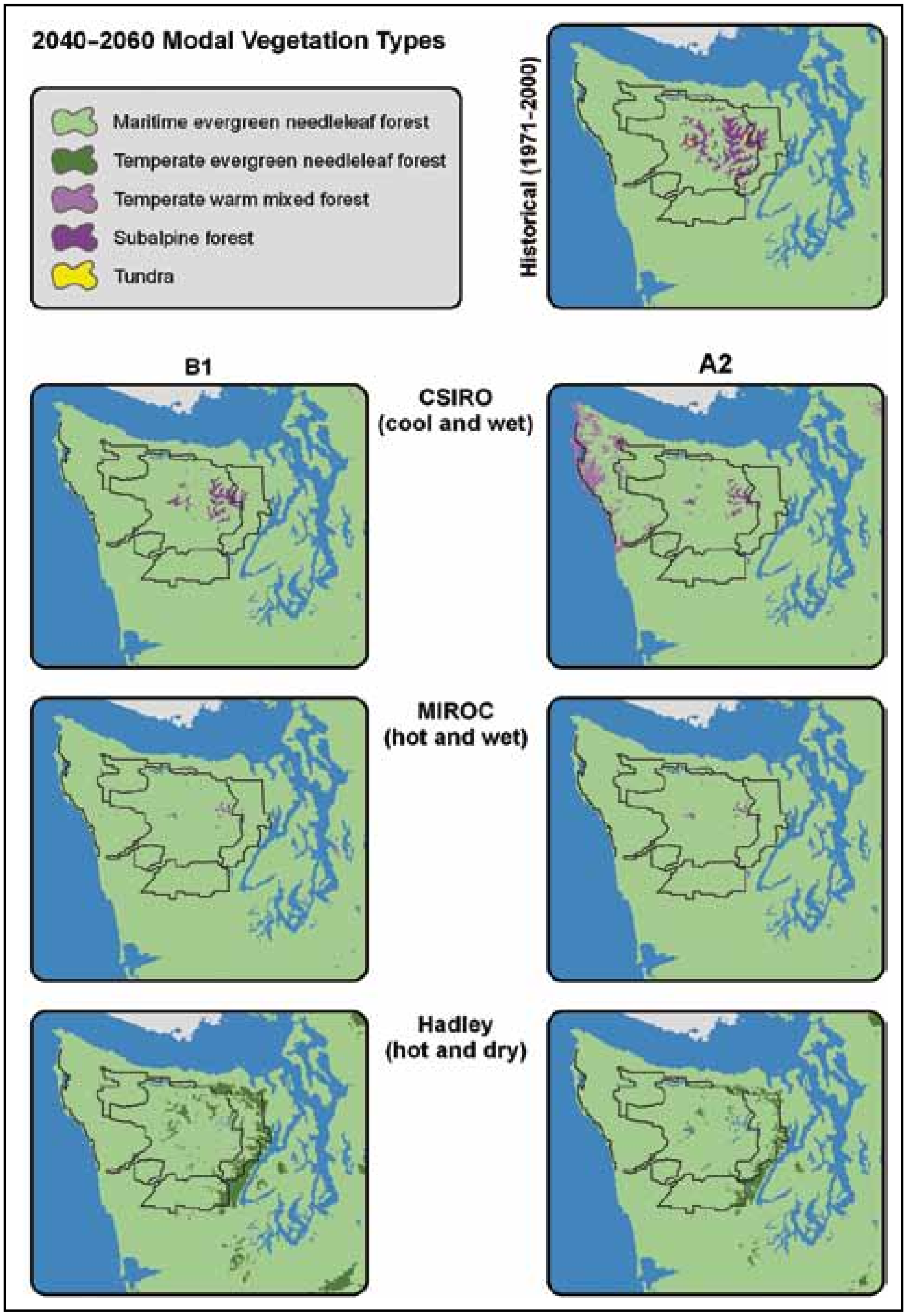

Figure 6.4—Projected modal vegetation types on the Olympic Peninsula for the 2040–60 period compared to modeled historical vegetation types. Projections are from the MC1 model for three global climate models (GCMs) (rows) and two Intergovernmental Panel on Climate Change IPCC carbon dioxide emissions scenarios (columns). The Commonwealth Scientific and Industrial Research Organization's (CSIRO) GCM projects a relatively cool and wet Pacific Northwest, whereas the Model for Interdisciplinary Research on Climate (MIROC) projects a hot and wet Pacific Northwest, and the Hadley model projects a hot and dry Pacific Northwest. The B1 emissions scenario is characterized by relatively low future emissions, whereas the A2 scenario is characterized by relatively high future emissions. Olympic National Park and Olympic National Forest are outlined in black. (Data from R. Neilson and the MAPSS Team, USDA Forest Service and Oregon State University, Corvallis, Oregon.)

Peterson 1999). In the former range of tundra and subalpine vegetation types, other species will likely become dominant, including tree species from lower elevations (see subalpine fir and alpine vegetation types in table 6.1).

Under the CSIRO GCM A2 scenario (cool and wet Pacific Northwest), there is a range expansion of the temperate warm mixed-vegetation type in the northwestern portion of the peninsula in the 2040–60 period (fig. 6.4). This vegetation change is in response to increased precipitation (specifically in the summer compared to the rest of the year), which allows for range expansion of deciduous broadleaf species. In the northwestern portion of the peninsula, this could include species such as vine maple, bigleaf maple, and red alder. However, by the end of the century, the maritime evergreen needleleaf forest again becomes more dominant than the temperate warm mixed-vegetation type (fig. 6.5). This is because precipitation increases under the CSIRO A2 scenario toward the end of the century, but the summers are not as wet relative to the rest of the year as they were in mid century. Evergreen needleleaf species are likely to maintain dominance under those conditions (Neilson 1995). Although the CSIRO scenarios are generally characterized by a relatively cool and wet Pacific Northwest, the distinct seasonality in rainfall and lower summer precipitation levels under the

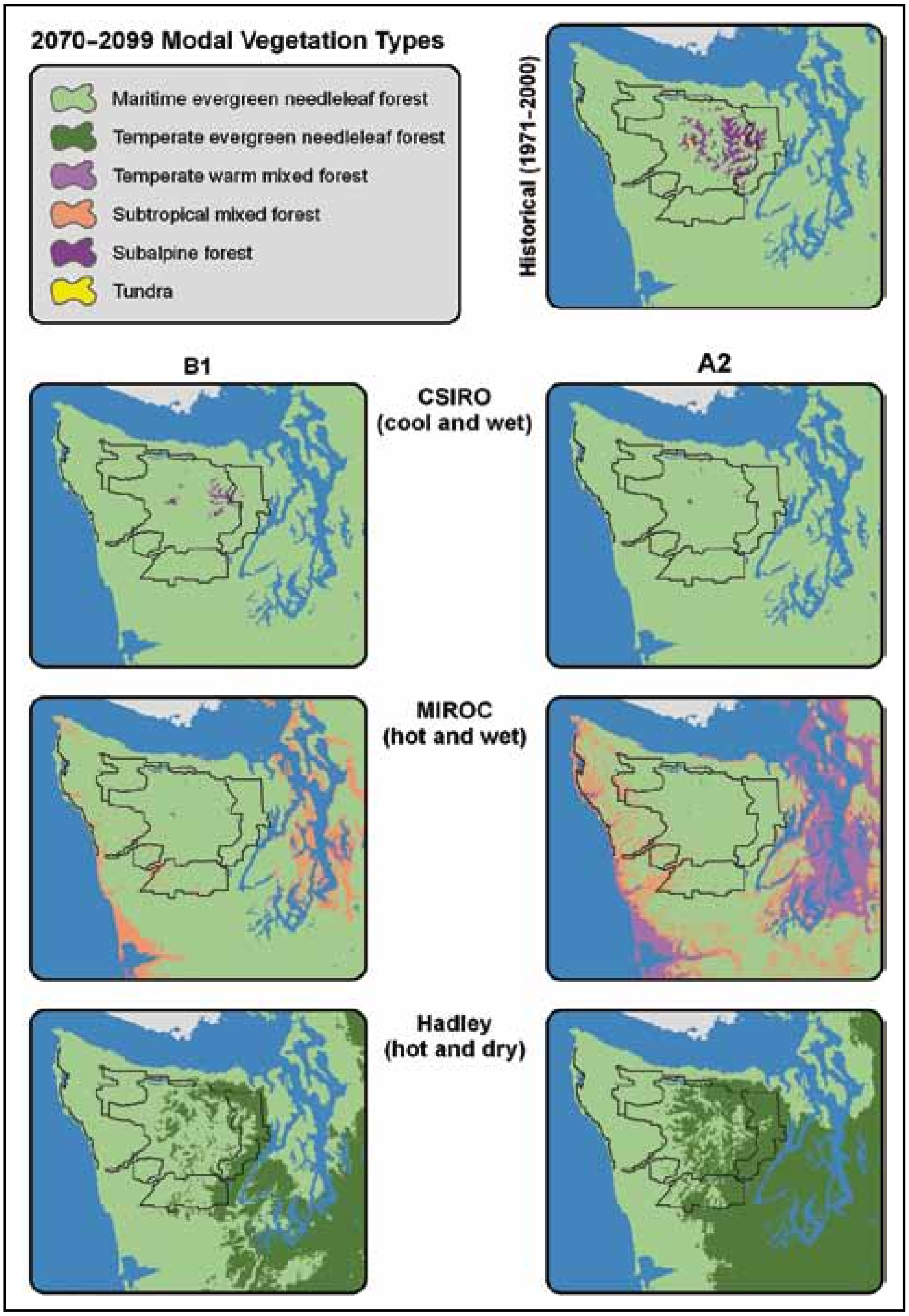

Figure 6.5—Projected modal vegetation types on the Olympic Peninsula for the 2070–99 period compared to modeled historical vegetation types. Projections are from the MC1 model for three global climate models (GCMs) (rows) and two Intergovernmenata Panel on Climate Change (IPCC) carbon dioxide emissions scenarios (columns). The Commonwealth Scientific and Industrial Research Organisation's (CSIRO) GCM projects a relatively cool and wet Pacific Northwest, whereas the Model for Interdisciplinary Research on Climate (MIROC) projects a hot and wet Pacific Northwest, and the Hadley model projects a hot and dry Pacific Northwest. The B1 emissions scenario is characterized by relatively low future emissions, and the A2 scenario is characterized by relatively high future emissions. Olympic National Park and Olympic National Forest are outlined in black. (Data from R. Neilson and the MAPSS Team, USDA Forest Service and Oregon State University, Corvallis, Oregon.)

CSIRO scenarios lead to increased fire activity at lower elevations on the eastern side of the peninsula by the end of the century (fig. 6.8). Fire-tolerant species, such as Douglas-fir and lodgepole pine, will likely expand their ranges on the east side of the peninsula with increased fire.

With the MIROC GCM (hot and wet Pacific Northwest) as input to MC1, there is a range expansion of the temperate warm mixed-forest and subtropical mixed forest vegetation types by the end of the 21st century, mainly on the west side of the Olympic Peninsula (fig. 6.5). The range expansion of these temperate and subtropical forest types is at the expense of the currently dominant maritime evergreen needleleaf forest. This shift to temperate and subtropical vegetation types is a response to increases in average monthly temperatures and a decrease in winter frosts. Higher summer temperatures may eventually lead to drought stress in forest types that are not currently stressed in the summer months, mainly Sitka spruce forests, leading to shifts in dominance to more drought-tolerant species, such as western redcedar (table 6.1).

Under the hot and dry scenario with the Hadley model, MC1 shows a range expansion of the temperate evergreen needleleaf forest on the east side of the Olympic Peninsula by mid 21st century, with even greater expansion by the end of the century (figs. 6.4 and 6.5). This

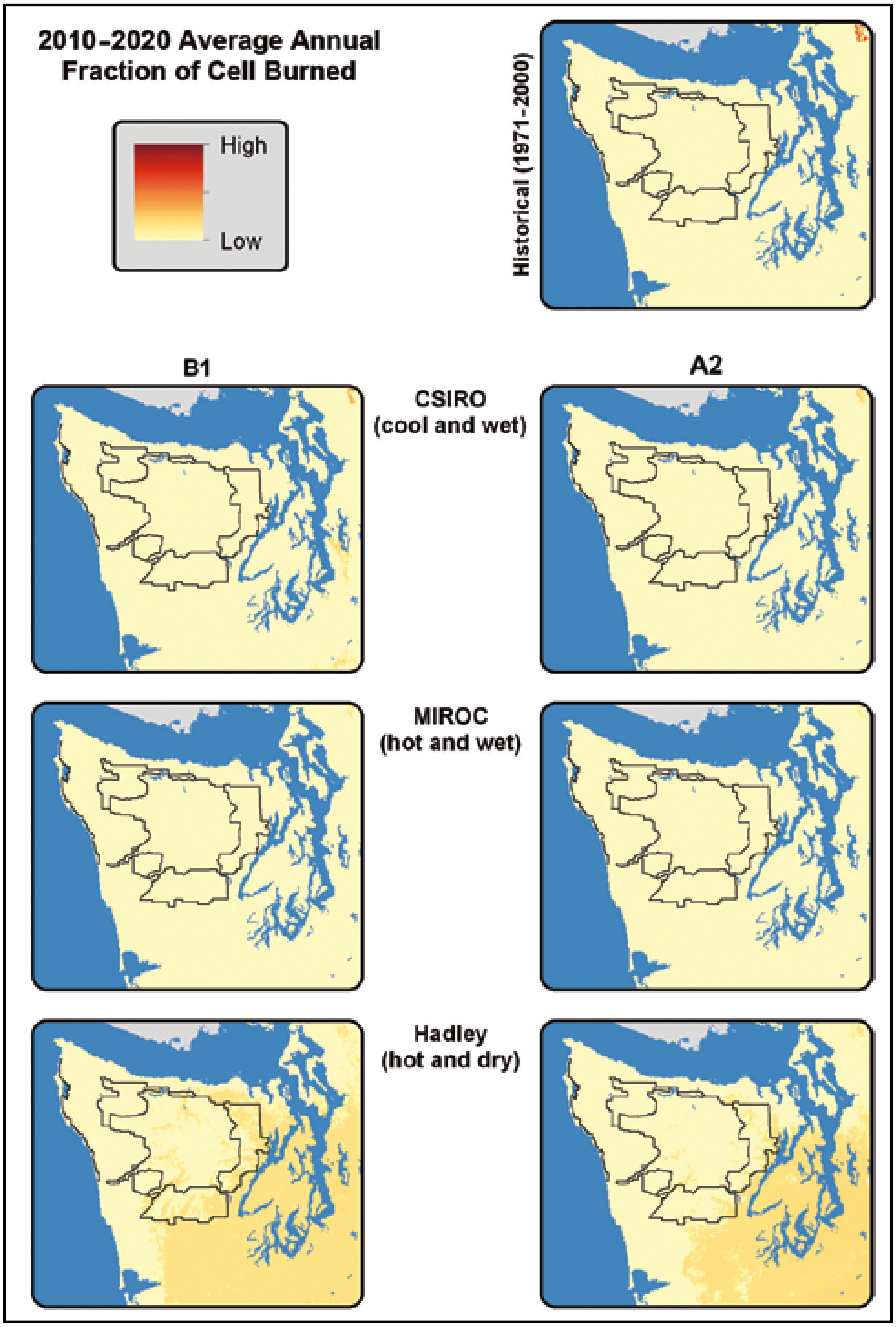

Figure 6.6—Projected average annual fraction of cell burned on the Olympic Peninsula for the 2010–20 period compared to modeled historical fire activity. This output is derived by averaging the area of a cell that is burned over the period of interest. Number are not shown in the legend because they are not intuitive. However, darker colors indicate more fire. Projections are from the MC1 model for three global climate models (rows) and two Intergovernnmental Panel on Climate Change carbon dioxide emissions scenarios (columns). The B1 emissions scenario is characterized by relatively low future emissions, and the A2 scenario is characterized by relatively high future emissions. CSIRO = Commonwealth Scientific and Industrial Research Organization; MIROC = Model for Interdisciplinary Research on Climate. Olympic National Park and Olympic National Forest are outlined in black. (Data from R. Neilson and the MAPSS Team, USDA Forest Service and Oregon State University, Corvallis, Oregon.)

shift is driven by increased fire activity on the east side of the peninsula with increasing temperatures and summer drought under the hot and dry Hadley scenario (figs. 6.6 through 6.8). In other locations in the Western United States, temperate evergreen needleleaf forests are characterized by regular fire occurrence and are dominated by pine species. The range expansion of this vegetation type on the east side of the peninsula suggests that fire- and drought-tolerant species, such as Douglas-fir, lodgepole pine, and western white pine, will become more abundant in east-side vegetation types, including the western hemlock and Douglas-fir types (table 6.1).

Overall, MC1 output indicates that vegetation change is expected by mid century across GCM and emissions scenarios. More substantial vegetation changes are expected by the end of the century. Decline in the extent of alpine and subalpine vegetation types is expected across scenarios. Other changes in vegetation and fire activity differ by GCM and the associated future changes in temperature and precipitation.

Vegetation Management at Olympic National Forest and Olympic National Park

The following section provides information on vegetation management at Olympic National Forest (ONF) and Olympic National Park

(ONP), including (1) the context in which ONF and ONP manage vegetation, (2) guidance and constraints on vegetation management at ONF and ONP, and (3) the primary issues and activities relevant to vegetation management at ONF and ONP. This information, coupled with the likely effects of climate change on vegetation on the Olympic Peninsula (described previously), provide a basis on which to develop climate change adaptation options for vegetation management at ONF and ONP.

Native Plants and Revegetation

The ONF has instituted a native plant program that aims to maintain biodiversity and ecosystem health through the use of locally adapted, self-perpetuating populations of native plant species. Olympic National Forest uses both internal capacity and contractors to develop and maintain locally adapted sources of native plant seed and plant material to ensure these materials are available when needed for revegetation (fig. 6.9). Several grass seed production fields have been established. All propagule sources (seeds, cuttings, transplants) across the forest are mapped to help ensure that genetically appropriate native plant materials are used for site restoration. On-forest expertise has been developed to help in creating and implementing revegetation and restoration plans that maximize use of native plants.

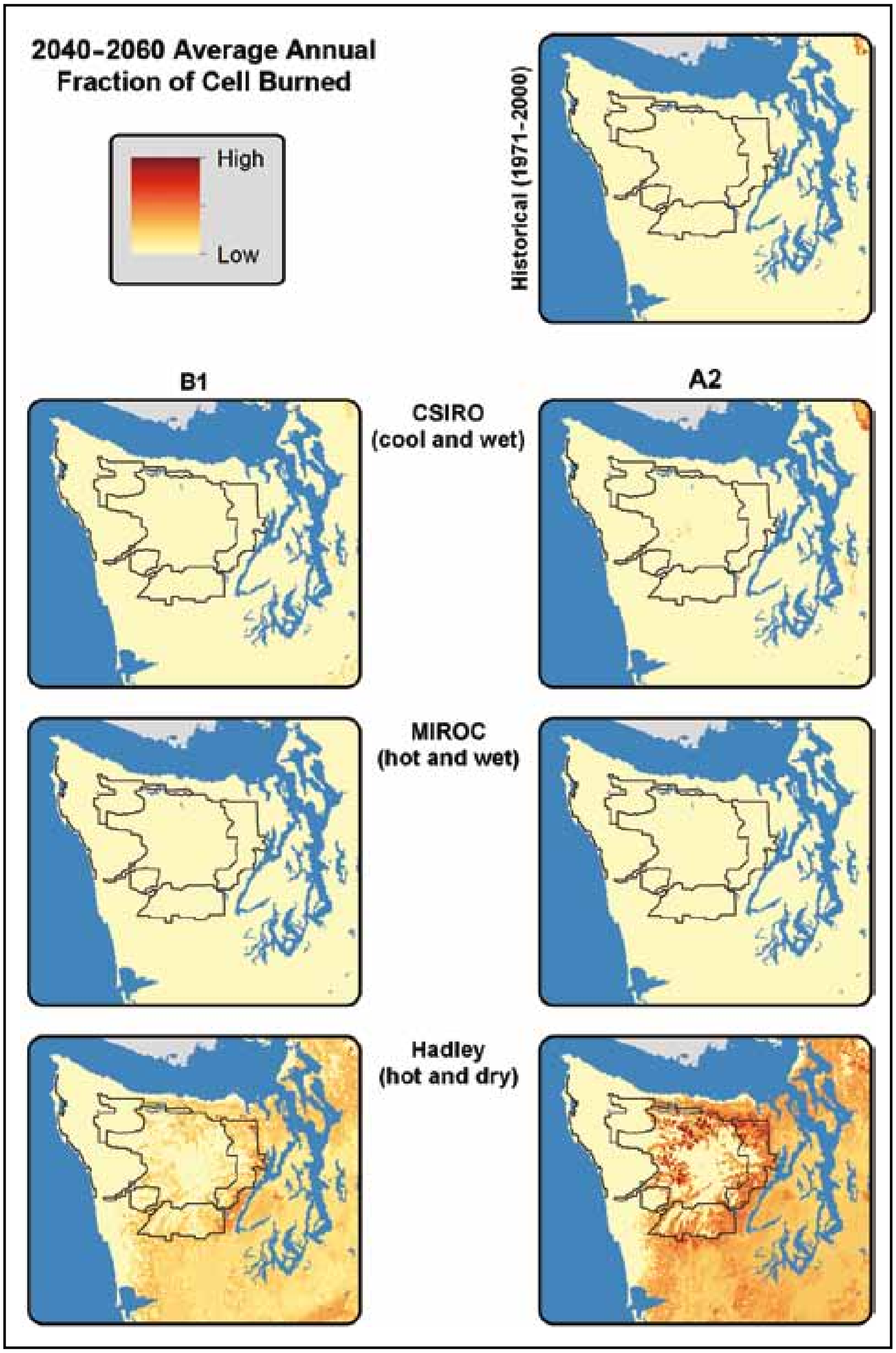

Figure 6.7—Projected average annual fraction of cell burned on the Olympic Peninsula for the 2040–60 period compared to modeled historical fire activity. This output is derived by averaging the area of a cell that is burned in a year over the period of interest. Number are not shown in the legend because they are not intuitive. However, darker colors indicate more fire. Projections are from the MC1 model for three global climate models (rows) and two Intergovernmental Panel on Climate Change carbon dioxide emissions scenarios (columns). The B1 emissions scenario is characterized by relatively low future emissions, and the A2 scenario is characterized by relatively high future emissions. Olympic National Park and Olympic National Forest are outlined in black. CSIRO = Commonwealth Scientific and Industrial Research Organization; MIROC = Model for Interdisciplinary Research on Climate. Olympic National Park and Olympic National Forest are outlined in black. (Data from R. Neilson and the MAPSS Team, USDA Forest Service and Oregon State University, Corvallis, Oregon.)

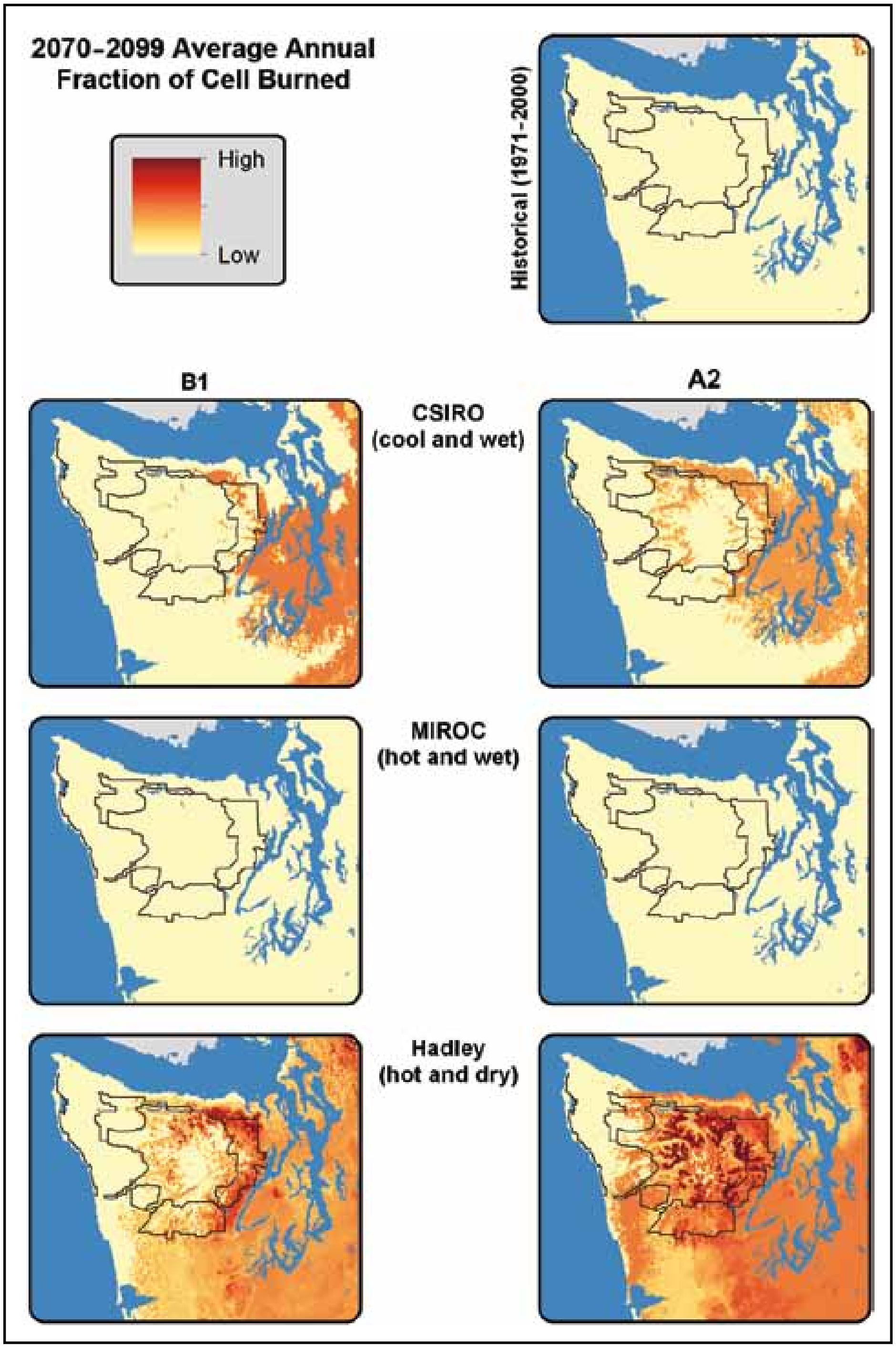

Figure 6.8—Projected average annual fraction of cell burned on the Olympic Peninsula for the 2070–99 time period compared to modeled historical fire activity. This output is derived by averaging the area of a cell that is burned over the period of interest. Number are not shown in the legend because they are not intuitive. However, darker colors indicate more fire. Projections are from the MC1 model for three global climate models (GCMs) (rows) and two Intergovernmental Panel on Climate Change carbon dioxide emissions scenarios (columns). The B1 emissions scenario is characterized by relatively low future emissions, and the A2 scenario is characterized by relatively high future emissions. Olympic National Park and Olympic National Forest are outlined in black. CSIRO = Commonwealth Scientific and Industrial Research Organization; MIROC = Model for Interdisciplinary Research on Climate. (Data from R. Neilson and the MAPSS Team, USDA Forest Service and Oregon State University, Corvallis, Oregon.)

Olympic National Park conducts revegetation activities in a variety of locations. Staff specialists conduct regular inventory and monitoring in wilderness areas, particularly along trails and at campsites, to determine if areas require revegetation. Park teams carefully select, plan, execute, and monitor success of restoration projects. Projects involve obtaining plant material, staging, site preparation, planting, mulching, and site protection/facilities improvement. Most restoration projects require plant seeds, cuttings, or transplants produced from native plant materials collected in the immediate vicinity.

Exotic Species Management

Exotic plants have become established in many locations at ONF. Some exotic species are considered invasive because their introduction causes or is likely to cause economic or environmental harm, and control efforts are focused on these invasive species. Invasive species infestations are primarily located in disturbed areas along road systems, in timber sale units, at administrative sites, in high public use areas (e.g., parking areas, viewpoints), in previously disturbed areas such as plantations, and in areas used for recreation such as campgrounds and dispersed recreation sites. Integrated manual, mechanical, herbicide, and restoration treatments are used at ONF to treat invasive plant infestations. Ongoing invasive

Figure 6.9—Wet meadow plant community adjacent to a road scheduled for decommissioning on Olympic National Forest. Seed and cuttings of several species were collected from this site and used in the revegetation of the decommissioned roadbed. (Photo by Cheryl Bartlett, U.S. Forest Service, Olympic National Forest.)

plant management efforts include prevention practices such as cleaning heavy equipment, using weed-free straw and mulch, using pelletized or certified weed-free animal feed, and restoring disturbed areas. Olympic National Forest is also involved in invasive species working groups to coordinate control efforts, including the Olympic Knotweed Working Group.

Similar to ONF, exotic plants occur in many locations at ONP, and 190 known exotic plant species occur in the park (Buckingham et al. 1995). To combat this problem, the North Coast and Cascades Network of the National Park Service established an exotic plant management team (EPMT) in 2002. The EPMT and park natural resources staff work together to prevent introduction and control the spread of all exotic plants. Prevention involves working with park staff to increase knowledge; minimizing and repairing soil disturbance; preventing spread on equipment, tools, and boats; regulating wilderness stock use; working with park maintenance staff to ensure outside contractors use weed-free gravel sources; and collaborating with other agencies and neighbors. Exotic plant control methods include hand pulling, mowing, girdling, and targeted spraying of glyphosate and narrow-spectrum, low-toxicity herbicides. In addition, exotic plant monitoring is included in the North Coast and Cascades Network plan for long-term ecological monitoring.

Sensitive and Rare Plants

Olympic National Forest has 70 sensitive flora species, including 37 vascular plants, 17 fungi, 12 lichens, and 4 bryophytes (mosses). The ONF runs a sensitive species program that includes biological evaluations of proposed actions on national forest lands to avoid and minimize negative impacts on the viability of sensitive species or a trend toward federal listings. The forest develops and implements conservation assessments and other tools for sensitive species, and develops and implements management practices to ensure that species do not become threatened or endangered because of Forest Service actions.

The Olympic Peninsula has the highest concentration of rare plants in Washington, owing to the broad range of habitats and the geographic isolation of the peninsula. Rare plants at ONP include endemics or near-endemics, isolated populations, and species more common to the north (or east). Five of the seven peninsula endemics occur exclusively in subalpine and alpine zones, and the other two species occur from montane to alpine zones (Buckingham et al. 1995). Rare plant conservation actions at ONP include surveys of areas of proposed management or research activities, detailed surveys of distribution, and site-specific protection plans.

Prescribed Fire, Wildland Fire Use, and Hazardous Fuel Treatment

Olympic National Forest conducts slash pile burning for brush disposal and hazardous fuel reduction, and occasionally uses prescribed fire for restoration purposes. For example, in 2005, a prairie restoration burn was conducted in the Skokomish watershed.

The Olympic National Park fire program is directed by a fire management plan, approved in 2005 (NPS 2003). Under the plan, prescribed burning is occasionally used, and fire managers may choose to monitor natural lightning-ignited fires to meet specific objectives. The park must complete a burn plan before any prescribed fire is permitted, and each planned fire must meet a specific set of conditions.

When fire cannot be used, hazardous fuel reduction is done by using manual removal or other means.

Vegetation Monitoring

Vegetation monitoring at ONF includes several different efforts. Botanists conduct rare plant monitoring in association with the University of Washington, Botanic Gardens Rare Plant Care and Conservation Program. Botanists intermittently monitor status of known populations of rare (to ONF) tree species. Silviculturists conduct informal ongoing silvicultural prescription effectiveness monitoring that includes monitoring of treatments such as understory precommercial thinning, commercial thinning, precommercial thinning with skips and gaps (skips are areas without tree harvest within a thinned stand; gaps are areas where all trees are harvested within a thinned stand), tree planting, and logging system effects on vegetation. Annual aerial surveys of insects and disease are also conducted regionally.

Olympic National Park conducts forest monitoring as a part of the National Park Service North Coast and Cascades Network.[2] The goal of this monitoring is to determine trends in tree mortality, recruitment, and growth in forests representing the range of environments in network parks. Attributes monitored include tree species, diameter, indicators of health, and factors contributing to death. Forest ecologists monitor three forest types (Sitka spruce, western hemlock-Douglas-fir, and subalpine fir) in the network in stands at least 80 years old. At this time, subalpine fir forests are monitored at Mount Rainier and North Cascades National Parks but not at ONP.

Forest Thinning Program at Olympic National Forest

Timber harvest activities began on the Olympic Peninsula in the mid 1800s and at ONF in the 1920s. Until the 1990s, timber management generally consisted of clearcutting, broadcast burning, and tree replanting. Douglas-fir was the primary tree species chosen for artificial regeneration. These management practices resulted in the regeneration of over one-third of ONF into relatively young even-aged forests. These resulting plantations and managed forests were designed to maximize the production of wood products and are therefore densely stocked and structurally and compositionally simplified. The 1994 Northwest Forest Plan (NWFP) (USDA and USDI 1994) led to a movement toward management for ecological priorities, mainly the protection, enhancement, and acceleration of late-successional forest conditions. Timber production became a collateral opportunity rather than a primary objective.

Olympic National Forest has instituted a multiple-objective commercial thinning program with the purpose of accelerating the process of late-successional forest development by creating conditions that encourage the growth of a diverse understory and multilayered stand structure. This thinning is conducted primarily in forest stands between 40 and 80 years old that are designated as late-successional reserves (fig. 6.10); stands in this age range are the most economically viable stands to thin given the age limitations under the NWFP in late-successional reserve management. However, thinning in adaptive management areas is concentrated in stands 40 to 120 years old (fig. 6.11). The thinning treatments at ONF are prioritized based on habitat improvement potential for the northern spotted owl, marbled murrelet, and Roosevelt elk; aquatic species needs; and economic considerations. Priority is generally given to young-growth forest located near old-growth forest to increase the area of contiguous late-successional habitat.

To promote structural diversity, tree thinning prescriptions include variable-density thinning (thinning with skips and gaps) and provisions for snags and coarse woody debris for wildlife habitat. The skips (no thinning) are designed to function as small reserves distributed across the treatment area, providing a refuge for plant and animal species sensitive to disturbance. The variation in the landscape created by the gaps and the thinned areas are designed to provide for the habitat needs of other species. When adjusted for

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[2] **Acker, S.A.; Woodward, A.; Boetsch, J.R. [et al.]. [N.d.]** Forest vegetation monitoring protocol for the North Coast and Cascades network. [Natural Resource Report NPS/NCCN/NRR—no. TBD.] Manuscript in preparation. Fort Collins, CO: National Park Service. http://science.nature.nps.gov/im/units/nccn/Reports/Monitoring/NCCN_Monitoring_Plan_20050930.pdf. (12 March 2010).

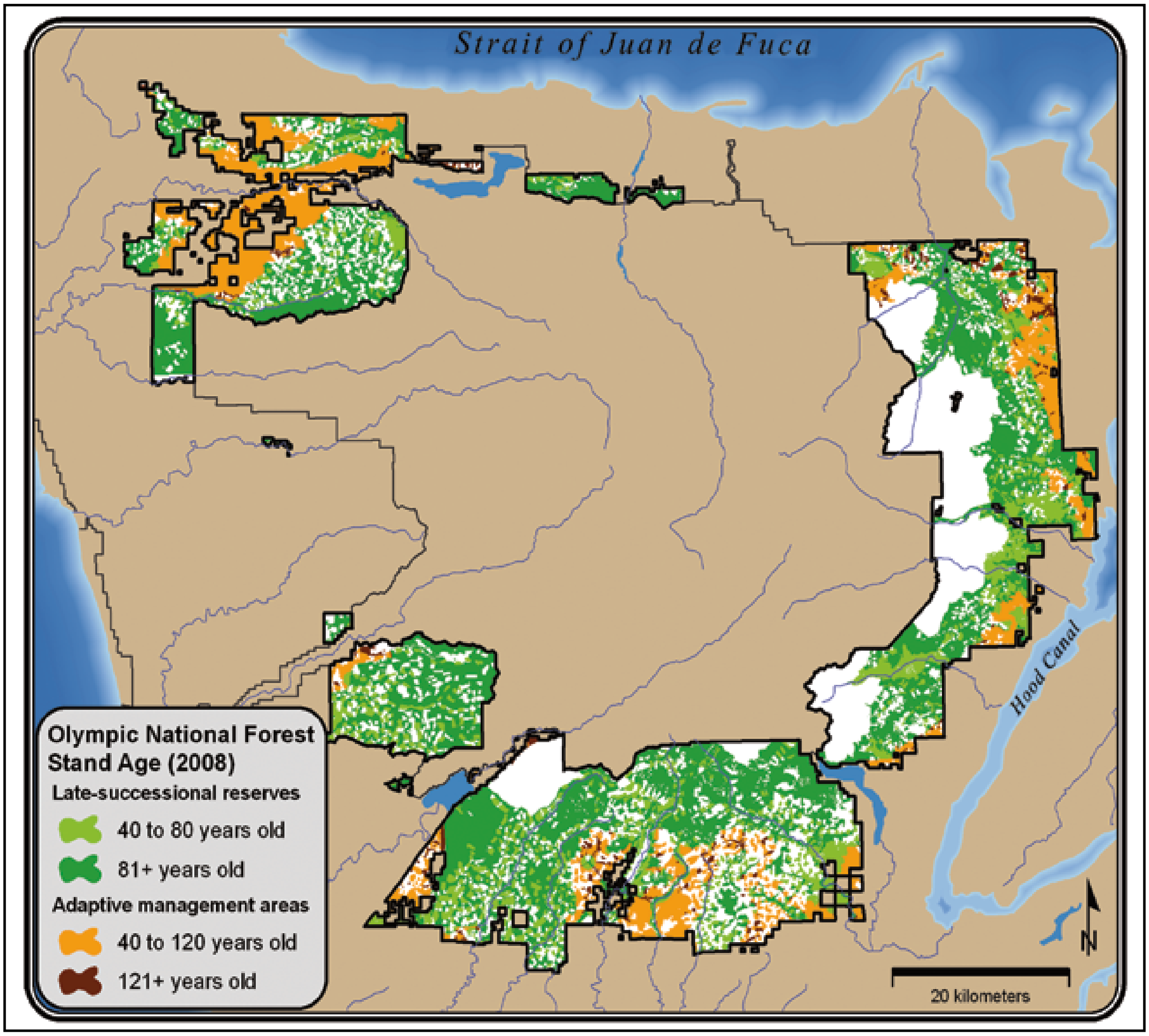

Figure 6.10—Location and age of late-successional reserve (LSR) and adaptive management area (AMAs) stands on Olympic National Forest (ONF). Thinning, with the goals of increasing forest structural diversity and improving wildlife habitat, is one of the primary vegetation management activities on ONF. Thinning on ONF is conducted primarily in LSR forest stands between 40 and 80 years old, as stands in this age range are the most economically viable stands to thin, and thinning in LSRs more than 80 years in age is not permitted. Although thinning is not permitted in LSRs older than 80 years, thinning in AMAs is concentrated in stands greater than 40 but less than 120 years old. Thus, 40- to 80-year old LSR stands (in light green) and the 40- to 120-year old AMA stands (in orange) are the locations where ONF has the most opportunity for active management in adapting to climate change.

tree species, initial tree size, and crown class, variable-density thinning generally increases average tree growth by about 25 percent (Roberts and Harrington 2008). Thinning in young stands is also often associated with improved tree health, vigor, long-term wind firmness, and possibly resilience to climate change. The redistributed sunlight, moisture, and nutrients can also further promote understory vegetative diversity and vigor (Thysell and Carey 2001).

Precommercial thinning at ONF is conducted primarily in single-story stands that are 15 to 35 years old, depending on tree form, tree density, and stand accessibility. Some thinning has also been conducted on understory tree canopy layers in young stands, and skips have also been used.

Figure 6.11—Thinning activities on Olympic National Forest. The forest has instituted a multiple-objective commercial thinning program with the purpose of accelerating late-successional forest development by creating conditions that encourage the growth of a diverse understory and complex multilayered stand structure. (Photo courtesy of USDA Forest Service, Olympic National Forest.)

Figure 6.12—Whitebark pine seedlings tested for resistance to white pine blister rust at Dorena Genetic Resource Center. (Photo courtesy of USDA Forest Service, Olympic National Forest.)

Figure 6.13—Whitebark pine cone collection as a part of the Olympic National Forest gene conservation program. (Photo courtesy of USDA Forest Service, Olympic National Forest.)

This thinning enhances or maintains species diversity by reducing competition around ecologically important minor tree species and other vegetation that would normally be eliminated through suppression mortality by faster growing tree species. In addition, precommercial thinning is used to improve tree growth, vigor, form, and rate of development of late-successional forest characteristics.

Genetic Resources Program at Olympic National Forest

Olympic National Forest established a conifer orchard in 1957 to maintain a seed bank of high-quality seed for use in reforestation and restoration. Orchard trees are grouped in blocks not only by species but also based on seed zones (by elevation, latitude, and longitude) so that collected seed is adapted to the areas in which it is planted. Douglas-fir, Sitka spruce, western hemlock, western white pine, and Pacific silver fir blocks are included. To plant trees resistant to the introduced disease white pine blister rust, western white pine and whitebark pine tree selections are tested through a regional disease resistance program (fig. 6.12). All the white pine seed harvested from the orchard has exhibited disease resistance, and the forest has developed a partnership with the Washington Department of Natural Resources, and the

Quinault Indian Nation to share in orchard management and the seed crop. The forest also maintains an ex situ gene conservation seed collection of Douglas-fir, western white pine, and whitebark pine by individual tree (fig. 6.13). Seed storage by tree allows for maximum flexibility in the creation of custom seed lots for various future applications.

Adapting Vegetation Management to Climate Change at Olympic National Forest and Olympic National Park

Process Used to Develop Adaptation Strategies for Vegetation Management

To develop adaptation strategies for vegetation management on the Olympic Peninsula, the geneticist, silviculturists, and natural resources staff officer from ONF and forest ecologist and other natural resources staff from ONP engaged in a year-long exchange of ideas with scientists from the Forest Service Pacific Northwest Research Station (PNW), University of Washington (UW), and UW Climate Impacts Group (CIG). These exchanges involved discussion of potential impacts of climate change on vegetation on the Olympic Peninsula and discussion of various models that project potential impacts of climate change on vegetation. This exchange contributed to the development of vegetation management strategies described below.

Participants identified limited experience with various models and model output as a challenge for managers in thinking about how to address potential effects of climate change, and as a result, ONF and ONP natural resources staff and UW and PNW scientists met to review various model types, model output, and the strengths and weaknesses of different models. A subsequent workshop focused on reviewing potential vegetation sensitivities to climate change and developing adaptation strategies and actions for vegetation management on the peninsula. Participants in the second workshop included regional scientists and natural resources staff from ONF and ONP. The workshop included a presentation from CIG scientist Jeremy Littell on climate projections for the state of Washington. Other presentations addressed the potential impacts of climate change on vegetation communities (J. Halofsky, UW) and on plant phenology and physiology (Connie Harrington, PNW), as well as current vegetation management at ONF (Carol Aubry) and ONP (Steven Acker). David L. Peterson (PNW) also gave a presentation on developing strategies for adaptation to climate change. The facilitated dialogue between scientists and managers that followed focused on development of adaptation options and action plans for vegetation management at ONF and ONP. The discussion was specifically focused on the following questions: (1) What are the principal vegetation sensitivities (e.g., tree growth, disturbance, geographic locations) on the Olympic Peninsula? (2) What are your priorities for adaptation? (3) Which approaches and techniques would you use to facilitate adaptation? and (4) How might the park and forest collaborate to adapt to climate change? Key points from the discussion are described in the section below and in table 6.2. See box 6.2 for a general summary of projected climate change effects on vegetation on the Olympic Peninsula and related adaptation strategies for vegetation management at ONF and ONP.

Key Vegetation Sensitivities With Climate Change on the Olympic Peninsula

Workshop participants identified several vegetation assemblages on the Olympic Peninsula, and the species that inhabit them, as being particularly sensitive to climate change. Establishment of trees and other woody species will likely increase with warming and decreased snowpack in subalpine and alpine meadows (Zolbrod and Peterson 1999). Tree encroachment and increased establishment of lower elevation species in alpine and subalpine plant communities may put some species that currently inhabit these locations at risk, especially rare and relict species. Warming temperatures and changes in hydrology with climate change could have significant impacts on moisture levels and species composition in wetlands on the peninsula, especially bogs and fens (Burkett and Kusler 2000). Increased drought stress and disturbance frequency may also put Sitka spruce rain forests at risk for compositional change (Holman and Peterson 2006, Nakawatase and Peterson 2006).

Changing disturbance regimes with climate change will likely affect vegetation on the Olympic Peninsula. Storm intensity is projected to increase (Salathé et al. 2010),

Table 6.2—Current and expected vegetation sensitivities to climate change on the Olympic Peninsula, and associated adaptation strategies and actions for vegetation management at Olympic National Forest (ONF) and Olympic National Park (ONP)[a]

Current and expected vegetation sensitivities to climate change	Adaptation strategies and actions
Increased opportunity for exotic species establishment	• Continue to implement early detection/rapid response for exotic species treatment (ONF). • Increase exotic species control efforts (ONP). • Continue to exchange information on exotic species spread and control between ONF and ONP.
Potential for mortality events and regeneration failures, particularly after large disturbances	• Develop a gene conservation plan for ex situ collections for long-term storage. • Identify areas important for in situ gene conservation. • Maintain a tree seed inventory with high-quality seed for a range of species, particularly species that may do well in the future under hotter and drier conditions. • Increase production of native plant materials for postflooding plantings.
Increased forest drought stress and decreased forest productivity at lower elevations	• Consider increasing the amount of thinning and possibly altering thinning prescriptions to reduce forest drought stress (ONF). • Use girdling, falling and leaving trees, prescribed burns, and wildland fire (ONP) to reduce stand densities and drought stress. • Maximize early successional tree species diversity by retaining minor species during precommercial thinning activities to promote greater resilience to drier conditions. • Consider including larger openings in thinning prescriptions and planting seedlings in the openings to create seed sources for native drought-tolerant species.
Altered ecosystem structure and potential disruption of process and function	• Prioritize actions that will help maintain ecosystem function. • Focus on actions that will help minimize mass die-off and effects of major disturbances. • Create structures and processes that are viable over the long term.
All of the above	• Conduct integrated and consistent inventory and monitoring of vegetation. • Focus monitoring on sensitive locations such as wetlands and high elevations, on endemic or at-risk species, and on plant phenology. • Use feedback from monitoring in implementation of adaptive management.

[a] Sensitivities are based on projected climate change effects on Olympic Peninsula, including decreased summer soil moisture, changing patterns of vegetation establishment, growth and mortality, shifting species distributions, shifting phenology, increased fire frequency, increased winter flood frequency and magnitude, and potential for increased insect outbreaks.

potentially leading to increased frequency of landslides and windthrow. Fire frequency and extent are projected to increase on the peninsula (see MC1 model output figs. 6.6–6.8). There is potential for more frequent and more severe disturbances owing to insects, including mountain pine beetle (Littell et al. 2010), and possibly Douglas-fir

Box 6.2—Summary of projected climate change effects on vegetation on the Olympic Peninsula and related adaptation strategies for vegetation management at Olympic National Forest Olympic National Park

- Increased temperatures with climate change, and corresponding increases in summer drought stress and fire frequency in the Pacific Northwest, will lead to changing species distribution in the region, resulting in forest types different from those we see today.
- Increased temperatures with climate change will lead to longer growing seasons on the peninsula, which will alleviate growth-limiting factors and likely result in increased growth and productivity in high-elevation forests.
- Increased drought stress with climate change will likely result in decreased tree growth and forest productivity in the northeastern forests of the Olympic Peninsula.
- Paleoecological (pollen and fossil) records from the Pacific Northwest and elsewhere show that during historically warm periods, many tree species moved poleward and upward in elevation, suggesting that on the Olympic Peninsula, species distributions will shift to higher elevations with warming.
- With warming on the Olympic Peninsula, warmer and drier conditions at lower elevations will likely result in expansion of the range of Douglas-fir and lodgepole pine.
- Increased temperatures and drought occurrence with climate change will likely lead to increased fire frequency and extent on the Olympic Peninsula, particularly in the northeastern portion.
- Species phenology, or timing of life history events, is also likely to shift in response to climate change on the peninsula.
- Olympic National Forest (ONF) and Olympic National Park (ONP) identified alpine and subalpine meadows, wetlands, and Sitka spruce rain forests as being particularly vulnerable to warming climate.
- Both the forest and park affirmed the maintenance of functioning ecosystems in the face of climate change as a primary goal to continue to provide ecosystem services. Management actions that will help to maintain ecosystem function, such as restoration activities that create structures and processes that are viable over the long term, will be prioritized, when possible.
- To conserve genetic resources, ONF will maintain a tree seed inventory with high-quality seed for a range of species, especially those that are adapted to a drier climate or greater variation in climate, and will develop a plant conservation framework for forest trees and habitats at risk under changing climate that includes a plan for ex situ seed collection.
- Both the forest and park will be prepared to treat increases in exotic plant species after disturbances by continuing to implement the early detection, rapid response program.
- The forest and park will work to conduct more integrated and consistent inventory and monitoring of vegetation.
- At ONF, increasing the amount and prioritization of thinning activities in forest stands could potentially increase resilience to climate change, because thinning can increase water availability and tree growth and vigor by reducing competition.
- At ONP, prescribed fire and wildland fire in wilderness could be managed to reduce stand density and drought stress.

beetle, and balsam woolly adelgid (Mitchell and Buffam 2001). Increases in these disturbances will increase opportunities for exotic species establishment (Joyce et al. 2008). Disturbances may also interact to drive ecosystem change (McKenzie et al. 2009).

Changes in plant phenology (Parmesan 2006), increased drought stress (Elsner et al. 2010, Littell et al. 2010), and changing disturbance regimes (Littell et al. 2010) could lead to significant changes in plant regeneration patterns on the Olympic Peninsula. Workshop participants suggested that propagule production could be reduced owing to a warmer climate and associated stresses. In addition, site availability for seedling establishment may be limited under changing climate; an increase in tree mortality could result in increased cover of clonal species such as salal, which can limit opportunities for other species to become established. However, warming may lead to increased fire frequency (Littell et al. 2009, Westerling et al. 2006), which will likely increase opportunities for seedling establishment, including seedlings of species that were not dominant on a site before a fire event. Changes in regeneration patterns may lead to changing distribution and abundance of currently common species on the peninsula, leading to changes in ecosystem structure and function.

Goals and Priorities for Adaptation in Vegetation Management

Both ONF and ONP affirmed the maintenance of functioning ecosystems in the face of climate change as a primary goal to continue to provide ecosystem services. Management actions that will help to maintain ecosystem function will be prioritized, when possible. Examples include actions to help minimize extensive tree mortality and effects of major disturbances, and restoration activities that create structures and processes that are viable over the long term. In addition, restoration planning will consider the functional role of species and habitats. For example, Sitka spruce may serve the same functional role as Douglas-fir in terms of stand structure (large trees or wood, or both) but not in terms of seed production and type of seed for wildlife (Peter and Harrington 2010).

Biodiversity is the sum of species, ecosystem, and genetic diversity (Lovejoy and Hannah 2005). Maintenance of native plant biodiversity is an ongoing priority for ONF and ONP and includes such actions as protection, restoration, and monitoring of rare plant species or populations; planting a variety of species; and in situ and ex situ gene conservation. However, it is unclear which levels of biodiversity should be maintained in a changing climate. The definition of exotic species will also need to be reexamined periodically, and possibly modified, because of shifting species distribution with climate change. The definition of exotic species will likely influence how vegetation and biodiversity are managed with climate change.

Adaptation Strategies and Actions for Vegetation Management at Olympic National Forest and Olympic National Park

Olympic National Forest will implement the following actions to maintain biodiversity and increase ecosystem resilience. These actions are likely to be effective under a variety of possible future scenarios.

- Maintain a tree seed inventory with high-quality seed for a range of species. One way to maintain seed inventory for tree species is to collect seed from the ONF conifer seed orchard, where seed is collected and stored by individual tree or by seed zone to maximize flexibility.
- Working in partnership with ONP and other land managers, develop a plant conservation framework for forest trees and habitats at risk under changing climate, with an emphasis on nontree species associated with those habitats. An essential component of the framework will be a gene conservation plan for ex situ seed collections for long-term storage, including seed collections from rare species and encompassing the range of variation in widespread species. New areas that may become important for in situ gene conservation will be identified. Forest tree species will be evaluated for relative sensitivity to climate change, and tools and options, such as assisted migration, will be reviewed. A 5-year action plan will be the result of this effort.
- Continue to increase disease resistance in western white pine and whitebark pine. Both of these species are threatened by white pine blister rust, which has caused mortality and reduced vigor in susceptible conifer hosts in many parts of the Western United States (McDonald and Hoff 2001).
- Increase the capacity to restore forest lands after large disturbances:
  - Increase seed production and storage for native tree species that are adapted to a drier or more variable climate. Lodgepole pine, western white pine, western redcedar, and Oregon white oak are candidate species.
  - Be prepared to treat increases in exotic plant species after disturbances by continuing to implement the early detection/rapid response program.
  - Be prepared to seed/plant appropriate native plant species after flooding by increasing the ONF native plant materials program.

Monitoring will be critical in detecting changes in phenology and plant species regeneration, growth, and mortality on the peninsula with changing climate (Joyce et al. 2008). Both ONF and ONP currently conduct vegetation inventory and monitoring, but the forest and park will conduct more integrated and consistent inventory and monitoring of vegetation. Monitoring can be focused on sensitivities identified through expert knowledge of Olympic Peninsula vegetation and climate-sensitive vegetation model projections (such as MC1 projections described previously). For example, monitoring could be focused on sensitive locations such as wetlands and high elevations, on endemic or at-risk species, and on plant phenology (both vegetative and reproductive events). Identifying species and ecosystems that are most susceptible to climate change through monitoring can inform prioritization of protection and restoration activities.

Control of exotic species will maximize the resilience of native vegetation on the peninsula with changing climate (Joyce et al. 2009). The ONF will continue to implement their strategy of early detection/rapid response for exotic species treatment, and ONP will increase exotic species control efforts. Treatment of species that have the potential to delay development of desired forest structure will be prioritized. For example, treatment of Japanese knotweed may be prioritized because this species prevents establishment of conifers in riparian forests and thus has a negative effect on coarse wood input to streams and on stream habitat quality. The ONF and ONP could undertake an explicit process to identify desired future forest structure and composition in different locations. The forest and park will also continue to exchange information on exotic species spread and control.

Thinning forest stands at ONF is another potential way to increase resilience to climate change, because thinning can increase water availability and tree growth and vigor by reducing competition (Roberts and Harrington 2008). The ONF currently has a forest thinning program focused on promoting late-successional forest conditions and improving wildlife habitat in young-growth stands, which could help to increase forest and wildlife resilience to climate change. Approximately 0.7 percent of the young-growth stands on the forest are treated annually, and increasing the amount of thinning could help to further increase resilience to climate change. However, funding for thinning at ONF is limited, and ONF has limited options on where thinning can occur owing to restrictions under the NWFP (fig. 6.10).

In addition to considering an increase in amount of thinning, shifting the strategy in placement of thinning treatments could help to increase broad-scale resilience to climate change. Thinning treatments could be prioritized in locations where climate change effects, particularly increased summer drought, are expected to be most pronounced. Thinning for climate change resilience may also require changes in thinning prescriptions, primarily decreases in forest density and increases in gap size to provide for establishment and vigorous growing conditions for desired tree, shrub, and herbaceous species.

Currently, many unthinned young-growth forests at ONF are characterized by high intertree competition, low tree and plant species diversity, low structural complexity, and declining structural stability (as compared to unmanaged old-growth forests) (Roberts and Harrington 2008). In young-growth forest stands under age 35, tree thinning could be used to reduce intertree competition that causes reductions in species diversity and suppression mortality and stress on trees. This thinning would be conducted to maximize tree growth and vigor by utilizing a uniform thinning with some skips to provide variation in understory growing conditions. This prescription could increase early successional tree species diversity by favoring retention of minor tree species regardless of their size. A wider range of tree species and more complex forest structure may provide resilience to a broader range of climatic conditions (Puettmann et al. 2009).

If the severity of wind events increases with climate change, thinning activities can initially result in increased wind damage until the trees become adapted to the new environment (Roberts et al. 2007). However, over the long term, thinning of young growth can improve tree resistance to wind damage by decreasing tree height-to-diameter ratios (an indicator of the slenderness or taper of a tree bole) (Cremer et al. 1982). Uniformity of young-growth size and density, owing to their even age and high stocking, reduces the rate of crown differentiation, resulting in high height-to-diameter ratio development (Mitchell 2000, Roberts et al. 2007). Forests developing at these higher densities and located in wind-exposed areas may be too structurally unstable to survive disturbance to old age.

In young-growth forest stands over age 40, thinning could be used to increase structural stability, individual tree vigor, and variability in overstory and understory growing conditions to improve resilience of vegetation to climate change. An initial commercial thinning entry could be used to reduce intertree competition and maximize individual tree growth and vigor. A second commercial thinning entry could be implemented 10 to 20 years later and use variable-tree spacing with skips and gaps. This would likely further release individual trees from competition and provide variability in growing conditions for understory vegetation to improve plant vigor and increase plant diversity (Carey and Wilson 2001).

To favor some of the tree species that may increase in abundance with climate change, such as relatively shade-intolerant western white pine, thinning prescriptions may include larger openings than those created in past thinnings. The ONF could also plant trees in openings to create seed sources for native species expected to increase in abundance with climate change.

Other tools can also be used to improve vegetative growth and vigor by increasing water availability. Within wilderness areas of ONF and ONP, managers employ minimal active management to protect wilderness values and ecosystem processes. In this context, ONP will focus on managing wildland fire in wilderness to create gaps and reduce stand density. In addition, at both ONF and ONP, girdling and prescribed burns could be used to reduce stand density and thus drought stress. To improve wildlife habitat, girdled, thinned, and fire-killed trees can be left as structure rather than being removed.

Key Questions and Future Directions

Climate change is one of many factors that must be considered by managers at ONF and ONP. Thus, projects will not be focused on climate change alone. However, expected effects of climate change can be incorporated into management strategies and the project planning process.

Climate change adaptation in vegetation management is essentially a long-term management experiment. Many of the proposed changes in vegetation management discussed above, such as the potential changes in thinning prescriptions, will provide opportunities to implement adaptive management, where feedback from monitoring provides direction for future management. It will be necessary for ONF and ONP to continue to support research, conduct monitoring, and develop tools to address effects of climate change. For example, a sensitivity rating for vegetation based on expected compositional changes could be developed to prioritize management actions. Identifying important triggers for life history events will also be critical in predicting likely vegetation change. These triggers will inform decisions in the future on such activities as assisted migration of plant species that are not currently found on the Olympic Peninsula. Until that time, ONF and ONP will work to increase ecosystem resilience and maintain ecosystem function by using the strategies and actions that have been outlined here.

Acknowledgments

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Chapter 7: Climate Change, Wildlife Management, and Habitat Management at Olympic National Forest and Olympic National Park

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Potential Climate Change Effects on Wildlife on the Olympic Peninsula

Although wildlife, or native animals, have some ability to cope with changing climate, human-caused climate change, in combination with other stressors to wildlife such as habitat loss and fragmentation, can greatly affect wildlife species and biodiversity (Hannah et al. 2005, Inkley et al. 2004). Similar to plant species, wildlife species will respond individualistically to climate change, with some species responding negatively and some positively. Species will respond to both direct and indirect effects of climate change. For example, increasing temperatures and changing precipitation will have direct physiological effects on some species. Other species will be affected mostly indirectly through climate-induced changes in phenology (timing of life history) relative to forage plants and invertebrate prey; shifts in geographic ranges and the density and ranges of competitor, forage, prey, and symbiotic species (and subsequent changes in biotic interactions); and effects from other stressors such as disturbance, insects, and disease. Related changes in habitat characteristics and quality will affect animal species viability. These effects will interact with existing stressors, leading to complex responses of wildlife populations to changing climate.

Change is already evident in some wildlife species in response to warming over the last few decades. Changes in species physiology, distribution, and phenology are widely documented and directly attributed to recent warming (Parmesan 2006, Parmesan and Yohe 2003, Root et al. 2003). These recent responses, along with past responses evident in the paleoecological record, and existing knowledge of species physiology and biogeography, can help in projecting how wildlife species will respond to future climate change. By using these lines of evidence, we discuss the potential direct and indirect effects of climate change on wildlife species and populations on the Olympic Peninsula and summarize potential climate change effects on Olympic Peninsula habitats.

Direct Effects of Climate Change on Wildlife

Climate change will lead to warmer temperatures and likely drier summers on the Olympic Peninsula, and these changes will have direct physiological effects on some species. Many species on the peninsula rely on specific microhabitats or microclimates to maintain metabolic functions within physiological parameters. Structural habitat components that mediate microclimate include forest canopy that reduces evaporation and solar radiation; large decaying logs, hollow snags, and leaf litter; and alpine

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environments in which slope, aspect, geologic attributes, and microtopography are controlling factors. Changes in the macroclimate or macrohabitat could either place more importance on these features or negate their ability to meet an animal's needs. For example, species such as the American marten (See "Common and Scientific Names") rely on thermal cover provided by snow in subalpine and montane habitats during winter (Buskirk et al. 1989, Taylor and Buskirk 1994). Reduced snowpack on the Olympic Peninsula because of climate change (Elsner et al. 2010) could expose the marten and other species to lethally cold temperatures during winter.

Bats also rely on specific microclimates in winter hibernacula. Hibernating bats require a cool, stable temperature in the winter to maintain a reduced metabolic rate (Brigham 1993, Fenton 1983, Fenton and Barclay 1980). Bats that either delay entering winter torpor because of higher ambient temperature or are aroused from torpor early because of unseasonably warm weather patterns could face energetic stress if insect prey is unavailable at those times (Humphries et al. 2002).

Endothermic (warm-blooded) species, such as birds and mammals, may have to expend more energy to maintain constant temperature (homeostasis) with higher ambient temperatures in the summer months (Root and Hughes 2005). Thus, higher temperatures may lead to changes in endothermic species' microhabitat choices (e.g., increased retreat to shady habitats) during the summer. However, warmer winters and springs will likely result in less thermal stress on some species. Furthermore, changes in the spatial distribution of preferred habitat (with specific vegetation structure and species composition) will likely have a more direct effect on vertebrate species spatial distribution than on behavioral changes that are directly related to temperature.

Ectothermic (cold-blooded) species, such as reptiles, may benefit from increased temperatures on the peninsula because the peninsula has a relatively cool environment, and reptiles rely on the environment to warm themselves. Other ectothermic species, such as amphibians, rely on cool, moist microhabitat conditions to prevent overheating and desiccation. High temperatures can be lethal to amphibians, but amphibian species are generally adapted to a range of temperatures typical for their environment, making direct mortality from high temperatures rare (Carey and Alexander 2003). However, the amount and timing of precipitation can greatly affect the yearly reproductive output of an amphibian population (Carey and Alexander 2003). For example, because most amphibians lay eggs in standing water (Duellman and Trueb 1985), too little rainfall can result in egg and larval desiccation (Carey and Alexander 2003). At the opposite extreme, too much precipitation at certain times during egg and larval development can lead to egg and larval mortality (Carey et al. 2005). Adult terrestrial amphibians are also susceptible to desiccation because of high rates of water loss from the skin and respiratory systems (Shoemaker et al. 1992). Survivorship may further decline during severe drought because low moisture levels can limit amphibian activity, mobility, ability to evade predators, and food supply (Carey and Alexander 2003).

These examples illustrate that the extremes in temperature and precipitation, rather than the means, often have major effects on animal species. Because events such as drought and intense precipitation are expected to increase on the Olympic Peninsula, species will need to cope with increased frequency of extreme events. The Olympic torrent salamander (fig. 7.1), Cascades frog (fig. 7.2), and Van Dyke's salamander are examples of species that may be directly affected by extremes in temperature and precipitation, and related changes in hydrology.

Indirect Effects of Climate Change on Wildlife

Phenological shifts—

Warming temperatures with climate change will likely alter seasonal climate patterns. For example, on the Olympic Peninsula and in temperate ecosystems in general, climate change will likely result in earlier snowmelt, a shorter winter season, earlier onset of spring, and a longer growing season (Elsner et al. 2010, Menzel et al. 2003). Plant and animal life cycles are closely linked with changing seasons, and changes in seasonality with climate change will likely lead to altered phenology, or timing of life history events, of both plant and animal species. These phenological shifts

Figure 7.1—The Olympic torrent salamander is endemic to the Olympic Peninsula and is an example of a species that will likely be sensitive to extremes in temperature and precipitation, and related changes in hydrology, with climate change. (Photo by Betsy Howell, USDA. Forest Service, Olympic National Forest.)

Figure 7.2—The Cascades frog will likely be sensitive to changes in hydrology and wetland habitats that occur with climate change on the Olympic Peninsula. (Photo by Betsy Howell, USDA Forest Service, Olympic National Forest.)

will likely influence wildlife, their food sources, and habitat attributes on the Olympic Peninsula.

Animal life history events that can be affected by changing seasonality include emergence from hibernation, mating, and migration. Plant species also respond to changing seasonality by shifting the timing of bud break, flowering, and fruiting, and insects respond by varying timing of emergence. However, the shifts in timing of life history events between trophic levels (e.g., plants, herbivores, predators) may not be proportionate or parallel. Varied phenological response to warming between trophic levels could result in mismatches in formerly coordinated phenology of animals and their food sources, leading to decreasing fitness and possibly mortality in some wildlife populations (Both et al. 2006, ISAB 2007, Parmesan 2006, Root and Hughes 2005). For example, for species that have specialized diets and carefully balanced energy budgets, such as bats, a shift in the timing of invertebrate prey availability could result in reduced survival or fecundity.

Concurrent with a 1.4 °C rise in local temperatures at the Rocky Mountain Biological Laboratory in Colorado between 1975 and 1999, yellow-bellied marmots began emerging from hibernation about 23 days earlier (Inouye et al. 2000). However, the flowering plant phenology did not shift in that period because warmer temperatures were coupled with increased precipitation and snowpack. Thus, the change in marmot behavior decoupled the relative phenology of marmots and their food plants (Inouye et al. 2000). Analogous mismatches could occur on the Olympic Peninsula. In contrast to the Colorado example, however, warmer temperatures on the Olympic Peninsula will likely lead to decreased snowpack, regardless of changes in precipitation, owing to the relatively warm conditions on the peninsula (Elsner et al. 2010). Thus, plant emergence and growth could remain synchronous with emergence of the Olympic marmot (fig. 7.3) and other hibernating wildlife species. Shifts in timing of migration could also impair foraging efficiency of some species. For example, some bird species are arriving earlier at summer breeding grounds in response to warming in the second half of the 20th century (Butler 2003, Inkley et al. 2004, Inouye et al. 2000, Sparks 1999, Tryjanowski et al. 2002). However, food resources at summer breeding grounds may not be as available earlier in the spring (Inouye et al. 2000) because warming patterns differ spatially and species respond individualistically to changing climate.

Changes in seasonality could also influence habitat suitability. For example, some amphibians produce eggs and move to breeding ponds based on temperature and moisture.

Figure 7.3—The Olympic marmot is endemic to the Olympic Peninsula. Warming temperatures with climate change will likely reduce snowpack and alter forage species composition and phenology in the alpine and subalpine habitats that marmots inhabit. (Photo by Betsy Howell, USDA Forest Service, Olympic National Forest.)

These species may encounter mismatches between breeding phenology, pond drying, and arrival at the pond (WGA 2008).

Examples of species shifting phenology in response to climate change in the late 20th century are not isolated (ISAB 2007). Rather, substantial evidence exists that phenological shifts are already underway for a variety of plant, animal, and insect species (e.g., Parmesan 2006, Parmesan and Yohe 2003, Root et al. 2003, Walther et al. 2002,). A meta-analysis by Parmesan and Yohe (2003) concluded that most of 677 species studied show trends toward spring advancement in the last few decades, with earlier frog breeding, bird nesting, first flowering, tree budburst, and arrival of migrant birds and butterflies. These consistent and directional responses to warming of about 0.6 °C (Pachauri and Reisinger 2007) over the last century suggest that there will be even more far-reaching effects on species as the climate warms at an increasing rate (Root et al. 2003). Although quantitative data on phenological shifts on the Olympic Peninsula are lacking, peninsula species likely have and will be similarly affected by increasing temperatures.

Distribution shifts—

Species occurrence (range) partially depends on the availability of suitable climatic conditions, along with other factors such as habitat suitability, food availability, and interactions with other species (MacArthur 1972). Wildlife species respond to climate and habitat variability in the short term through shifts in geographic range (migration) when suitable conditions are not present in the former range. Where suitable climates and habitat are no longer present, mortality and local population contraction and extirpation often occur in parts of a species' former range (Grayson 2006). For example, contraction or local population extirpations may occur at the southern end of a species range with warming, while at the same time, there are increases in northward colonization. Over time, extirpation and colonization events cumulatively result in shifts of species' distribution ranges. Shifts in animal species' geographic ranges owing to physiological constraints and changes in plant species distribution and habitat structure, as well as shifts in the abundance and phenology of associated species (competitors, predators, prey, and forage species) will interact to determine how climate change affects species and communities.

Species ranges will probably move northward and to higher elevations as temperature increases (Parmesan 2006). However, range shifts will depend on factors such as degree and speed of vegetation change, specific habitat conditions, shifts in distribution of competitors and predators, changes in precipitation patterns, species' physiological requirements, and species' differential sensitivity and response to various aspects of changing climate (e.g., increase in minimum temperature versus maximum temperature) (Inkely et al. 2004). The ability of wildlife species to disperse or migrate will depend on the availability of migration corridors and suitable habitats, and the concurrent movement of forage, prey, and cover (Inkely et al. 2004). For example, high-elevation species will likely be particularly sensitive to warming temperatures and experience range contractions (Moritz et al. 2008) because contiguous, higher elevation habitat may not be available to colonize. Soil formation at higher elevations is a slow process, and vegetation establishment at higher elevations may not occur quickly enough to provide habitat under rapid warming. Snowpack at higher elevations may also be prohibitive. Similarly, it may be more difficult for endemic and specialist species with strict habitat requirements or dependencies on specific forage species to find suitable habitat conditions under changing climate, whereas generalist species with high climatic tolerance, broad habitat and forage requirements and high dispersal ability will likely increase in abundance under a changing climate (Pounds et al. 2005). Barriers such as topographic features and habitat fragmentation could further inhibit potential range shifts (Inkley et al. 2004). For example, the Strait of Juan de Fuca will inhibit northward movement of terrestrial species on the peninsula, although new species could move onto the peninsula from the south.

Recent observed shifts in species ranges are consistent with those expected under a warming climate, and examples of shifts in species ranges from around the world are numerous (Parmesan 2006, Parmesan and Yohe 2003, Root et al. 2003, Walther et al. 2002). An analysis of recent range shifts of 99 species of birds, butterflies, and alpine herbs in the Northern Hemisphere showed an average shift in species' range boundaries of 6.1 km northward or 6.1 m upward in elevation per decade (Parmesan and Yohe 2003). Similarly, an analysis of 40 years of Audubon Society Christmas Bird Count observations showed that 177 of 305 bird species seen in North America during the first weeks of winter have moved northward (Audubon 2009). The average distance moved was 56 km, but more than 60 species moved more than 160 km north. Annual altitudinal shifts were correlated with annual temperature.

There is also evidence that small mammals are shifting their ranges in response to warming; an analysis by Moritz et al. (2008) in Yosemite National Park showed that half of 28 small mammal species monitored over the last century shifted their elevation limits upward an average of about 500 m, consistent with the observed warming trend in the region. As expected, range shifts are associated with population losses for some species, and other species' extinctions are attributed to recent climate change (Beever et al. 2003; Parmesan 1996; Pounds et al. 1999, 2006). Moritz et al. (2008) found that range contractions were more likely for high-elevation small mammal species, whereas range expansions were more likely for lowland species that are short lived and more productive than their long-lived, less fecund counterparts.

Some Olympic Peninsula species will probably respond similarly to increasing temperature by shifting their ranges upward in elevation. The degree and rate of species' distribution changes will depend on several factors, including species' physiological constraints, the speed and nature of vegetation change, habitat suitability, barriers to dispersal, and interactions with other species. For subalpine meadow and alpine meadow habitat specialists such as the Olympic marmot (fig. 7.3), western heather vole, and Olympic pocket gopher, there may not be any suitable habitat conditions available at higher elevations. These species are found at the highest elevations of many ridge systems; on other ridge systems or mountains, these species will not be able to survive unless snowpack is sufficiently low in summer and deep soils and meadow vegetation develop. However, declines in snowpack with warming will be lower at the highest elevations (>2000 m): (Elsner et al. 2010), and soil development may take decades to centuries. Furthermore, it is not clear if these rodents will be able to establish new populations if there are barriers to their dispersal.

Biotic interactions—
As species individualistically shift their ranges in response to a warming climate, novel predator-prey interactions and new interspecific interactions will develop among species (ISAB 2007, Schmitz et al. 2003). Predicting future interspecific interactions is very difficult, although clearly new interspecific interactions, as with all climate change effects, will positively affect some species and populations, and negatively affect others. For example, movement of a predator out of portions of a prey species' range will allow the prey species to expand but may reduce predator fitness owing to decreased prey availability. In contrast, the movement of a predator into new areas could negatively affect prey species. The range expansion of the coyote into high-elevation areas on the peninsula, for example, may be having a negative impact on Olympic marmot (fig. 7.3) populations (Griffin et al. 2008, Witczuk 2007). Bobcat

populations could have similar effects on prey species if they begin spending more time at higher elevations with warming temperatures and reduced snowpack. Movement of competitors could also influence species abundance and viability. Although not necessarily related to climate change, the negative influence of the barred owl (native to North America but relatively new to western North America) on the specialist northern spotted owl is a good example of how new competitive interactions can lead to pronounced effects on species distributions and viability (Kelly et al. 2003).

Changes in interspecific interactions with climate change will include changing interactions with exotic species, as well as pests and pathogens. New exotic species will likely establish with changing climatic conditions (Hellmann et al. 2008). Some existing exotic species will likely expand with climate change, because ecosystem disturbance and shifts in native species ranges will provide opportunities for exotic establishment. Some exotic species are invasive, with characteristics that facilitate their expansion and dominance under changing climate, such as broad climatic tolerances and high dispersal ability (Hellmann et al. 2008).

Parasites, pests, and pathogens are also expected to respond to climate change. Forest pests and pathogens could have widespread effects on wildlife habitat quality on the peninsula (see chapter 6 for more details). Increased temperatures and moisture at mid-latitudes could accelerate parasite vector and pathogen life cycles, improve survival by relaxing overwintering restrictions, and lead to northward expansion of tropical and subtropical pathogens (Harvell et al. 2002, Inkley et al. 2004). Shifting ranges of wildlife species will lead to new disease exposures (Brooks and Hoberg 2007), and shifts in parasite vectors will introduce new diseases (Kovats et al. 2001, WGA 2008). Climate warming can also increase host susceptibility to diseases (Harvell et al. 2002). Increases in parasites and infectious diseases associated with climate change have the potential to influence the size of wildlife populations and accelerate species extinctions (Harvell et al. 2002, WGA 2008).

Interaction with other stressors—

Climate change will not act alone in influencing wildlife populations on the Olympic Peninsula in the coming decades. Instead, climate change will act synergistically with other stressors to affect wildlife populations (Inkley et al. 2004, WGA 2008). Current stressors that influence wildlife on the peninsula and many ecosystems across the Western United States include land use legacies, ongoing habitat loss and fragmentation, altered disturbance regimes, disease, and exotic species. Land use changes and introduction of exotic species can impede the ability of species to adaptively respond to climate change (Hansen and DeFries 2007). For instance, many land use changes impose barriers to species' migration to favorable new environments, small population sizes and isolation resulting from land uses impedes gene flow, and landscape fragmentation reduces corridors for movement (Joyce et al. 2008). At Olympic National Forest (ONF), historical widespread logging activity reduced the area of late-successional forest and isolated existing late-successional forest patches, which could impede adaptive response of species with low dispersal ability. Highways and land converted to agricultural, residential, or industrial uses further fragments the Olympic Peninsula. The spread of exotic species on the peninsula may cause a reduction in forage plants on which some wildlife species depend, thus making it more difficult for these species to respond adaptively to climate change. These interactions increase uncertainty and complicate actions to mediate climate change effects, but also suggest that treatment of other stressors (e.g., exotic species and habitat fragmentation) may help alleviate the negative effects of climate change.

Potential Genetic Responses to Climate Change

It is possible that wildlife species will respond to changing climate through genetic change. However, the expected rates of increase in temperature with climate change are greater than those of the past, making it difficult to predict genetic response (ISAB 2007). Evidence exists for adaptive genetic change in some species in response to changing climate, including mosquitoes, fruit flies, birds, and squirrels (Bradshaw and Holzapfel 2006, ISAB 2007). The adaptive genetic changes all involved adaptation to the timing of seasonal events or to season length (Bradshaw and Holzapfel 2006). In mosquitoes, which have the shortest generation times of this group, evolutionary change occurred in as little as 5 years. Changes for squirrels and birds were smaller and became apparent only over longer periods (10 to 30 years), suggesting that larger and longer lived species may experience population decline or be replaced by other species (Bradshaw and Holzapfel 2006). Habitat fragmentation and resulting population isolation that prevents gene flow is a barrier to this type of genetic response. Although such evolutionary responses occur, there is little evidence that the responses are of the type or magnitude to prevent species extinctions (Parmesan 2006), because the rate and magnitude of climate change may overwhelm a species' capacity for genetic change (Barnosky and Kraatz 2007).

Potential Climate Change Effects on Olympic Peninsula Habitats

Related to the potential direct and indirect effects of climate change on wildlife, there are also many potential climate change effects on wildlife habitats on the Olympic Peninsula. A description of potential effects of climate change on Olympic Peninsula habitat types and related species follows (see chapter 6 for more detailed information on potential vegetation changes).

Varied climatic conditions on the peninsula result in highly varied ecological communities, and thousands of years of geographic isolation have resulted in fauna that are distinct from those in the Cascade Range to the east. There are several endemic wildlife species, including the Olympic marmot (fig. 7.3), the Olympic pocket gopher, and Roosevelt elk. Wildlife on the Olympic Peninsula is noteworthy not only for its endemic species, but also for species missing from the Olympics yet found elsewhere in western mountains, including American pika, white-tailed ptarmigan, ground squirrels, Canada lynx, red fox, wolverine, grizzly bear, and bighorn sheep. Historically, mountain goats and coyote did not occur on the Olympic Peninsula.

Glaciers and snowfields—

At the highest elevations on the Olympic Peninsula, warming temperatures will likely cause loss of snowpack and snowfields and recession of glaciers (Elsner et al. 2010). The greatest effects of reduced snowpack and glacial recession will be hydrologic; loss of glaciers, decreased snowpack, and earlier snowmelt with warming temperatures will reduce water availability in summer months in glacier- and snowmelt-fed streams, lakes, and wetlands (Elsner et al. 2010). Although glaciers and snowfields currently provide habitat for only a few species, such as the gray-crowned rosy finch, the loss of snowpack with warming may allow vegetation establishment in these areas, leading to improved habitat conditions for other high-elevation wildlife species. In the short term, vegetation establishment will be limited to areas with substrate that is favorable to rapid soil development, such as shallow-gradient slopes with deep layers of fine-grained glacial till. The more rocky (scree, talus, boulder) areas from which snow or glaciers retreat will not be hospitable to soil development in the short term.

Alpine tundra—

Alpine tundra provides seasonal habitat for a variety of wildlife species on the Olympic Peninsula, including Roosevelt elk, North American black bear, and the western heather vole (table 7.1). Similar to effects on glaciers and snowfields, warming temperatures will likely reduce snowpack and cause earlier snowmelt in alpine tundra habitats. These conditions could favor tree establishment, provided that the soils in tundra areas can sustain trees. Several paleoecological studies show the expansion of subalpine fir into alpine tundra in the northeastern portion of the Olympic Peninsula during historically warm periods (Brubaker and McLachlan 1996, Gavin et al. 2001, McLachlan and Brubaker 1995). Warmer temperatures and increased tree establishment may lead to loss of tundra habitat (see MC1 model output in chapter 6). The paleoecological record does not provide evidence that the highest (>1800 m in elevation) alpine habitats underwent great change during past warm periods (Gavin et al. 2001, McLachlan and Brubaker 1995), suggesting that only high levels of warming (>1–2 °C) may result in major changes in the highest alpine areas. However, anthropogenic climate change may be characterized by more extreme temperature increases than past warming periods, and warming greater than 1.0 to 2.0 °C is projected

Table 7.1—Olympic Peninsula habitat types, generally from highest to lowest elevation, and associated species most likely to be influenced by climate change and related changes in habitat[a]

Habitat type	Associated species likely to be influenced by climate-induced habitat changes
Alpine tundra	Black bear, mountain goat, Olympic marmot, Olympic pocket gopher, Roosevelt elk, western heather vole
Talus fields	Gray-crowned rosy finch
Subalpine	Black bear, bobcat, coyote, mountain goat, snowshoe hare, Clark's nutcracker
Wet meadows	Black bear, coyote, Olympic marmot, Roosevelt elk, western heather vole, dog star skipper butterfly
Dry meadows	Black bear, coyote, Olympic marmot, Olympic pocket gopher, Roosevelt elk, dog star skipper butterfly, Taylor's checkerspot butterfly
Montane forest	American marten, black bear, bushy-tailed woodrat, coyote, mountain beaver, northern flying squirrel, Pacific fisher, Roosevelt elk, snowshoe hare, barred owl, Northern spotted owl, ensatina
Lowland forest	American marten, black bear, bushy-tailed woodrat, coyote, mountain beaver, northern flying squirrel, opossum, Pacific fisher, porcupine, Roosevelt elk, barred owl, marbled murrelet, northern spotted owl, northern alligator lizard, ensatina, Van Dyke's salamander, warty jumping slug
Riparian and flood-plain habitat	Pacific fisher, American dipper, hairy woodpecker, harlequin duck, hooded merganser, red-breasted sapsucker, wood duck, chorus frog, red-legged frog, Van Dyke's salamander, western toad, warty jumping slug
Lakes, wetlands, and bogs	Garter snake, Cascades frog, long-toed salamander, northwestern salamander, western toad, Makah copper butterfly
Prairies and balds	Roosevelt elk, American kestrel, pallid horned lark, dog star skipper butterfly, Taylor's checkerspot butterfly
Caves and mines	Keen's myotis bat, little brown bat

[a] Species are grouped by vertebrate phylogenetic class (mammals, birds, reptiles, amphibians) and invertebrates, and listed alphabetically within group. The species included in this table were identified by Olympic National Forest; Olympic National Park; Forest Service, Pacific Northwest Research Station; and U.S. Geological Survey specialists as being high profile or most likely to be influenced by climate change, or both. This is not an exhaustive list of species that will be influenced by climate change on the peninsula.

to occur in the Pacific Northwest by the middle to late part of the 21st century (Mote and Salathé 2010). Even in the persistent alpine tundra habitats, increased summer drought could decrease berry production, likely causing reduced fitness of berry-dependent species such as North American black bear. Decreased berry production and berry crop failures may also force species such as black bear to search for other food sources, which could bring them into greater conflict with humans.

Talus fields—

Decreased snowpack and earlier snowmelt will likely cause changes in microenvironments in talus fields, particularly decreased moisture in the later parts of the growing season. However, cover of talus fields may increase with decreased snow cover, providing additional habitat for species such as the gray-crowned rosy finch (table 7.1).

Subalpine habitat—

Subalpine habitats on the Olympic Peninsula will likely experience decreased snowpack and earlier snowmelt with warming temperatures. These conditions will cause changes in vegetation community composition, with likely increases in tree establishment and growth, and thus loss of meadow habitat. Mortality of whitebark pine caused by white pine blister rust, and potentially by climate-induced outbreaks of mountain pine beetle (see chapter 6), will impact species that depend on whitebark pine, most notably the Clark's nutcracker (fig. 7.4).

Figure 7.4—Species such as the Clark's nutcracker that depend on whitebark pine will be impacted by mortality of whitebark pine caused by white pine blister rust, and potentially by climate-induced outbreaks of mountain pine beetle. (Photo courtesy of USDA Forest Service, Olympic National Forest.)

Figure 7.5—Taylor's checkerspot butterfly is a federally listed sensitive species that uses meadow and prairie habitat on the Olympic Peninsula. (Photo by Betsy Howell, USDA Forest Service, Olympic National Forest.)

Meadows—

Wet meadow habitat, which occurs primarily in high snow areas on the west side of the Olympic Peninsula, will likely decrease with warming because of changes in hydrology (decreased snowpack and earlier snowmelt leading to earlier runoff and increased summer drought). Decreases in this habitat could influence wet meadow-dependent species, such as the western heather vole (table 7.1). However, dry meadow habitat, which occurs primarily in the rainshadow in the northeastern portion of the Olympic Peninsula, may increase with increased fire frequency and increased drought limitations on tree species distribution (Littell et al. 2010). Increased area of dry meadows could provide additional habitat for species such as the Olympic marmot (fig. 7.3), Olympic pocket gopher, and Taylor's checkerspot butterfly (fig. 7.5) (table 7.1). Alternatively, upward-elevation shifts in tree line could result in tree encroachment of meadows and decreased meadow habitat. Also, increased temperatures may lead to changes in species composition in both wet and dry meadows, with the potential for increases in exotic species.

Montane forests—

Montane forest habitats on the Olympic Peninsula, including forests dominated by Pacific silver fir, Douglas-fir, and western hemlock, will likely experience a variety of changes with a changing climate. Reduced snowpack and more precipitation falling as rain rather than snow will shift the timing of runoff and increase summer drought (Elsner et al. 2010), and thus potentially decrease the area of headwater riparian habitat in montane forests. Decreases in headwater habitat could influence species that depend on this habitat, such as the Olympic torrent salamander (fig. 7.1) and Cope's giant salamander (fig. 7.6). Increased summer drought and reductions in soil moisture could influence species such as the mountain beaver (fig. 7.7) that require

Figure 7.6—Cope's giant salamander inhabits headwater streams and may be affected by decreased summer low flows on the Olympic Peninsula with climate change. (Photo by Betsy Howell, USDA Forest Service, Olympic National Forest.)

Figure 7.7—Increased summer drought and reductions in soil moisture with climate change could influence species such as the mountain beaver that require moist soils for digging burrows. (Photo by Betsy Howell, USDA Forest Service, Olympic National Forest.)

moist soils for digging burrows (table 7.1). Changes in hydrology may also affect seeps and springs, which provide critical habitat for peninsula species such as Van Dyke's salamander and the Olympic torrent salamander (table 7.1).

Increased temperatures with climate change will likely lead to shifts in plant species distribution, influencing the composition and thus habitat characteristics of montane forests on the Olympic Peninsula. Species such as western hemlock and Douglas-fir will likely increase in abundance in forests currently dominated by Pacific silver fir. Species such as Douglas-fir and lodgepole pine may increase in abundance in forests currently dominated by western hemlock and Douglas-fir. Changes in species phenology, and related changes in production of wildlife food sources such as berries, will likely influence the quality of habitat provided by montane forests for species such as the North American black bear. Increased frequency of disturbances, such as fire, insect outbreaks, wind events, and drought, will also influence montane forest habitat. Initially (and without management intervention) increased disturbance frequency will likely lead to increases in snags and coarse woody debris, which will benefit some species such as birds, amphibians, and mammals that use these habitat elements. Drought- and fire-induced reduction in forest density may lead to more open-canopied forests and larger residual trees. However, repeated fires may eventually lead to a reduction in legacy structures and an increase in early seral forest, with negative consequences for species that rely on large trees and mature forest conditions, such as the northern spotted owl and marbled murrelet.

Prairies and balds—

Some prairies on the Olympic Peninsula were created and maintained by Native American burning (Peter and Shebitz 2006). Without fire, tree and shrub encroachment can reduce prairie habitat quality. Increased fire with warming on the peninsula may increase the quality of prairie habitat for dependent species such as the Taylor's checkerspot butterfly (fig. 7.5). However, increased temperatures could also lead to changes in plant species composition, with the possibility of increased exotic species and reduced habitat quality.

The presence of balds on the Olympic Peninsula is primarily controlled by edaphic conditions; balds largely exist in areas where soils are too shallow and dry to support trees (Chappell 2006). Increased fire frequency with climate change could increase the area of balds by killing small young trees on the margins (Chappell 2006). However, increased drought and fire frequency associated with climate change may also affect composition in the unique and relatively species-rich plant communities that inhabit balds, possibly increasing establishment of exotic species.

Lowland forests—

Similar to the outlook for montane forests, a variety of potential effects of climate change may occur in lowland forests of the Olympic Peninsula, including forests dominated by Douglas-fir, western hemlock, and Sitka spruce. Climate-induced changes in hydrology, phenology, forest species composition, and increased disturbance will affect these lowland forests. Increased drought could decrease forest productivity in lowland forests and increase abundance of more drought-tolerant species, such as Douglas-fir and western redcedar. Also, projected increases in winter precipitation and precipitation intensity on the peninsula (Elsner et al. 2010, Salathé et al. 2010) and the effects on hydrologic regimes (see chapter 4) will affect lowland forests through increased frequency and magnitude of flooding and disturbance in riparian areas (scouring, removal of off-channel areas, deposition, and transport of woody debris). The current prevalence of exotic plant species in this forest type on the peninsula, coupled with projections for increased disturbance, suggest that exotics may become even more common with climate change in lowland forests. Because some exotic plants are also invasive and can outcompete native species on which wildlife species depend, an increase in exotic plants may have negative consequences for some wildlife species.

Increases in disturbances such as wind events and flooding may decrease the area of late-successional forests, on which species such as the northern spotted owl and marbled murrelet depend. However, increased disturbance may also lead to increased abundance of sprouting deciduous hardwoods, such as red alder and bigleaf maple, which can provide nesting and foraging habitat for some woodpecker species and Neotropical migrants, as well as leaf litter that increases habitat quality for some mollusks and salamander species. Increased disturbance and drought may also lead to increased abundance of mast-producing species, such as Pacific madrone and Oregon white oak (see chapter 6).

Riparian habitat—

As described above, altered hydrologic regimes will likely increase flood frequency and disturbance in riparian areas. Additional scouring, sediment deposition, and transport of woody debris from flooding will influence habitat characteristics in streams and adjacent riparian forests. Increased flooding severity may decrease flood-plain complexity and sinuosity of rivers, thereby reducing flood-plain habitat complexity and habitat quality for amphibian species. Increased disturbance frequency and severity in riparian areas could also reduce the area of mature riparian conifer forests and increase area of younger riparian forests dominated by deciduous hardwoods, which could degrade habitat quality for some birds and other species that use older conifers. However, deciduous hardwoods can provide valuable nesting habitat for cavity-nesting ducks and nesting and foraging habitat for some woodpecker species and Neotropical migrant birds.

Besides increased flooding, changes in hydrology with climate change will exacerbate summer drought, reduce streamflow, and produce drier conditions in adjacent riparian areas. These increases in extremes (both flooding and drought) may make riparian and flood-plain habitat less hospitable for wildlife species, such as the Pacific chorus frog, western toad, and red-legged frog (table 7.1). More frequent disturbance may also make these areas more prone to exotics, such as Japanese knotweed, which may outcompete native species and influence habitat quality for species such as songbirds. However, increased heat and drought may improve habitat for some species, such as the northern alligator lizard, because the peninsula is currently a relatively cool environment, and reptiles rely on the environment to warm themselves.

Lakes, wetlands, and bogs—

Reduction in snowpack and changes in timing of runoff with warmer temperatures will likely lead to drying of some wetland habitats, such as alpine ponds and wetlands, reducing habitat quality for dependent species such as the Cascades frog (fig. 7.2), northwestern salamander, long-toed salamander, and garter snakes. Wildlife species that depend on wetlands may be particularly sensitive to changing habitat conditions with climate change because there is little opportunity for migration to other suitable habitat (Burkett and Kusler 2000).

Cliffs, caves, and mines—

Increases in air temperatures with climate change could affect the temperatures of cliff habitats, thus affecting nesting conditions for birds that rely on cliff habitats. However, cave and mine habitats, along with other forest structures with similar microclimates, will likely remain thermal refugia, and for this reason, may become more important with climate change.

Wildlife and Habitat Management at Olympic National Forest and Olympic National Park

This section provides information on wildlife and habitat management at ONF and ONP, including (1) the context in which ONF and ONP manage wildlife and habitat,

(2) guidance and constraints on wildlife and habitat management at ONF and ONP, and (3) the primary issues around and activities currently conducted in wildlife and habitat management at ONF and ONP. This information, coupled with the likely effects of climate change on wildlife and their habitats on the Olympic Peninsula (described above), provide a basis on which to develop climate change adaptation options for wildlife and habitat management at ONF and ONP.

Policy Guidance and Goals

Both ONF and ONP manage wildlife habitat to maintain biodiversity, prevent extinctions of native species that are federally listed as threatened or endangered, and maintain healthy populations of all native species. Olympic National Forest manages wildlife habitat under the direction of the Northwest Forest Plan (NWFP) (USDA and USDI 1994) and the 1990 Olympic Land and Resource Management Plan (USDA FS 1990). At ONF, a major land allocation under the NWFP is the late-successional reserve (LSR) allocation in which the goal is to maintain interactive, late-successional and old-growth forest ecosystems. A fundamental goal of LSRs is to provide habitat for late-successional and old-growth-related species, including the northern spotted owl. Other goals for managing wildlife habitat at ONF include maintaining biodiversity and sufficient habitat to ensure viable populations and prevent extinctions of all native species. Special attention is given to native species that are federally listed as threatened, endangered, or sensitive

Table 7.2—Federally listed threatened (T) and endangered (E), and state (WA-S) and federally listed sensitive (S) terrestrial wildlife species on the Olympic Peninsula[a]

Common name	Scientific name	Status
Townsend's big-eared bat	*Corynorhinus townsendii*	S
Olympic marmot	*Marmota olympus*	WA-S
Pacific fisher	*Martes pennanti*	S
Keen's myotis	*Myotis keenii*	WA-S
Olympic pocket gopher	*Thomomys mazama melanops*	WA-S
Marbled murrelet	*Brachyramphus marmoratus*	T
Common loon	*Gavia immer*	WA-S
Bald eagle	*Haliaeetus leucocephalus*	S
Harlequin duck	*Histrionicus histrionicus*	S
Northern spotted owl	*Strix occidentalis caurina*	T
Cope's giant salamander	*Dicamptodon copei*	S
Van Dyke's salamander	*Plethodon vandykei*	WA-S
Olympic torrent salamander	*Rhyacotriton olympicus*	WA-S
Johnson's hairstreak butterfly	*Callophrys johnsoni*	S
Puget Oregonian snail	*Cryptomastix devia*	S
Evening fieldslug	*Deroceras hesperium*	S
Taylor's checkerspot butterfly	*Euphydryas editha taylori*	S
Keeled jumping-slug	*Hemphillia burringtoni*	WA-S
Warty jumping-slug	*Hemphillia glandulosa*	S
Malone jumping-slug	*Hemphillia malonei*	WA-S
Oregon megomphix mollusk	*Megomphix hemphilli*	WA-S
Olympic arctic butterfly	*Oeneis chryxus valerata*	WA-S
Dog star skipper	*Polites sonora siris*	WA-S
Blue-gray taildropper slug	*Prophysaon coeruleum*	WA-S
Hoko vertigo snail	*Vertigo* n. sp. (new unnamed species)	WA-S

[a] Species are grouped by vertebrate phylogenetic class (mammals, birds, reptiles, amphibians) and invertebrates, and listed alphabetically by scientific name within group.

(TES) or classified as sensitive under the Pacific Northwest regional forester's sensitive species program (table 7.2).

Besides managing for TES species, ONF manages for species classified as management indicator species. Indicator species are chosen to reflect an assemblage of species having similar habitat or ecosystem affinities and requirements, with an assumption that management that maintains or enhances the habitat of indicator species will also benefit the larger assemblage of species. Seven species, or groups of species, have been selected as indicators at ONF. These include primary excavators as indicators for snag-dependent cavity nesters; Roosevelt elk and Columbia black-tailed deer as game species indicators; American marten and pileated woodpecker as mature coniferous forest species indicators; northern spotted owl as an old-growth forest species indicator; and bald eagle as a riparian/mature forest species indicator. Additional management direction guides habitat maintenance for game species. The park's wildlife management program promotes sustaining a full range of natural genetic variability and long-term viability through maintenance of wildlife population age-structures, abundance, density, and distributions within normal ranges.

When adequate habitat exists and several additional criteria are met, National Park Service management policies (NPS 2006) direct park managers to restore extirpated native species such as the Pacific fisher, which is believed to have been extirpated from the state of Washington. In 1988, the Pacific fisher was listed as a state endangered species in Washington state, and in 2004 as a federal candidate species (west coast distinct population segment). In 2004, the Washington State Department of Fish and Wildlife completed a feasibility study, concluding that the Olympic Peninsula was best suited as a release site for the initial restoration of Pacific fisher to the state. In 2008, a multiyear, interagency program began to restore Pacific fishers to the Olympic Peninsula, with releases over a 3-year period in ONP. This program also addressed a National Park Service policy objective of restoring a full complement of native species to ONP. At present, the only native species absent from the park is the gray wolf. Although there are no current proposals to reintroduce the wolf, the return of wolves could influence populations and distributions of herbivores, which would affect riparian vegetation communities (Beschta and Ripple 2008), and potentially ecosystem resiliency to climate change.

Habitat Improvement and Restoration Activities

Activities to improve wildlife habitat quality at ONF include snag and coarse wood creation, pruning, cavity treatments, forage plantings, and mechanical treatments to maintain open habitats. Snag creation, often conducted in thinning treatments, can include blasting or removing the tops of trees with chain saws, inoculation with local stem decay fungi, or girdling. Biologists also install nest boxes for northern flying squirrels. Coarse wood treatments include creating furrows in felled trees, piling fine or coarse downed wood, and bundling logs together from felled trees to create coarse wood structures. Pruning treatments include pruning of understory shrubs or hardwood trees to stimulate sprouting and increase availability of big game browse or suitability for shrub-nesting birds. Treatments include creating artificial cavities in topped or live trees to benefit cavity-using wildlife. Forage plantings for large game include planting willow and red-osier dogwood. Mechanical treatments (chain saws and loppers) include removing salmonberry and some small conifers from areas that were once meadow or openings created from earlier management practices.

Within ONF, road decommissioning and culvert installation improve habitat for fish and aquatic species, as well as some terrestrial wildlife species. For example, road decommissioning and culvert installation can improve water quality and access to habitats for species that have an aquatic phase, such as the Olympic torrent salamander (fig. 7.1), tailed frog, and Cope's giant salamander (fig. 7.6). Many vegetation management activities (described in chapter 6) can also be considered wildlife habitat restoration activities at ONF. For example, thinning in young stands (40 to 80 years old) focuses on creating forest structural diversity intended to accelerate the development of late-successional forest characteristics used by old-growth-dependent species such as the northern spotted owl and marbled murrelet. Young plantations that are proximal to old-growth forests receive priority for thinning treatments to increase the area of contiguous old-growth habitat. Habitat improvement for Roosevelt elk is also a factor in setting priorities for thinning. Wildlife habitat provisions in silvicultural prescriptions focus on snag and coarse woody debris density and distribution at the watershed scale.

Olympic National Park works to restore ecosystems, habitats, and disturbance regimes altered by human activities or exotic species. As the park acquires private properties from willing sellers within the park boundaries, biologists work to restore these sites by planting native species propagated from adjoining areas.

Within aquatic systems of the park, management priorities include pollution prevention, protection of riparian and lake habitat, and water quality maintenance to meet the needs of aquatic organisms. A major restoration effort is underway to remove two dams from the Elwha River. Dam removal will occur over a 2-year period beginning late in 2011, with active fish and vegetation restoration projects occurring during several years thereafter. After this restoration project, the river will support all five species of Pacific salmonids that inhabited the river before dam construction. Succession of riparian communities over the next several years to decades will provide habitat for a variety of mammals and birds. In preparation for dam removal, biologists conducted baseline surveys in the Elwha valley to assess occurrence and distribution of North American black bear, riparian carnivores, small mammals, beavers, otters, amphibians, and birds. Prior studies on prey base adequacy for wolves examined Roosevelt elk and Columbia black-tailed deer distribution and density in the Elwha and other drainages in the park (Jenkins and Manley 2008).

Surveys and Monitoring

The ONF conducts surveys to assess wildlife populations on the forest. Surveys for wildlife species by ONF personnel in the last decade have generally focused on species listed as sensitive and included aerial surveys for bald eagles, documenting nesting success, and also searching for new nests. In 2009, the forest began the first formal surveys for Taylor's checkerspot butterfly (fig. 7.5). Biologists conduct surveys for other species opportunistically and sometimes not to any strict protocol. There is also documentation of egg masses, larvae, and adult pond breeding amphibians in some areas, as well as surveys for the northern goshawk. The forest installed remote cameras to monitor the recently reintroduced Pacific fisher on the peninsula and is working with ONP, the Washington State Department of Fish and Wildlife, the U.S. Geological Survey, and the Forest Service Pacific Northwest Research Station to establish a survey protocol for Pacific fisher. Annual bat surveys in one portion of the ONF include bridge and building inspections to document use by Townsend big-eared bat and Myotis species.

Forest staff discontinued surveys for marbled murrelet and northern spotted owl in the late 1990s after the forest began to switch its harvest program to second-growth stands instead of old growth. However, the Forest Service Pacific Northwest Research Station oversees the Olympic Demography Study, which involves annual surveys by scientists at selected northern spotted owl activity centers on the forest. Olympic National Park biologists conduct surveys for northern spotted owl within the park boundaries at about 50 sites. Annual survey data from this work dates to the early 1990s.

Olympic National Park protects the largest population of Roosevelt elk in its natural environment in the world. Decades of protection from human harvest and habitat manipulation not only sustained high densities of elk, but also preserved the natural composition, social structure, and dynamics of this unique coastal form of elk found nowhere else. Population surveys and other studies of park elk populations since 1985 documented that herds on the west side of the park generally reside for most of the year wholly within the park, whereas east-side herds spend a portion of the year out of the park (Houston et al. 1987, 1990). Understanding these differences may be even more important with climate change as biologists work across boundaries to conserve species and their habitats.

Biologists monitor elk populations at ONP as a part of the National Park Service North Coast and Cascades Network monitoring program. Other components of the monitoring program address plant communities, landscape change, climate, high-elevation lakes, fish in large rivers, and land birds. Monitoring protocols are peer reviewed, and each includes a data management component. Additional monitoring addresses northern spotted owls (and the barred owl invasion), and water quality at Lake Crescent. When project funds can be obtained, biologists monitor mountain goat populations, with at least five surveys completed since 1983. Long-term research has been, or is being conducted, on terrestrial, lotic, and lentic amphibians, Olympic marmot (fig. 7.3), North American black bear, Columbia black-tailed deer, marbled murrelets, and bald eagles (Weber et al. 2009).

Adapting Wildlife and Habitat Management to Climate Change at Olympic National Forest and Olympic National Park

Process Used to Develop Adaptation Strategies for Wildlife and Habitat Management

During 2009, a series of three workshops was held to discuss potential effects of climate change on Olympic Peninsula wildlife species and habitats, examine anticipated wildlife sensitivities to climate change, and develop potential adaptation strategies and actions for wildlife management at ONF and ONP. Workshop participants included natural resources staff from ONF and ONP, specialists from the Washington Department of Natural Resources and U.S. Fish and Wildlife Service, and scientists from the Forest Service Pacific Northwest Research Station, U.S. Geological Survey, and University of Washington.

The first workshop focused on potential climate change effects on wildlife on the peninsula, including general climate change effects, as well as effects anticipated within each Olympic Peninsula habitat type. Based on the anticipated climate change effects, participants identified species on the peninsula most likely to be impacted by climate change (table 7.1).

Participants in the first workshop concluded that further analysis of Olympic Peninsula wildlife species sensitivity to climate change would be useful in developing climate change adaptation strategies and actions for wildlife habitat management at ONF and ONP. During a second meeting, biologists participated in a climate change sensitivity assessment process for select wildlife species on the Olympic Peninsula, applying methods developed by Joshua Lawler (School of Forest Resources, University of Washington). The climate change sensitivity assessment involved wildlife experts answering a series of questions about a particular species based on their knowledge and experience. Participants were asked to (1) classify a species' maximum annual dispersal; (2) determine whether barriers to dispersal exist for a given species; (3) rate a species' dependence on disturbance regimes; (4) rate a species' dependence on other species (i.e., interspecific dependencies); (5) rate a species' physiological sensitivity to temperature; (6) rate a species' sensitivity to changing precipitation; (7) rate a species' sensitivity to salinity, pH, and carbon dioxide; (8) classify a species reproductive strategy (on an r-selected to K-selected scale); and (9) identify any sensitive habitats that a given species occupies (see table 7.3 for specific questions). An automated electronic system collected and tallied responses and provided summary results to participants. Participants then rated how confident they were in the summary response, thus quantifying the degree of certainty in the group response to a given question. In addition, each participant subjectively rated each species' overall sensitivity to climate change.

Participants completed the sensitivity assessment for a limited number of species during the workshop, and individual experts conducted additional species assessments through an online database after the workshop. A sensitivity score for each species incorporated mean group responses from the workshop as well as responses from individuals in the online database. An additive function (sum scores for each question) (table 7.3), divided by the maximum possible score, and multiplied by 100) produced the sensitivity scores, on a 0 to 100 scale. Figure 7.8 illustrates results of the sensitivity assessment for the 21 Olympic Peninsula species analyzed by the group, as discussed below.

A third meeting focused on development of adaptation strategies and actions for wildlife management at ONF and ONP. Objectives of this third workshop were to (1) review Olympic Peninsula wildlife habitat and species sensitivities to climate change identified in the first two workshops and (2) through an interactive dialogue between scientists and managers, use the latest scientific information on climate change and impacts to wildlife to develop adaptation

Table 7.3—Questions posed to participants in the process used to assess the sensitivity of wildlife species to climate[a]

Question 1. Maximum annual dispersal distance for this species is:							
(0) N/A	(1) >100 km	(2) 75–100 km	(3) 50–75 km	(4) 25–50 km	(5) 5–25 km	(6) 1–5 km	(7) <1 km
Question 2. Do barriers to dispersal exist? Are there landscape elements that would prevent this species from moving in response to climate change?							
(0) No	(3) Yes						
Question 3. How dependent is this species on one or more disturbance regimes?							
(1) not dependent on the nature of any disturbance regime	(2) slightly dependent	(3) somewhat dependent	(4) moderately dependent	(5) more dependent	(6) definitely dependent	(7) highly dependent on the nature of one or more disturbance regimes	
Question 4. Broadly, where does this species fall on the spectrum of generalist to specialist?							
(0) N/A	(1) generalist	(2)	(3)	(4)	(5)	(6)	(7) specialist
Question 5. Species' sensitivity to temperature[b]:							
(0) N/A	(1) low sensitivity	(2)	(3)	(4)	(5)	(6)	(7) high sensitivity
Question 6. Species' sensitivity to precipitation[c]:							
(0) N/A	(1) low sensitivity	(2)	(3)	(4)	(5)	(6)	(7) high sensitivity
Question 7. Species' sensitivity to salinity[d]:							
(0) N/A	(1) low sensitivity	(2)	(3)	(4)	(5)	(6)	(7) high sensitivity
Question 8. Species' sensitivity to pH[e]:							
(0) N/A	(1) low sensitivity	(2)	(3)	(4)	(5)	(6)	(7) high sensitivity
Question 9. Species' sensitivity to CO_2[f]:							
(0) N/A	(1) low sensitivity	(2)	(3)	(4)	(5)	(6)	(7) high sensitivity
Question 10. Species' reproductive strategy:							
(0) N/A	(1) r-selection (can exploit empty niches/ reproduce quickly)	(2)	(3)	(4)	(5)	(6)	(7) K-selection (present as strong competitors in crowded niches/ invest heavily in fewer offspring)

Table 7.3—Questions posed to participants in the process used to assess the sensitivity of wildlife species to climate[a]

Question 11. Occupies the following sensitive habitat types[g]						
Coastal lowlands/marshes/ estuaries	Perennial streams	Shallow wetlands/ shallow pools	Vernal pools or seasonal wetlands	Ecotones	Alpine/ subalpine	Other

[a] The number in parentheses before each answer choice represents the score that answer would produce for the calculation of the climate change sensitivity score. Sensitivity scores are on a scale of 0 to 100 and based on an additive function. In addition to the calculated sensitivity scores, after each question, each participant was asked to rate their level of confidence in the value that was collectively reached through this process, giving a measure of uncertainty to collective answers for each question.

[b] Sensitivity to temperature is directly related to a species' physiological ability to tolerate temperatures that are higher or lower than the range that it currently experiences. If a species can tolerate a wide range of temperatures, it would be deemed less sensitive.

[c] Sensitivity to precipitation should be based on the species' ability to tolerate higher or lower levels of precipitation than that which it currently experiences. If a species can tolerate a great deal more or less precipitation than usual, they should be deemed less sensitive.

[d] Sensitivity to salinity refers to the species' ability to tolerate either higher or lower levels of salinity than it currently experiences. The ability to tolerate a wide range of salinity indicates that the species is less sensitive.

[e] Sensitivity to pH refers to a species' ability to tolerate either higher or lower pH than it currently experiences. (This is most applicable to aquatic organisms.) If a species can tolerate a wide range of pH, it should be deemed less sensitive.

[f] Sensitivity to carbon dioxide (CO_2) refers to the ability of a species to tolerate greater or lesser amounts of CO_2 than it currently experiences (this may be most important in plant species). If a species can tolerate a wide range of CO_2 levels, it should be deemed less sensitive.

[g] If the species occupies none of these habitats, then the score is 0. If the species occupies one or more of these habitats, then the score is 7.

options and action plans for wildlife habitat management. Jessica Halofsky (University of Washington) provided an overview of potential impacts of climate change on wildlife and vegetation on the Olympic Peninsula. Michael Case (University of Washington) presented results of the sensitivity assessment for selected wildlife species on the peninsula, and wildlife specialists Susan Piper (ONF) and Patti Happe (ONP) gave presentations on wildlife habitat management at ONF and at ONP, respectively. A discussion on adaption options for wildlife management with climate change followed. Part of the discussion involved review of suggested adaptation strategies for wildlife management and biodiversity conservation in a recent journal article (Mawdsley et al. 2009). Key points from the discussion are described below and in table 7.4. See box 7.1 for a general summary of projected effects of climate change on wildlife on the Olympic Peninsula and related adaptation strategies for wildlife and wildlife habitat management at ONF and ONP.

Olympic Peninsula Wildlife Species Sensitivity to Climate Change

The wildlife species sensitivity assessment indicated that, in general, specialist species and species that use sensitive habitats will likely be more sensitive to climate change than more generalist species and species that use less sensitive habitats (fig. 7.8). Species that occupy sensitive habitats, such as the Olympic torrent salamander (headwater streams), Cascades frog and Van Dyke's salamander (aquatic habitats), dog star skipper butterfly (meadows), Makah copper butterfly (wetlands), and the Olympic marmot (fig. 7.3), mountain goat, Clark's nutcracker (fig. 7.4), and gray-crowned rosy finch (high-elevation habitats), were generally ranked as highly sensitive to climate change. Similarly, specialist species in terms of habitat and diet, such as Clark's nutcracker, northern spotted owl, gray-crowned rosy finch, Van Dyke's salamander, American marten, and northern flying squirrel, were ranked as highly sensitive to climate change. More generalist species, such as the barred owl, snowshoe hare (fig. 7.9), North American black bear, mountain beaver, and Roosevelt elk were not ranked as highly for sensitivity to climate change.

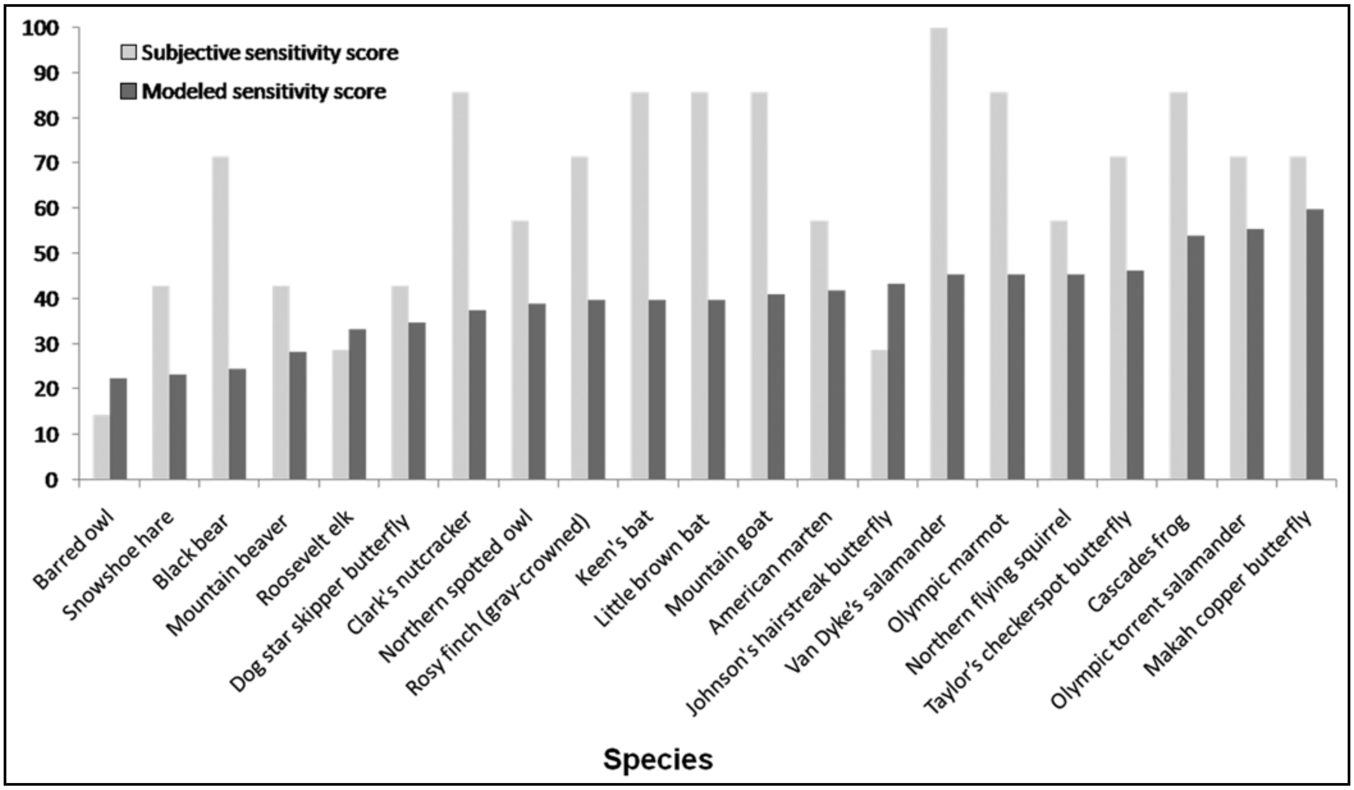

Figure 7.8—Modeled and subjective climate change sensitivity scores for selected species on the Olympic Peninsula. Modeled sensitivity scores were determined from experts' answers to questions and calculated based on an additive function (see table 7.3). Subjective sensitivity scores were experts' opinions on how sensitive a given species will be to climate change.

Figure 7.9—Snowshoe hare does not change fur color seasonally on the Olympic Peninsula as it does in other regions. Snowshoe hare is a generalist and thus may not be as sensitive to climate change as other species on the Olympic Peninsula. (Photo by Betsy Howell, USDA Forest Service, Olympic National Forest.)

The sensitivity assessment process assisted in initially identifying species and groups of species that will likely be most sensitive to climate change on the peninsula. The process also led to useful discussion and deeper thinking about how individual and groups of species may be affected by climate change. However, the sensitivity assessment is still under development, and participants identified several limitations of the tool. For example, there was a large discrepancy between the modeled sensitivity and the subjective sensitivity scores for some species, likely because there are effects of climate change and other factors that make species sensitive to climate change that are not captured in the assessment. Alternatively, experts' expectations for wildlife sensitivities to climate change are greater than the model suggests. In either case, the assessment process left a high level of uncertainty about the actual sensitivity of any of the species considered. Developers received critiques of

Table 7.4—Projected climate change sensitivities, and associated adaptation strategies and actions for wildlife and habitat management at Olympic National Forest (ONF) and Olympic National Park (ONP)[a]

Current and expected sensitivities	Adaptation strategies and actions
Limited connectivity of late-successional forests	• Collaborate with neighbors about priority areas for treatments, and increase extent of protected areas.
Limited ability of species to respond to climate change owing to current stressors, such as habitat loss and fragmentation	• Increase thinning treatments in young-growth forests that promote late-successional forest conditions and improve habitat quality and suitability for some wildlife species at ONF. • Focus thinning treatments (to promote late-successional conditions) around existing late-successional forests to increase landscape connectivity and increase wildlife habitat quality at ONF. • Increase restoration treatments in, and protection of, headwater streams to increase late-successional habitat connectivity at ONF. • Add a climate layer to ONF's 10-year plan that shifts priorities for thinning treatments and road decommissioning and leads to increased habitat quality and connectivity.
Risk of large, high-severity fire	• Determine how to jointly manage fire (ONF and ONP). • Consider allowing fires to burn more frequently. • Monitor postfire regeneration to determine what can be expected after large fires. • Decrease stand densities and increase use of prescribed fire to lower wildfire severity.
Reduced late-successional habitat area and habitat quality	• Continue to create and protect legacy structures at ONF. • Increase density of legacy structures in younger forest near late-successional forest to increase habitat quality and connectivity at ONF. • Continue to thin stands at ONF to promote tree vigor and produce future legacy structures. • Continue to restore degraded sites.
Reduced habitat quality, particularly in riparian areas and wetlands	• Restore habitat in degraded headwater streams at ONF that are expected to retain adequate summer streamflow.
Increased spread of aquatic exotic plant species	• Control spread of exotic species.
Loss of cold water refugia for cold-water adapted amphibians	• Consider creating wetland habitats.
Change in wetland, bog, and fen distribution	
Increased risk of species extinction, particularly for endemics	• Consider inventory and monitoring opportunities to address questions for species sensitive to climate change, including listed species. • Conduct integrated surveys and monitoring for key species to obtain baseline information and determine when population changes are occurring. • Reduce existing pressures on species from sources other than climate change.

[a] Sensitivities are based on projected climate change effects on the Olympic Peninsula, including changing habitat distribution and quality with changing vegetation patterns, shifts in geographic ranges of wildlife species, shifts in ranges of competitor, forage, prey, and symbiotic species (and biotic interactions), changing species phenology, increased fire frequency, potential for increased insect and disease outbreaks, changing hydrology, and reduced summer streamflows.

Box 7.1—Summary of projected climate change effects on wildlife on the Olympic Peninsula and related adaptation strategies for wildlife and wildlife habitat management at Olympic National Forest (ONP) and Olympic National Park (ONP).

- Climate change, in combination with other stressors to wildlife such as habitat loss and fragmentation, has the potential to greatly affect wildlife species and biodiversity on the Olympic Peninsula.
- Species will respond to both direct and indirect effects of climate change. For example, increasing temperatures and changing precipitation will have direct physiological effects on some species, such as amphibians. Other species will be affected mostly indirectly through:
    - Climate-induced changes in phenology (timing of life history) relative to forage plants and invertebrate prey
    - Shifts in geographic ranges and the density and ranges of competitor, forage, prey, and symbiotic species (and subsequent changes in biotic interactions) in response to changing climate
    - Effects from other stressors such as disturbance, insects, and disease
    - Climate-induced changes in habitat characteristics and quality
- Some Olympic Peninsula species will likely respond to increasing temperature by shifting their ranges upward in elevation. High-elevation species will likely be particularly sensitive to warming temperatures and experience range contractions because contiguous, higher elevation habitat may not be available to colonize.
- It may also be more difficult for endemic and specialist species with strict habitat requirements or dependencies on specific forage species to find suitable habitat conditions under changing climate.
- Active management by restoration thinning in existing young-growth forest at ONF is a strategy that may help to ensure maintenance of enough forest with desired late-successional habitat characteristics (currently rare) across the landscape. Thinning to promote late-successional conditions at ONF may be most effective around existing late-successional forests to increase landscape connectivity and increase wildlife habitat quality.
- Protection and restoration of headwater streams and encouraging vigorous conifer growth could help to prevent increasing stream temperatures with climate change and increase habitat connectivity.
- At the stand scale, ONF can continue to increase wildlife habitat quality through creation and protection of legacy structures, including old-growth trees, snags, and large downed wood, as these legacy structures have disproportionate habitat value for a large number of species.
- Because many actions that could help increase wildlife species' resilience to climate change will be most effective at large spatial scales and with consideration of landscape context, ONF and ONP will increase collaboration with neighbors to develop and increase the extent of a landscape strategy.

the assessment during the workshops and will consider the critiques in further refinement of the assessment tool and associated database. However, issues with the sensitivity assessment tool and database may stem from a fundamental lack of empirical data on wildlife species and their likely responses to changing climate. Additional empirical data and baseline assessments are needed to track changes in species' response in the early phases of climate change. Such early assessments will be vital as we attempt to forecast long-term changes in response to climate change.

Adaptation Strategies and Actions for Wildlife and Habitat Management at Olympic National Forest and Olympic National Park

Many actions that could help increase wildlife species' resilience to climate change will be most effective at broad spatial scales (Millar et al. 2007), especially for management targeted at increasing habitat connectivity. Given the many landowners on the peninsula, increasing habitat quality and connectivity will require collaboration with neighbors about where to apply treatments to benefit wildlife habitat. Dialogue with the Washington Department of Fish and Wildlife, Washington Department of Natural Resources (a major landowner on the peninsula), and other federal agencies could help to develop and increase the extent of a landscape strategy. The ONF and ONP will also seek opportunities for collaboration with other peninsula landowners.

Logging activities through the end of the 20th century left a scarcity of late-successional forest at ONF. Late-successional forests provide high-quality habitat for many species, including the northern spotted owl. Some late-successional forests may decline with climate change and be replaced by natural regeneration. Active management by thinning in existing young-growth forest at ONF is a strategy that may help to ensure maintenance of enough forest with desired habitat characteristics across the landscape. Thinning can reduce habitat quality and suitability for certain species that prefer dense forest conditions typical of the stem exclusion phase of forest succession (Hagar et al. 1996, Hayes et al. 2003, Suzuki and Hayes 2003). However, thinning in structurally simple young-growth forests can also improve habitat quality and suitability for a variety of other species by promoting tree growth, species and structural diversity, and understory development (Carey and Wilson 2001, Hagar et al. 1996, Hayes et al. 2003, Suzuki and Hayes 2003). Young-growth thinning increases tree vigor by increasing availability of water, light, and nutrient resources; enhances tree species diversity by providing growing space for less competitive minor species; and provides growing space for understory vegetation to increase in abundance and diversity (Roberts and Harrington 2008).

Thinning to promote late-successional conditions at ONF may be most effective adjacent to existing late-successional forests to increase landscape connectivity and increase wildlife habitat quality (the exception to this would be around known owl and murrelet nesting sites, where concern for short-term disturbance could outweigh long-term habitat improvement). Alternatively, thinning treatments could be focused in areas dominated by young forests. For example, young forests dominate the northwestern corner of ONF, which is the least connected to the park. Focusing treatments in that portion of the forest may have the greatest effect on habitat quality.

Areas selected for thinning also need to be strategically located with the consideration of climate-altering disturbance processes and growing conditions. Some treatments may be a combination of habitat characteristic development and fire fuel reduction, depending on the location. Fuel reductions may be particularly important to high-value riparian areas, where habitat value would be susceptible to fire.

Another way to potentially increase late-successional habitat connectivity is through restoration thinning treatments and protection of headwater stream areas at ONF, because forests that surround headwater streams are widespread and connected. Protection of headwater streams, and encouraging vigorous conifer growth, could help to prevent increasing stream temperatures with climate change and prevent sediment movement downstream. Management activities that promote forest resilience around non-fish-bearing headwater streams could also improve habitat for amphibians, which are likely to be highly sensitive to climate change. For example, during thinning treatments, some trees could be dropped into streams to create instream structures that provide habitat and improve water holding capacity.

Currently, ONF uses a 10-year strategic plan to direct locations of thinning and road decommissioning activities (among others). The strategic plan emphasizes restoring and connecting fragmented terrestrial and aquatic habitats. The plan does not currently consider potential effects of climate change, but modifying treatment prioritization could help to incorporate climate change in the plan. For example, thinning treatments could be prioritized around existing late-successional forest and around headwater streams to increase late-successional habitat connectivity. A geographic information system analysis could be used to identify gaps in desirable conditions and determine where treatments would be most effective. Also, habitat surveys could help to determine where the best corridors for movement exist on the peninsula, and treatments could be positioned accordingly. Wildlife could also be given greater consideration in prioritization of road decommissioning on the forest; roads that inhibit species movement could be prioritized for decommissioning.

Another step for ONF and ONP is to determine how to jointly manage fire. The ONP will revise their fire plan in the near future and broaden the scope of the planning effort to include ONF. Allowing wildfires to burn more frequently at ONF and ONP may have some benefits, such as maintenance of alpine meadows, which will likely see increased tree encroachment with warming temperatures. Monitoring of recent burns and postfire regeneration could help determine if forage species are likely to regenerate after fire (e.g., Do important meadow species return after fire?). Management could also be tailored to decrease fire intensity. For example, decreasing stand density and increasing use of prescribed fire could help to decrease wildfire intensity, and firebreaks could be created to slow wildfire spread. These activities could be particularly useful in productive areas in the northeastern portion of the peninsula, where fire is more frequent and stands would likely respond to thinning through increased tree growth and vigor.

At the stand scale, ONF could continue to increase wildlife habitat quality through creation and protection of legacy structures, including old-growth trees, snags, and large downed wood. Legacy structures have disproportionate habitat value for a large number of species. Although not a specific habitat type, these structures may mediate structural deficiencies in younger stands by providing for critical habitat needs. Old-growth trees have furrowed bark, cavities or basal hollows, large limbs, and defects that can provide nesting or roosting substrate, prey, or resting cover for species that might not otherwise be able to inhabit a younger stand. For example, long-legged bats, pygmy nuthatches, violet-green swallows, and Vaux's swifts were documented reproducing in individual old-growth redwood trees with basal hollows or other cavities that were located in younger managed stands, and a variety of other bat and bird species used them for foraging or roosting (Mazurek and Zielinski 2004, Zielinski and Gellman 1999). Large standing hollow trees or fallen logs can provide hibernation dens for bears, natal and maternal dens for meso-predators such as the American marten and Pacific fisher, and cool, moist conditions for amphibians (such as Van Dyke's salamander) and mollusks. Overall, snags and coarse wood are very important to a variety of wildlife because of the food or prey they provide, protection from the elements, or structures for rearing young.

Olympic National Forest currently induces mortality of large trees for snag creation. This practice could be continued and possibly increased for further habitat quality improvement. Increasing density of legacy structures in younger forests may be particularly effective near late-successional forest to increase habitat quality and connectivity. Protection of existing legacy structures will also be important in providing critical habitat elements for a variety of species that may help them to respond adaptively to climate change.

Although there is a need for legacy structure creation in the short term, there is also a need for high tree vigor for creation of future legacy structures. At ONF, stands could be thinned and trees left on site to elicit both a growth response and a positive effect on habitat quality. Thinning could also help forests to be more resilient to drought and disturbance with climate change.

Besides legacy structure protection and creation, other measures could be taken to further increase habitat quality at the stand scale. For example, creation of habitat structures, such as brush piles, could provide habitat for salamander species under increasing summer drought. Restoring currently degraded sites could also help to increase the area of high-quality habitat at ONF and ONP.

Policy Considerations and Next Steps

Policy will be highly relevant to wildlife management at ONF and ONP with climate change. Both ONF and ONP currently focus resources on species that are sensitive, threatened, endangered, or iconic, but it is uncertain what will happen in the future when climate-related changes could lead to many more extinction possibilities. Because of the number of endemic species on the peninsula, there will be an opportunity for the forest and park to direct the discussion on what to do about many species at risk of extinction. The forest and park will keep up-to-date on the federal threatened and endangered list, as well as the Washington sensitive species list. Integrated surveys and monitoring can be conducted for key species to obtain baseline information and determine when population changes are occurring (e.g., the endemic Olympic marmot and amphibians in the high lakes areas). The forest and park will consider expanded data sharing and joint or expanded monitoring projects with common protocols, involving other adjacent landowners whenever possible. Specific recommendations for managing the effects of climate change can be developed for species for which a large amount of information already exists.

Reducing existing pressures on species from sources other than climate change will also be important to protect TES species. The ONF and ONP will work to evaluate current activities to determine if stresses can be reduced for species that will be most impacted by climate change (e.g., focus on keeping streams cool for the Olympic torrent salamander, and increase coordination on exotic species control).

In the future, depending on agency policies and partnerships, ONF and ONP may also consider assisted migration and captive breeding for species that may otherwise go extinct. It is possible that the peninsula will be a refuge for species from other parts of the Pacific Northwest over the long term. However, criteria and methods for conducting assisted migration as a strategy, as well as potential ecosystem impacts, are unclear.

Although ONF and ONP are mandated to protect TES species, there are currently policy limitations on the actions that can be taken to protect these species. Under current policies, management actions that would affect native species to protect or restore TES species must be undertaken through a careful planning process and in a way that will not produce unacceptable impacts on resources or natural processes. For ONP, policy guidance on when or whether to intervene in ecosystem processes in the face of climate change is limited. For example, the population of Olympic marmot (fig. 7.3), an endemic species to the peninsula, is declining on the peninsula owing in part to unsustainable levels of coyote predation (Griffin et al. 2008), and warming temperatures may enhance coyote presence in the high-elevation marmot habitat. Potential options for coyote control are complicated under existing policies. Policy guidance regarding how or if to manage the situation is imprecise. Reintroduction of a top predator, the gray wolf, could decrease coyote numbers but would likely have other ecosystem impacts and raise controversy. Similarly, there are limitations to actions that can be taken to control the barred owl and its negative impact on the northern spotted owl. Other similar situations may arise in the future with species ranges that may shift in response to climate change.

The Endangered Species Act (ESA 1973) guides agencies to consider the needs of individual species in their management activities, and conservation of individual species under the Endangered Species Act will likely continue for some time. In some cases, management for particular species whose presence is crucial to the maintenance of current ecosystem dynamics (e.g., top predators and major herbivores) may be required to maintain ecosystem function with changing climate. However, other efforts to maintain and restore ecosystem function will be important with the changes in forest species composition and disturbance that will likely occur with warming. With climate change, it may be particularly important to focus management on habitats, habitat structural components, and headwaters and cold water flows. Monitoring these habitats and habitat components will be particularly useful for detecting changes in habitat attributes and taking management action, when possible, to limit negative consequences for the species that use the habitats.

To garner public support for policies and actions related to climate change, ONF and ONP may need to expand outreach to explain the reasoning behind policies and actions. The park and forest can increase interaction with local communities about how they are addressing climate change in management and how climate change may affect the public. Education about potential changes in wildlife may be especially necessary because, for example, black bear conflicts increase when there are berry crop failures, which may become more frequent with climate change.

Overall, current wildlife management at ONF and ONP is consistent with strategies and actions that would help to increase species and ecosystem resilience to climate change. For example, ONP currently manages for ecosystem function, and ONF focuses much of their management on restoration. However, there are ways, outlined here, that

ONF and ONP could shift their strategies and foci to better address potential changes with warming temperatures.

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Chapter 8: Synthesis and Conclusions

Catherine Hawkins Hoffman, Kathy A. O'Halloran, Jessica E. Halofsky, and David L. Peterson[1]

Utility of the Adaptation Planning Process

The Olympic Climate Change Case Study illustrated the utility of place-based vulnerability assessments and science-management workshops in facilitating climate change adaptation planning. We built on climate change education, and initial science-management discussions to develop specific and tangible ways for Olympic National Forest (ONF) and Olympic National Park (ONP) to incorporate climate change adaptation strategies into management. Development of science-based adaptation strategies was fostered by direct engagement of scientists and managers in the workshops. Presentations describing results of science-based vulnerability assessments helped to spur dialogue. The workshop format gave managers an open forum to brainstorm, express initial thoughts and ideas, and vet those ideas among peers. Careful facilitation of workshop discussions led to a productive dialogue (Schmoldt and Peterson 1991).

This study is an unprecedented example of collaboration by the U.S. Forest Service and National Park Service in preparation for climate change. The process used, involving sensitivity assessments, reviews of current management and management constraints, and adaptation workshops, can provide an example for other land and resource managers on how to initiate the climate change adaptation process. Many ideas from the case study could apply to other locations or agencies, and contribute to current planning processes and management programs.

Lessons Learned

Where Is the Recipe?

For climate change adaptation, there is no recipe, no road map, and yet no time to lose; science and management partners must tackle the climate change issue in a timely way, despite uncertainty.

It is challenging for agency managers to stay abreast of the rapidly evolving field of climate change science that contains as many questions as answers, further complicating decisionmaking. Consequently, the temptation is strong to wait for ready-made templates or fully developed, tried-and-true examples of how to adapt to climate change. There are numerous efforts underway nationally and internationally to develop adaptation concepts and processes. Comparing and contrasting these to learn from other examples is critical to advancing climate change adaptation. However, this issue must be addressed as soon as possible to limit unwanted effects of changing climate.

Timing

The case study was timed to build on the momentum of a previous effort and was sufficiently long to enable the completion of a critical step in the adaptation process.

The case study was timed to build on the momentum of previous adaptation work on ONF and to take advantage of available funding for the effort. The case study was conducted over a 1½ year period. Although this period was not sufficient to fully incorporate all resulting ideas into forest and park management, it was sufficient to complete a step in the adaptation process in which relevant science was presented and summarized, vulnerabilities were assessed, and initial adaptation strategies and options were developed.

Scale and Participants

For all workshops, we encountered the challenge of balancing between soliciting input from many people and having a group small enough to facilitate discussion.

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The need for progress within a specific timeframe, and for continuity and commitment to the process over many months, in addition to the scheduling, logistics, and orchestration of a large-group planning process, were primary factors that led to limiting this initial effort to the forest and park. The structure of the workshops, which differed in size and composition depending on the topic, engaged program managers and resource specialists, and efficiently used the time of all participants while also ensuring ample time for discussion. To keep the meetings to a reasonable size, the majority of participants at most workshops were personnel of ONF and ONP (including regional-level staff), and invited scientists. The wildlife workshop included staff from the Washington Department of Natural Resources, the U.S. Geological Survey, and the U.S. Fish and Wildlife Service. The first fish workshop was larger by design because fish (particularly salmonids) are one of the widest ranging, multijurisdictional organisms inhabiting the peninsula. Over 100 representatives from other federal agencies, the state, tribes, universities, and nongovernmental organizations attended this workshop. A clear next step is to include these and other partners in a broader climate change adaptation effort on the peninsula.

Scope

Framing the planning discussions around discrete topics allowed participants to discuss ideas within a group size that allowed all to contribute.

This was especially beneficial because some of the ideas and concepts were new, and participants ranged in knowledge of or engagement in climate change discussions. Participants were able to vet their ideas among peers and found it helpful to either validate or challenge their thinking.

How to Deal With Copious New Information

A common foundation and understanding of information needs to be developed among personnel to proceed in the adaptation process. This can be a time-consuming process.

The workshop format was useful to begin the conversation on how climate change may influence land management and to consider appropriate actions. However, there is much uncertainty associated with climate change, and an enormous amount of climate change information for managers to absorb. Consequently, the planning process should include sufficient time to establish a common foundation of information among participants. In other words, personnel need to be on the same page before they are able to take the next step in the adaptation process, which is to directly incorporate adaptation ideas into projects and planning. Establishing that degree of understanding among all personnel can be a time-consuming process.

Structure for Results

Having more structure to the initial workshops, more prework, or having the workshops expand to several days may help in crafting more specific adaptation actions.

Initial discussions in group settings are often broad and general to explore different perspectives and solicit ideas. Additional steps may be required to distill and refine ideas and consider how these may affect management decisions and priorities. We dealt with this issue through iterative small group (three to four individuals) discussions after workshops. Additional structure may help in developing more specific adaptation options and would also enable more consistent partner participation, as several of the subsequent, small group discussions occurred opportunistically.

The Case for Splitting

The more focused the study emphasis, the more specific the adaptation strategies that resulted.

Bracketing specific disciplines (i.e., hydrology/roads, fish, vegetation, and wildlife) helped to move discussions from generic adaptation ideas, such as increasing ecosystem resilience, to more specific strategies that the agencies can more easily implement. In the vegetation focus area, ONF considered the idea of planting more drought-tolerant species to increase forest resilience, and determined that there are several drought-tolerant, native species that will likely do well in the future on the peninsula, including lodgepole pine and disease-resistant western white pine.

In the hydrology and roads focus area, forest and park engineers discussed the idea of resizing culverts to accommodate increasing streamflow volumes, and ONF proposed two alternative methods for culvert sizing—by using a hydrologic model to predict future peak flows, and by using the last 30 years of record to estimate future peak flows instead of the entire period of record. Plans are underway to explore these approaches.

These focus-area discussions produced tangible strategies. We are not certain that the engineers would have relished the Olympic marmot discussions, nor the wildlife biologists the culvert discussions. Some degree of splitting seemed advantageous.

The Case for Lumping—Synthesis Across Disciplines

Integrating the concepts and plans from various program areas was an important step that should be expanded in future work.

After the various workshops were conducted, we held a synthesis session to compile ideas from the different focus areas, identify common approaches, and determine if any adaptation strategies and actions presented potential conflicts with one another. The synthesis workshop and subsequent small meetings gave resource specialists the opportunity to provide input on adaptation strategies developed in areas outside of their primary area of expertise. For example, the fish biologists could give input on adaptation strategies developed for vegetation management and identify any potential conflicts with fish resources. This synthesis of adaptation options for different focus areas helped refine the adaptation ideas and focus on key strategies that were common across focus areas (see themes section below). The strategies that were common across focus areas are most likely to be implemented, because these strategies are most likely to have the biggest impact. In future adaptation planning, this synthesis portion of the work could be expanded, with periodic integrated discussions (across focus topics) held at regular intervals throughout the planning process.

Making It Real—Incorporate Geospatial Planning

The Olympic Climate Change Case Study process is an excellent first step as the agencies move forward in preparing for a changing climate, but scaling to local actions requires additional work.

To apply results from the workshops, more detailed and site-specific examples would assist managers and other landscape planning efforts. Ideally these adaptation concepts would have geospatial references. For example, the next iteration of planning for fish resources would include delineation of high-priority restoration sites. However, that level of effort was not possible within our funding and time limits.

Dealing With Uncertainty

We used several approaches to work with or around uncertainty, including focusing on changes that have been observed in the past and with recent warming; focusing on similarities between different climate and impacts scenarios, and the most likely and plausible trends; using local knowledge of forest and park specialists to predict system response to climate change; and focusing on no-regrets strategies.

A key lesson learned about dealing with uncertainty is that the full range of future climate and climate change effect projections must be considered when developing adaptation strategies. We quickly realized it was impossible to know the best future projection for any particular area (e.g., hydrology and vegetation), so adaptation strategies must be robust. Adding scenario planning to the exercise would be a useful next step. However, we used several other approaches to work with or around uncertainty to develop tangible adaptation strategies. First, in assessing sensitivity to climate change in each focus area, we considered ecological changes that have been observed with climatic variability in the past or that have already been observed with recent warming. When assessing projected effects of climate change, we focused on similarities between the various future climate and effects scenarios, and the most likely trends. We used local knowledge of ONF and ONP staff and regional scientists to help predict species and system response to changing climate on the Olympic Peninsula. Finally, in developing adaptation strategies, we always focused on no-regrets approaches, or strategies that will increase ecosystem function and resilience regardless of the exact nature of future climate. Additional work will be needed to build on these results, and to integrate with neighboring lands.

Rethinking Management Goals

Climate change challenges current precepts and guidelines, and determining management goals within what may be entirely new ecosystems will be needed.

In the long term, yet still within planning horizons for both agencies, ecosystem changes and disturbances may occur more quickly in systems that have been relatively stable for hundreds or thousands of years. Determining management goals within what may be entirely new ecosystems will be needed. When once we might have observed or monitored, we may now need to undertake manipulative experiments that are different from any current management practices, particularly in the park. Goals that will be appropriate for fire management in environments modified by climate change are unclear. Similarly unclear are goals for wilderness management in potentially highly altered environments of the future. These and other questions indicate the limits of current understanding.

The case study exercise highlighted other situations that challenge our precepts and current guidelines. For example, although specialists may readily accept new concepts of ecosystem change, imagining how to address anticipated new conditions within current guidelines and definitions was sometimes a challenge. This was particularly evident at the wildlife workshop in which participants readily acknowledged that communities will be disrupted, that there will likely be different species assemblages in the future, and that managing for processes may be more important than managing for particular species. In this context, the question of whether the definition of exotic species will be altered with climate-induced changes in species distributions is, as yet, unanswered by ecologists and policymakers. For example, the barred owl arrived relatively recently on the peninsula and scientists have hypothesized that human-caused landscape changes or even recent climate change enabled its population expansion to the west coast of the United States (Kelly et al. 2003). Under current policies, biologists view the barred owl as an invader as opposed to a member of a new faunal assemblage. Climate change, like human structural development, is a human-caused modifier of habitats and ecosystems. As species move in response to habitat loss or gain caused by climate change, new management goals and a new definition for exotics will be needed.

Capacity

The climate change adaptation process benefits from having an individual or individuals dedicated to facilitating the process and also requires focused time from staff specialists.

This case study project had the benefit of full-time assistance from a research ecologist associated with the University of Washington’s School of Forest Resources who organized and facilitated the workshops, invited and scheduled speakers, took notes, synthesized literature, provided presentations of projected climate change effects, and prepared draft manuscript chapters for the case study report. This effort was essential for developing science-based adaptation strategies with sufficient depth for clear application to agency management.

In addition to managing the workload associated with organizing a planning process, focused time from staff specialists is essential. Adaptation or scenario planning added to existing workloads is challenging to implement. To fully develop robust, place-based adaptation strategies, either the responsibilities of staff specialists’ day jobs must be temporarily relieved, or a process established and funded much like watershed analysis conducted under the Northwest Forest Plan (USDA and USDI 1994) to develop adaptation strategies. Climate change could also be incorporated into other appropriate planning efforts. Appropriate facilitation and strong commitments by all parties are essential. Lack of funding or support may hinder progress, but in the face of potential effects of climate change, postponing discussions on adaptation may reduce options for managing potentially adverse conditions in some ecosystems.

Raising Awareness

The workshops helped foster a cultural shift needed to incorporate climate change considerations into thoughts, plans, and actions for managers. This will be an ongoing, continually evolving process.

In some respects, at this early stage, it is less about developing the best adaptation plans and more about raising awareness, engaging a full range of participants, and enabling federal land managers to collectively think in new ways.

Themes in Climate Change Adaptation Strategies at Olympic National Forest and Olympic National Park

Several themes in adaptation strategies and actions emerged during the case study. In all four focus areas, contemplating the projected effects of climate change made the new management paradigm obvious—decisions can no longer assume a future that mirrors historical ecosystem conditions. Given the dynamic nature of climate and ecosystems, maintaining ecosystem function and biodiversity and increasing ecosystem resilience are often cited as suitable goals for adaptation in a changing climate (e.g., Baron et al. 2008, Blate et al. 2009, Dale et al. 2001, Joyce et al. 2009, Millar et al. 2007, Spittlehouse and Stewart 2003). The case study identified numerous ways to maintain ecosystem function and biodiversity and increase resilience to climate change at ONF and ONP. However, the looming questions of determining conditions for considering assisted migration, or redefining exotics, remain for discussion across broader spatial scales.

Workshop participants frequently remarked on the importance of monitoring as a critical element in tracking ecosystem change, and in serving adaptive management efforts to determine effects of management actions. Monitoring, restoration, and protection were often proposed for the most climate-sensitive habitats on the peninsula, including headwater streams and high-elevation ecosystems.

Assessment of current management activities revealed that management strategies at ONF and ONP are generally consistent with those that are likely to increase species and ecosystem resilience to climate change. The case study also helped identify new potential actions, and actions that could be increased or reprioritized, or both. For example, an adaptation strategy for both agencies is to plan for larger and additional culverts on roads. A new strategy for ONF, where managers currently conduct forest thinning to promote late-successional conditions, may be to alter the nature and increase the extent of thinning activities to further increase forest resilience to drought. Prioritization of thinning activities around existing late-successional forest could also help to increase habitat quality for some wildlife species. And although ONF does not currently place large wood in headwater channels to restore natural sediment routing, this will be considered as a way to help restore and protect headwater streams and the species that depend on them. These and other ideas will require more indepth and integrated analysis before implementation.

Next Steps

Collaboration between land and resource management agencies in response to climate change is critical. The Olympic Climate Change Case Study illustrated the utility and success of agency collaboration in climate change adaptation planning. Although differences in mandates and management approaches exist between the forest and park, many ideas were developed about ways that ONF and ONP can work together to adapt to climate change.

Some adaptation ideas can be implemented right away, whereas others may be inappropriate until some of the projected effects of climate change are realized. Alternatively, small-scale experiments can be considered in the near term as a hedging strategy. Scenario planning to describe plausible futures, associated management strategies, and conditions that would trigger one decision over another, is a next logical step to build on this case study. Continual evaluation of the realized and projected effects of climate change will help determine appropriate triggers for specific actions. Future iterations of a process such as the one used in this case study will also likely lead to better informed adaptation actions by natural resource agencies.

Agency policies may either help or hinder collaboration and the adaptation process in general. Except for actions proposed in small areas, or for species that have very limited range, many adaptation strategies may fail unless managers of large landscapes concur on goals and objectives more broadly than at present. Although it is uncertain exactly how regulations, agency policies, or guidelines may change in the future, they may need to evolve to encourage greater agency collaboration in addressing climate change. Climate change adaptation is a process that requires continued awareness and attention by managers. Staying abreast of available information on potential climate change effects is essential to determine additional ways to incorporate climate change adaptation into management. This case study is a beginning; in the future, we plan to expand its scope and create additional partnerships that will improve the process and products from this work.

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English Equivalents

When you know:	Multiply by:	To find:
Millimeters (mm)	0.039	Inches
Centimeters(cm)	.394	Inches
Meters (m)	3.28	Feet
Kilometers (km)	.621	Miles
Hectares (ha)	2.47	Acres
Square meters (m^2)	10.76	Square feet (ft^3)
Square kilometers (km^2)	.386	Square miles
Cubic meters per second (m^3/sec)	35.3	Cubic feet per second (cfs)
Degrees Celsius	1.8 °C + 32	Degrees Fahrenheit

Common and Scientific Names

American kestrel	*Falco sparverius* L.
American marten	*Martes americana* Turton
American pika	*Ochotona princeps* Richardson
American shad	*Alosa sapidissima* Wilson
Bald eagle	*Haliaeetus leucocephalus* L.
Balsam woolly adelgid	*Adelges picea* Ratzeburg
Barred owl	*Strix varia* Barton
Bass	*Micropterus* spp.
Beargrass	*Xerophyllum tenax* (Pursh) Nutt.
Bighorn sheep	*Ovis canadensis* Shaw
Bigleaf maple	*Acer macrophyllum*
Pursh	
Bobcat	*Lynx rufus* Schreber
Bracken fern	*Pteridium aquilinum* (L.) Kuhn
Bull trout	*Salvelinus confluentus* Suckley
Bushy-tailed woodrat	*Neotoma cinerea* Ord
Camas	*Camassia quamash* (Pursh) Greene
Canada lynx	*Lynx canadensis* Kerr
Cascades frog	*Rana cascadae* Slater
Cattail	*Typha latifolia* L.
Channel catfish	*Ictalurus punctatus* Rafinesque
Chinook salmon	*Oncorhynchus tshawytscha* Wolbaum
Chum salmon	*Oncorhynchus keta* Wolbaum
Clark's nutcracker	*Nucifraga columbiana*
Coho salmon	*Oncorhynchus kisutch* Wolbaum
Columbia black-tailed deer	*Odocoileus hemionus columbianus* (Richardson)
Cope's giant salamander	*Dicamptodon copei*
Coyote	*Canis latrans* Say
Cutthroat trout	*Salmo clarki* Richardson
Dog star skipper butterfly	*Polites sonora siris* (W.H. Edwards, 1881)
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Douglas-fir beetle	*Dendroctonus pseudotsugae* Hopkins
Garter snake	*Thamnophis* spp.
Giant chinquapin	*Chrysolepis chrysophylla* (Douglas ex Hook.) Hjelmqvist
Grand fir	*Abies grandis* (Douglas ex D. Don) Lindl.
Gray wolf	*Canis lupus* L.
Gray-crowned rosy finch	*Leucosticte tephrocotis*
Grizzly bear	*Ursus arctos horribilis* Ord
Ground squirrel	*Spermophilus* spp.
Huckleberries	*Vaccinium* spp.

Japanese knotweed	*Polygonum cuspidatum* Siebold & Zucc.
Keen’s myotis bat	*Myotis keenii* (Merriam)
Little brown bat	*Myotis lucifugus* LeConte
Lodgepole pine	*Pinus contorta* Dougl. ex Laud.
Long-legged bat	*Myotis evotis* (H. Allen)
Long-toed salamander	*Ambystoma macrodactylum* (Baird, 1889)
Makah copper butterfly	*Lycaina mariposa*
Marbled murrelet	*Brachyramphus* (Reakirt, 1866) *marmoratus* Gmelin
Mountain beaver	*Aplodontia rufa* Rafinesque
Mountain goat	*Oreamnos americanus* de Blainville
Mountain hemlock	*Tsuga mertensiana* (Bong) Carr.
Mountain pine beetle	*Dendroctonus ponderosae* Hopkins
Nettle	*Urtica dioica* L.
New Zealand mud snail	*Potamopyrgus antipodarm* J.E. Gray
North American black bear	*Ursus americanus* Pallas
North American Porcupine	*Erethizondorsaturn* (L.)
Northern alligator lizard	*Elgaria coerula* Wiegmann
Northern flying squirrel	*Glaucomys sabrinus* Shaw
Northern goshawk	*Accipiter gentilis* L.
Northern spotted owl	*Strix occidentalis caurina* Merriam
Northwestern salamander	*Ambystoma gracile* Baird
Olympic marmot	*Marmota olympus* Merriam
Olympic mudminnow	*Novumbra hubbsi* Schultz
Olympic pocket gopher	*Thomomys mazama melanops* Merriam, 1899
Olympic torrent salamander	*Rhyacotriton olympicus* (Gaige, 1917)
Oregon white oak	*Quercus garryana* Douglas ex Hook.
Pacific chorus frog	*Pseudacris regilla* Baird & Girard
Pacific fisher	*Martes pennanti* (Erxleben, 1777)
Pacific madrone	*Arbutus menziesii* Pursh
Pacific silver fir	*Abies amabilis* (Douglas ex Louden) Douglas ex Forbes
Pallid horned lark	*Otocoris alpestris arcticola* Orberholser
Perch	*Perca* spp.
Pileated woodpecker	*Dryocopus pileatu* L.
Pink salmon	*Oncorhynchus gorbuscha* Wolbaum
Ponderosa pine	*Pinus ponderosa* Dougl. ex C. Laws.
Pygmy nuthatch	*Sitta pygmaea* Vigors
Rainbow trout	*Oncorhynchus mykiss* Wolbaum
Red alder	*Alnus rubra* Bong.
Red fox	*Vulpes vulpes* L.
Red osier dogwood	*Cornus sericea* L.
Red-legged frog	*Rana aurora* Baird & Girard
Redwood	*Sequoia sempervirens* (Lamb. ex D. Don) Endl.
Roosevelt elk	*Cervus canadensis roosevelti* T
Salal	*Gaultheria shallon* Pursh
Salmonberry	*Rubus spectabilis* Pursh
Snowshoe hare	*Lepus americanus* Erxleben
Sockeye salmon	*Oncorhynchus nerka* Wolbaum
Steelhead	*Oncorhynchus mykiss* Wolbaum
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Tailed frog	*Ascaphus truei* Stejneger
Taylor’s checkerspot butterfly	*Euphydryas editha taylori* (Edwards)
Townsend big-eared bat	*Plecotus townsendii* (Cooper, 1837)

Van Dyke's salamander	*Plethodon vandykei* (Van Denburgh, 1906)
Vaux's swift	*Chaetura vauxi* (J.K.Townsend, 1839)
Violet-green swallow	*Tachycineta thalassina* Swainson
Virginia Opossum	*Didelphis Virginiana* Kerr
Warty jumping slug	*Hemphillia glandulosa* Bland & Binney
Western heather vole	*Phenacomys intermedius* Merriam
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western redcedar	*Thuja plicata* Donn ex D. Don.
Western toad	*Bufo boreas* Baird & Girard
Western white pine	*Pinus monticola* Douglas ex D. Don
White-tailed ptarmigan	*Lagopus leucura* Richardson
Willow	*Salix* spp. L.
Wolverine	*Gulo gulo* L.
Yellow-bellied marmot	*Marmota flaviventris* Audubon & Bachman
Zebra mussel	*Dreisenna polymorpha* Pallas

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Glossary

Adaptation—(1) An adjustment in ecological, social, or economic systems in response to climate stimuli and their effects, which moderates harm or exploits beneficial opportunities; (2) a process, action, or outcome in a system (household, community, organization, sector, region, country) in order for the system to better cope with, manage, or adjust to some changing condition, stress, hazard, risk, or opportunity.

Adaptive capacity—The ability of a system to adjust to changes in climate (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Biodiversity—The sum of species, ecosystem, and genetic diversity Average conditions (mean and variability) in the atmosphere, ocean, and ice sheets and sea ice over a period of time, ranging from months to thousands or millions of years.

Climate change—Change in climate (in mean state or variability) over time. Climate change can occur as a result of changes in the Earth's orbit around the sun, cyclical patterns in circulation of the oceans and atmosphere, cycles in the ocean-atmosphere system, or human-caused activities.

Climate envelope models—Statistical models that predict future species distribution based on the relationship between current species distribution and climate variables (and sometimes other variables).

Climate forcing—A mechanism that affects climate (e.g., changes in the composition of the Earth's atmosphere through greenhouse gas emissions).

Dynamic global vegetation model—Model that is based on soil and climate information that simulate key physiological processes in plant communities to infer vegetation type over time.

Ecosystem—A system of interacting living organisms together with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study, and thus, the extent of an ecosystem may range from very small spatial scales to the entire Earth.

Ecosystem management—(1) Management that integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term; (2) any land-management system that seeks to protect viable populations of all native species, perpetuate natural disturbance regimes on the regional scale, adopt a planning timeline of centuries, and allow human use at levels that do not result in long-term ecological degradation.

Ecosystem resilience—The amount of change or disturbance that can be absorbed by an ecosystem before the ecosystem is redefined by a different set of processes and structures (e.g., the ecosystem recovers from the disturbance without a major phase shift).

Ecosystem services—Ecological processes or functions that have value to individuals or society.

Exotic species—Also referred to as "alien," "nonnative," and "'introduced" species. These terms refer to any species that is not native to a particular ecosystem. Nonnative species may or may not be invasive.

Exposure—The character, magnitude, and rate of climate change and variation to which a system is exposed.

Gap model—Model that simulates forest interactions and dynamics on a small, gap-sized patch of land (usually 0.02 acre [0.01 hectare] and larger). Gap models can be used to project potential forest response to climate change.

Global climate models—Global climate models (GCMs) are coupled global climate models of the Earth's atmosphere, oceans, sea ice, and terrestrial biosphere. These computationally intensive numerical models have been under development for many decades and are based on the integration of fluid dynamics, chemical, and sometimes biological equations. They spontaneously exhibit interannual and interdecadal oscillations like those observed in the real Earth system. They are run under different starting conditions and using different amounts of solar, volcanic, and greenhouse gas forcing of the atmospheric dynamics. Using this ensemble approach, various GCMs have successfully simulated the Earth's climate over the past 1,000 years.

Greenhouse gases—Gases that trap heat in the atmosphere. The main greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Invasive species—A species, usually exotic, with the potential to spread rapidly and cause economic or environmental harm.

Intergovernmental Panel on Climate Change (IPCC)— A scientific intergovernmental body that evaluates the risks associated with human-caused climate change. The United Nations established the panel in 1988. The IPCC has published a series of special reports and periodic assessment reports (approximately every 5 years since 1990).

Native species—A species that historically occurred or currently occurs in a given ecosystem and that has not been introduced through human activities.

Phenology—The timing of an organism's life history events (e.g., flowering in plants) that are cued by the organism's environment.

Rain-dominant watershed—A watershed that receives most precipitation as rain. Climate change will likely have minimal impact on timing of streamflow in rain-dominant watersheds.

Restoration—Manipulation of the physical and biological environment in order to restore a desired ecological state or set of ecological processes.

Sensitivity—The degree to which a system will respond to a given stimulus.

Snowmelt-dominant watershed—A watershed that stores most winter precipitation in snowpack. This snowpack melts in the spring and early summer, resulting in peak streamflow in the late spring or early summer and lower streamflow during the winter months. Both increased winter rain (as opposed to snow) and shifts to earlier spring snowmelt with climate change will result in higher winter and spring streamflows and lower summer streamflows in snowmelt dominant watersheds.

Snow water equivalent—The depth of water in the snowpack, if the snowpack were melted.

Special Report on Emissions Scenarios (SRES) emissions scenarios—The SRES was published by the Intergovernmental Panel on Climate Change for their third assessment report in 2001. The report gave details on potential future greenhouse gas emissions scenarios, which are dependent on current and future human activities, to drive global climate models. There are 40 emissions scenarios, all making different assumptions about technological and economic development. Of these 40, the three most commonly used scenarios are the B1 (relatively low future emissions), A1B (moderate future emissions), and A2 (relatively high future emissions).

Stressor—An agent, condition, or other stimulus that can reduce the vigor or functionality of biological entities ranging from species to ecoystems.

Transient watershed—Watersheds located primarily at mid elevations that receive some snow and some rain. Streams and rivers draining transient watersheds often have one streamflow peak in fall or early winter owing to runoff generated by precipitation falling as rain, and another peak in late spring when the snowpack accumulated in midwinter melts. Both increased winter rain (as opposed to snow) and shifts to earlier spring snowmelt with climate change will result in higher winter and spring streamflows and lower summer streamflows in transient watersheds.

Vulnerability—The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climatic variability and extreme.

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