SECTION 9

How Will Climate Change Affect Terrestrial Ecosystems?

Terrestrial ecosystems in the Puget Sound region are projected to experience a continued shift in the geographic distribution of species, changes forest growth and productivity, increasing fire activity, and changing risks from insects, diseases, and invasive species. These changes have significant implications for ecosystem composition and species interactions. Changes are projected to be most pronounced at high elevations, where increasing air temperatures and declining snowpack can degrade habitat quality for some species but benefit others via a longer snow-free season and increased biological productivity. Many of the changes expected for Puget Sound forests are likely to be driven by increases in the frequency and intensity of disturbances such as fire, insect outbreaks, and disease. Efforts to address impacts on terrestrial ecosystems in the region are increasing, particularly in the area of adaption planning, where many local organizations, agencies, and tribes have already begun to engage in planning and collaboration between scientists, managers, and stakeholders.

Climate Drivers of Change

Projected changes in the Puget Sound region's[A] terrestrial environment are driven by increasing air temperature, reduced snow accumulation, and declining summer precipitation.

- *Observations show a clear warming trend, and all scenarios project continued warming during this century*. Most scenarios project that this warming will be outside of the range of historical variations by mid-century (see Section 2).[1,2,3] Warming, along with reduced snowpack, will result in a longer growing season and an earlier onset spring growth. Declining snowpack will also drive a decline in summer water availability, with consequences for soils, streams, and groundwater.[4,5,6] Finally, the associated shift to earlier peak streamflows could negatively affect floodplain wetlands.[7]

- *Most models are consistent in projecting a substantial decline in summer precipitation.* Projected changes in other seasons and for annual precipitation are not consistent among models, and trends are generally much smaller than natural year-to-year variability.[2] Projected decreases in summer precipitation will exacerbate the temperature-induced shift from snow accumulation to rain.

A Throughout this report, the term "Puget Sound" is used to describe the marine waters of Puget Sound and the Strait of Juan de Fuca, extending to its outlet near Neah Bay. The term "Puget Sound region" is used to describe the entire watershed, including all land areas that ultimately drain into the waters of Puget Sound (see "How to Read this Report").

Changes in Timing of Biological Events

Climate change could alter the timing (or "phenology") of some biological events.

- *A lack of sufficiently cold air temperatures may delay leaf emergence.* Studies of Douglas-fir in western Washington and Oregon[B] have found that warmer air temperatures may result in earlier spring growth initiation,[8] but that rising winter air temperatures could lead to delayed leaf emergence due to an unfulfilled winter chill requirement.[9] One study documented irregular leaf timing in plants with a winter chilling requirement (including Douglas-fir) that received no to low levels of chilling.[10]

Changes in the Geographic Distribution of Species

Climate change is projected to alter species' geographic distributions. Some species may be unable to move fast enough to keep pace with shifting climates, which may result in local extinctions. Both range shifts and local extinctions are likely to lead to changes in the composition of biological communities in the Puget Sound region. Because species will respond individualistically, effects should be considered on a case-by-case basis. For many species, the effects of land-use and fragmentation may act as a more serious stressor than climate change. Regional examples include:

- *Wolverine (Gulo gulo) habitat is projected to decline*. One study, modeling snow distribution[C,D], predicted that while contiguous areas of spring snow cover would shrink and fragment, large areas of wolverine habitat (>400 mi^2) would persist in north-central Washington (Figure 9-1).[11] Another study found that climate change could result in a significant decline in wolverine distributions across the western three-quarters of Washington.[12] Wolverines are also projected to undergo a significant shift to higher elevations in Western Washington.[E,12]

- *Northern Spotted Owl (Strix occidentalis caurina) habitat may decline*. The primary threat to northern spotted owls is a lack of old-growth forest, primarily as a consequence of historical logging practices. Climate change may put these habitats

[B] Many characteristics of Puget Sound's climate and climate vulnerabilities are similar to those of the broader Pacific Northwest region. Results for Puget Sound are expected to generally align with those for western Oregon and Washington, and in some instances the greater Pacific Northwest, with potential for some variation at any specific location.

[C] Distribution of snow cover was modeled using a downscaled ensemble climate model. The ensemble model was based on the arithmetic mean of 10 global climate models under a single greenhouse gas scenario, A1B.

[D] Greenhouse gas scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. These are described in the text as follows: "very low" refers to the RCP 2.6 scenario; "low" refers to RCP 4.5 or SRES B1; "moderate" refers to RCP 6.0 or SRES A1B; and "high" refers to RCP 8.5, SRES A2, or SRES A1FI – descriptors are based on cumulative emissions by 2100 for each scenario. See Section 1 for details.

[E] Data for the mammal species' current ranges were obtained from the Washington State Gap Analysis Project. Future climate and ecological data (all provided by the Oregon State MC1 model) were based on two global climate models, including the high-sensitivity MIROC 3.2 medres and the intermediate-sensitivity Hadley CM 3. The mid-level A1B, and a high-level A2 CO_2 greenhouse gas scenarios prepared by the IPCC were used in this analysis.

at risk as a result of projected increases in wildfire. In addition, one study examining the effects of climate change and management practices on northern spotted owl habitat in coastal Washington found that climate change may result in vegetation shifts away from types that are typically associated with high quality spotted owl habitat, with many outer coastal watersheds having a <20% probability of maintaining current levels of high quality owl habitat by the end of the century.[B,F,13]

- *Garry Oak (Quercus garryana) habitat may increase or decrease.* One set of model projections showed a significant contraction of the range of Oregon white oak / Garry oak on the west side of the Cascades and an expansion on the east side of the Cascades by the end of the century. This shift is a result of increasing air temperatures projected west of the Cascades.[G,14] However, another study found that climate suitability for Garry oak is generally projected to increase across Washington, Oregon, and British Columbia.[B,15]

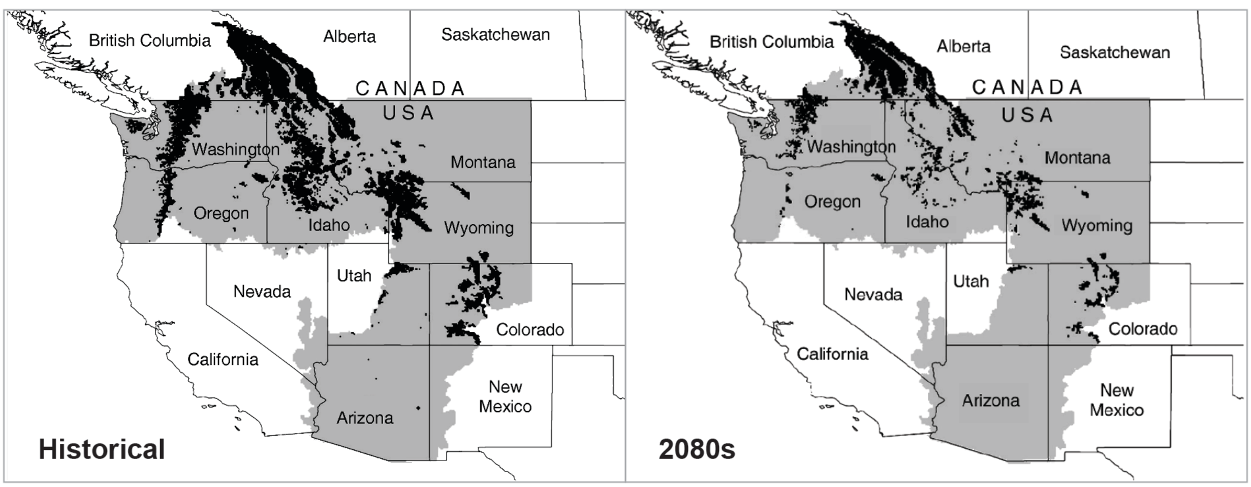

Figure 9-1. Declining Wolverine habitat with increasing temperatures. Maps show the extent of snowcover historically (1916-2006, left) and simulated for the 2080s (2070-2099, right) for a moderate (A1B) greenhouse gas scenario. The study area is shown in gray, and snow cover is black. The authors classified each point as wolverine habitat if snow depth exceeded 13 cm (about 5 inches) through 15 May. *Figure Source: McKelvey et al. 2011.[C,11] Reproduced with permission.*

F MC2 Dynamic Global Vegetation Models were run using different GCM projections. Global climate models were from the World Climate Research Program's Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset and were run under the Intergovernmental Panel on Climate Change Special Report on greenhouse gas scenario A2.

G Species distributions were simulated under present climate using observed data (1951–80, 30-year mean) and under future climate (2090–99, 10-year mean) using scenarios generated by three general circulation models—HADCM2, CGCM1, and CSIRO.

- *Increasing air temperatures and decreasing summer precipitation are projected to reduce the climatic range of bird species in the region.* While specific estimates for the Puget Sound region are not available, projections for Washington State indicate that the current climatic ranges of 113 bird species may decline by −50% or more (relative to 1971-2000) by the 2080s.[B,H] Bird species with projected climate range declines include, but are not limited to: the bald eagle, black oystercatcher, black-bellied plover, western grebe, trumpeter swan, rhinoceros auklet, and the gray-crowned-rosy-finch.[16]

- *Increasing air temperatures may result in increased tree growth at high elevations,[17] as well as local tree expansion into subalpine meadows.* One study projects that suitable conditions for subalpine and tundra vegetation could decline by the end of the 21st century with warming on the Olympic Peninsula.[I,18] Montane meadows in the North Cascades may also decrease in extent as reduced snowpack and longer growing seasons allow trees to establish in meadow areas.[17,19]

- *Climate change may lead to prairie expansion in the Puget Sound region.* Increases in summer water stress will negatively affect less drought tolerant trees and species adjacent to prairies, potentially enabling prairie ecosystems to expand.[20] Increases in winter precipitation may also lead to an increase in the area of wetland prairies in south Puget Sound.[20] Further research is needed on how exotic prairie species in the Puget Sound region will respond to climate change.

Forests

Climate change is projected to affect the distribution and productivity of Puget Sound forests. Changes are driven by increasing air temperatures, reductions in snowpack, and declining summer water availability.

- *The geographic distribution of forests is projected to change.* Increasing air temperatures and drier summer conditions are likely to reduce the area of climatically suitable habitat for Douglas-fir[21] in lower elevations of the Puget Sound region, specifically in the south Puget Sound and southern Olympic Mountains, by the end of the 2060s.[23] Across the entire Pacific Northwest, western hemlock, whitebark pine, and western redcedar may expand their ranges under climate change by the end of the century.[J] The occupied area of climatically suitable habitat

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H Spatially downscaled (5-min resolution) climate grids for 2010-2039, 2040-2069, and 2070-2099 were obtained from the International Center for Tropical Agriculture (CIAT) for combinations of 3 greenhouse gas scenarios (A2, A1B, B2) and 9 general circulation models. Results shown used a high greenhouse gas scenario (A2).

I Projections for the MC1 vegetation model incorporated two greenhouse gas scenarios: A2 and B1, and three global climate models: CSIRO, MIROC, Hadley. Projections were generated for 2040-2060, and 2070-2099.

J These projections do not account for the deleterious effects of forest pests, which could potentially affect distributions of tree species.

for ponderosa pine is projected to decline by the end of the century.[K,22]

- *Declining snowpack is projected to result in increased growth.* In the high elevations of the Olympic and Cascade ranges, tree establishment and growth is limited by the amount of snowpack and the duration of the snow season.[19,24] Increasing air temperatures will result in lower snowpack levels and earlier snowmelt. This will allow for an earlier start to the growing season and increased productivity in high elevation forests.[19,24]

- *Decreased water availability will cause further summer water stress.* Forests that are currently water stressed in summer are likely to experience more severe or longer duration water stress in the future.[2,19,23] Increased water stress is likely to result in decreased tree growth and declining forest productivity,[I] in particular for the northeastern forests of the Olympic Peninsula.[24] These declines in water availability will decrease fuel moisture, and will likely increase fire risk in these forests,[23] which in turn, could increase susceptibility to pine beetle outbreaks.[25]

- *The balance between increases in the growing season and decreased summer water availability will differ from place to place.* North Cascade forests will experience a longer growing season but less water available to support ecosystems. The southwest Olympic Peninsula will experience a longer growing season with sufficient moisture levels to support increased growth, while the northeast Olympic Peninsula will experience a longer growing season with drier summer conditions.[26] Projections are not currently available for central Cascade forests. The net effect of these shifts depends on the extent of summer drying in each location. [19,23]

Wildfire

WILDFIRE ***Climate change is expected to increase fire activity in the Puget Sound region, even though the area is not thought to have been fire prone historically.***[L,23,27] Increasing air temperatures and drier conditions are the primary mechanisms leading to projected increases in area burned for Washington State.[23]

- *Past fires have been large but rare in the Puget Sound region.* Fire history west of the Cascades is defined by infrequent, large, stand-replacing fires[M] occurring every 200 to 500 years.[28,29,30] There were three major burning episodes on the Olympic Peninsula during the Little Ice Age (1300-1750), the last of which occurred between 313 and 346 years ago. This fire (or multiple fires) burned more than one million acres on the Olympic Peninsula, and between three and ten million acres in western

K This study extended through 2100 and used projections from the Canadian global circulation model with a high greenhouse gas scenario (A2) and a baseline climate period between 1950-1975.

L Statistical models of area burned were not run for the Coast Ranges/Olympic Mountains and Puget Trough / Willamette valley because there were too few observations from which to draw a statistical relationship.[23]

M A “stand-replacing fire” refers to a fire in which most of the forest is killed.

Washington.[31] On the Olympic Peninsula, fires are more frequent among the drier western hemlock, subalpine fir, and Douglas fir forests on the eastern side of the peninsula.[31,32,33]

- *Area burned is projected to increase.* Two different studies estimate that the annual area burned for Northwest forests west of the Cascade crest could more than double, on average, by 2070-2099 compared to 1971-2000.[N,23,O,34] However, the models used to project fire risk west of the Cascades are limited in their ability to capture the rare combination of conditions associated with wildfires in the region. Further research is needed to clarify the mechanisms of changing fire risk and severity in the Puget Sound region.

WILDFIRE ***Projected increases in wildfires in the western Cascades may negatively affect the ability of terrestrial ecosystems to store carbon.*** It is not known if increased ecosystem productivity resulting from longer growing seasons and increased carbon dioxide (CO_2) concentrations will offset carbon losses from wildfires.[N,27,35,36]

- *Carbon storage is projected to decline.* Fire risk is projected to increase for the maritime forests west of the Cascades. These forests could possibly lose up to –46% of ecosystem carbon stocks (1.2 billion metric tons of carbon) by the end of the century. Fire suppression was incorporated in model simulations but was shown to be unable to mitigate these fire-induced carbon emissions.[N,34] Another study projects that by the 2040s the mean live biomass (Mg C/ha) in the western Cascades will decrease by –24% to –37% by the 2040s (2030-2059).[P,27]

Insects and Disease

Insect and disease outbreaks are projected to change in prevalence and location, as forests become more susceptible due to climate stressors (e.g., increasing water stress), and areas climatically suitable for outbreaks shift. However, making generalizations about how pathogens will respond to climate change is difficult because responses are likely to be species- and host-specific.

- *Some diseases and pathogens could become more prevalent, while others may not.* Projected increases in air temperature and declines in summer water availability will likely decrease the effect of sudden oak death, *Dothistroma* needle blight, Swiss

[N] Based on a statistical model linking wildfire area burned with climate conditions. Projections are based on ten global climate model projections for a low (B1) and a moderate (A1B) greenhouse gas scenario.

[O] Changes from historical (1971-200) to future (2070-2099) modeled using MC1 vegetation model projections based on three global climate models (CSIRO-Mk3, Hadley CM3, and MIROC 2.3 medres) under a high (A2) greenhouse gas scenario.

[P] Climate variables and area burned were projected based on the ensemble of 20 general circulation models archived for the IPCC AR4 with two SRES greenhouse gas scenarios: a low (B1) and moderate (A1B) greenhouse gas scenario. These projected changes were relative to the "historical" time period which was classified as the "presettlement" period, ranging from late 1500s – 1910.

needle cast (Figure 9-2), and white pine blister rust on forest communities in the Puget Sound region. Some tree species affected by these forest diseases include Douglas-fir, Pacific madrone, and white pine. Conversely, warming and declines in summer water availability will likely increase the impact that *Armillaria* root disease and some canker pathogens have on forest communities in the Puget Sound region.[37] *Armillaria* root disease and canker pathogens affect conifer and hardwood trees in the Puget Sound region.

- *Bark beetles are projected to become less prevalent in the Cascade and Olympic ranges.* While current air temperatures in areas of the Olympic Mountains and western white pine forests of the Cascade Mountains are suitable for bark beetles, modeled results suggest that increasing air temperatures may lead to shifts in the areas of suitability for bark beetles to higher elevation forests in the Cascade and Olympic ranges.[Q,23]

Figure 9-2. Douglas-fir needles showing the effect of Swiss needle cast (*Phaeocryptopus gaeumannii*) infection. *Figure source: USDA Forest Service https://en.wikipedia.org/wiki/Phaeocryptopus_gaeumannii*

[Q] In this study, historical (1970–1999) air temperatures were used to predict current adaptive seasonality of bark beetles. Future (2070–2099) air temperature suitability was calculated for two future climate scenarios (ECHAM5 and HADCM, A1B SRES scenario).

Invasive Species

Climate change will affect the establishment, distribution, and impact of current and potential invasive and non-native species.[38] However, it is difficult to make generalizations regarding these species because responses will be based on species-specific climatic tolerances.[19]

- *Non-native species not currently established in the Puget Sound region may be able to colonize the region if climatic conditions fall within their thermally optimum ranges.* Cold air temperature constraints, which may have previously prevented invasive establishment at higher-elevations, will be reduced, potentially leading to increased non-native species establishment in those regions.[38] More research is needed to understand how specific invasive and non-native species within the Puget Sound region will respond to climate change, and which new species will emerge as invasive.

Climate Risk Reduction Efforts

CLIMATE RISK REDUCTION ***Many communities, government agencies, organizations, and tribes are preparing for the effects of climate change on Puget Sound's terrestrial ecosystems.*** Examples include:

- *Science-management collaborations have been established to develop adaptation strategies for addressing climate change effects on forests in western Washington.* For example, the North Cascadia Adaptation Partnership is a Forest Service / National Park Service collaboration that joined with city, state, tribal, and federal partners to increase awareness of climate change, assess the vulnerability of cultural and natural resources, and incorporate climate change adaptation into current management of federal lands in the North Cascades region. More information is available at http://adaptationpartners.org/ncap, which includes the Climate Change Adaptation Library.

- *A guidebook has been developed to assist with developing adaptation options for national forests, including those in Washington.* "Responding to Climate Change in National Forests: A Guidebook for Developing Adaptation Options" includes both strategies and approaches to strategy development.[39] http://www.fs.fed.us/pnw/pubs/pnw_gtr855.pdf

- *Climate adaptation strategies have been or are being developed for specific national forests and national parks.* Developed by bringing numerous stakeholders together with scientists, these strategies include a climate change vulnerability assessment as well as a list of options identified for federal agencies working to incorporate climate change into planning.
    - Adapting to Climate Change at Olympic National Forest and Olympic National Park[18] http://www.fs.fed.us/pnw/pubs/pnw_gtr844.pdf

    - Climate Change Vulnerability and Adaptation in the North Cascades Region, Washington[19] http://www.fs.fed.us/pnw/pubs/pnw_gtr892.pdf

- *The Climate Change Adaptation Library for the Western United States* is derived from climate change vulnerability assessments conducted by Adaptation Partners[R]. Adaptation options are intended to inform sustainable management of natural resources, reduce the negative effects of climate change, transition ecosystems to a warmer climate, and help integrate climate change in natural resource management, planning, and business operations of federal land management agencies. http://adaptationpartners.org/library.php

- *The Pacific Northwest Tribal Climate Change Network* fosters communication between tribes, agencies, and other entities about climate change policies, programs, and research needs pertaining to tribes and climate change. More information is available at http://tribalclimate.uoregon.edu/network/.

- *Many Puget Sound area tribes have already begun to engage in adaptation planning.*

    - *Stillaguamish Tribe Vulnerability Assessment.* The Stillaguamish Tribe is currently conducting a comprehensive climate change vulnerability assessment of target species and habitats within the Stillaguamish Watershed.

    - *Vulnerability assessment and adaptation plan: Jamestown S'Klallam Tribe*. The climate vulnerability assessment and adaptation plan identified key tribal resources, expected climate-related effects, and created adaptation strategies for each resource.[40]

    - *Swinomish Indian Tribal Community Climate Change Initiative.* This project led to the development of two reports: an impact assessment technical report,[41] and a community action plan[42] that included suggestions for adaptation strategies. The Swinomish Indian Tribal Community are currently implementing the following: a regulatory code review with a focus on shoreline/sensitive areas to address issues raised in the assessment and action plan; a reservation wide program to reduce risk of wildfire; and a North Reservation coastal protection plant which focuses on the 1,100 low lying acres on the Reservation most vulnerable to flood risk.

    - *Port Gamble S'Klallam Tribe Vulnerability Assessment and Web-Based Adaptation Tool.* The Port Gamble S'Klallam Tribe is currently conducting a climate change vulnerability assessment and is also developing a web-based "Tribal Government Adaptation Planning Tool" capable of rapid climate

[R] "Adaptation Partners" is a science management partnership, led by the U.S. Forest Service and other federal agencies, focused on climate change adaptation in the western United States. Adaptation efforts are intended to inform sustainable management of natural resources, reduce the negative effects of climate change, transition ecosystems to a warmer climate, and help integrate climate change in natural resource management and operations: http://adaptationpartners.org/index.php exposure. The Tribe also plans to develop an adaptation plan that will be used to address economic and resilience concerns of the Tribe.

- *The Nooksack Indian Tribe has commenced a large climate change project that addresses glacier ablation, altered river hydrology, changes in sediment dynamics, and increasing stream temperatures.* A climate change impacts analysis, vulnerability assessment, and an adaptation plan for salmon habitat restoration are in preparation.

- *Quinault Treaty Area Climate Vulnerability Assessment.* An assessment will evaluate potential risks to natural resources of economic and cultural importance.

- *The Puyallup Tribe vulnerability assessment and adaptation plan.* This assessment and subsequent adaptation plan will addresses priority issues within planning areas and sectors such as: Ecosystems, Species, Habitats (including hunting & gathering areas); Water Resources; Agriculture & First Foods; Traditional Lifestyles; Forests; Oceans and Shorelines; Human Health; and Infrastructure and the Built Environment.

Additional resources for evaluating and addressing the effects of climate change on terrestrial ecosystems in Puget Sound.

The following tools and resources are suggested in addition to the reports and papers cited in this document.

- **AdaptWest** is a climate adaptation conservation planning database for Western North America. It offers a spatial database and synthesis of methods for conservation planning aimed at enhancing resilience and adaptation potential of natural systems under climate change. http://adaptwest.databasin.org/
- **Climate and hydrologic scenarios.** The Climate Impacts Group provides downscaled daily historical data implemented at a spatial resolution of 1/16th degree (~30 km^2) and future projections of temperature, precipitation, snowpack, streamflow, flooding, minimum flows, and other important hydrologic variables for 297 specific streamflow locations throughout the western U.S. including 18 locations the Puget Sound region.[45,46,47] http://cig.uw.edu, http://warm.atmos.washington.edu/2860, http://cig.uw.edu/cig/data/wus.shtml
- **Climate and hydrologic scenarios for the Western U.S.** (2015 dataset) This dataset provides future projections of daily climate and hydrology at a spatial resolution of about 4 miles, using new statistical downscaling methods and the new climate projections included in IPCC 2013.[3,43,44] http://climate.nkn.uidaho.edu/IntegratedScenarios/index.php
- **Climate Change Sensitivity Database**, produced by the University of Washington and partners, summarizes the results of an assessment of the inherent climate-change sensitivities of species and habitats of concern throughout the Pacific Northwest. http://climatechangesensitivity.org/
- **Data Basin** is a science-based mapping and analysis platform that aggregates, describes, and shares datasets, maps, and galleries of information of relevance to forest and disturbance change in the Pacific Northwest. http://databasin.org/
- **The Washington Wildlife Habitat Connectivity Working Group** (WHCWG) is a large collaborative effort to identify opportunities for maintaining and restoring landscape connectivity in Washington. Increasing connectivity is a key recommendation of the *Washington State Integrated Climate Change Response Strategy*. WHCWG products offer tools for implementing this recommendation. More information is available at: http://waconnected.org.
- **Climate Adaptation Handbook.** The Washington Department of Fish & Wildlife (WDFW) is developing a *Climate Adaptation Handbook* designed to provide practical, hands on guidance for integrating climate considerations into WDFW activities.
- **Climate Change Adaptation Library.** Adaptation Partners[R] has developed a library that synthesizes climate change vulnerabilities and adaptation options for land management agencies. http://adaptationpartners.org/library.php

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