Adaptations to Climate Change: Colville and Okanogan-Wenatchee National Forests

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Abstract

Forest managers are seeking practical guidance on how to adapt their current practices and, if necessary, their management goals, in response to climate change. Science-management collaboration was initiated on national forests in eastern Washington where resource managers showed a keen interest in science-based options for adapting to climate change. Over a two-day workshop, scientists and managers reviewed current climate change science and identified resources vulnerable to expected climate change. The vulnerabilities identified by the group related to vegetation and habitat management included in two general themes: the conservation of biodiversity, and the restoration of resilient forests and disturbance regimes. The vulnerabilities related to aquatic and infrastructure resources included water quality and quantity; the risk to roads and other facilities from changes to hydrologic regimes; and at-risk aquatic species and habitats. Managers then worked in facilitated groups to identify adaptations that could be implemented through management and planning to reduce the vulnerability of key resources to potential negative consequences of climate change. The identified adaptations were grouped under two major headings: Increasing Ecological Resiliency to Climate Change, and Increasing Social and Economic Resiliency to Climate Change. The information generated from the science-management collaborative represents an initial and important step in identifying and prioritizing tangible steps to address climate change in forest management. Next would be the development of detailed implementation strategies that address the identified management adaptations.

Keywords: Science-management collaborative, Okanogan-Wenatchee National Forest, Colville National Forest, climate change, resource vulnerability, adaptations, resiliency

Contents

Introduction 4
Methods 5
Resource vulnerability questions 7
Adaptation and Mitigation Questions 7
Biogeographical Setting and Natural Resources 8
Colville National Forest 9
Okanogan-Wenatchee National Forest 10
Policy, Planning, and Management Environments 13
Observed and Anticipated Climatic Changes and Effects on Natural Resources 14
Regional Climate Change Overview 14
Disturbances 17
Hydrology and Fish 18
Vegetation 21
Wildlife 23
Changes in species distributions 23
Changes in the timing of breeding and other activities 25
Changes in pathogens and invasive species distributions 25
Changes in survival and extinction risks 26
Changes in interactions among species 27
Resource Vulnerabilities 27
Adapting to Climate Change through Management and Planning 31
Increasing Ecological Resiliency to Climate Change 33
Restore landscape resiliency 33
Restore resiliency of forest stands 34
Maintain or restore biological diversity 35
Implement early detection rapid response for invasive species 35
Treat landscape disturbances as management opportunities 36
Increase social and economic resiliency to climate change 36
Information and Tool Needs 38
Conclusions 39
Literature Cited 41

Introduction

In 2008, then Forest Service Chief Abigail R. Kimbell characterized the Agency's response to the challenges presented by climate change as, "one of the most urgent tasks facing the Forest Service." Kimbell stressed that, "as a science-based organization, we need to be aware of this information and to consider it any time we make a decision regarding resource management, technical assistance, business operations, or any other aspect of our mission" (Kimbell, 2008). The U.S. Forest Service developed a *Strategic Framework for Responding to Climate Change* (USFS 2008a) that identified seven areas to address: science development, adaptation, mitigation, policy, sustainable operations, education, and alliances with partners. Direction provided to forest and district planning teams further developed some of these emphasis areas. These include manual direction on Ecological Restoration and Resilience (FSM 2000, Chapter 2020), and Climate Change Considerations in Project Level NEPA Analysis (USFS 2008b).

Forest managers are seeking practical guidance on how to adapt their current practices and, if necessary, their management goals (Blate et al. 2009, Ogden and Innes 2009, Spies et al. 2010). Adaptations to forest management would ideally reduce the negative impacts of climate changes and help managers take advantage of any positive impacts (Blate et al. 2009, Ogden and Innes 2009). However, it is currently a challenge for national forest and project level planners to scale down both national level policy and regional scale climate science to address site-specific issues. Provided in this report is information for the Okanogan-Wenatchee National Forest (OWNF) and Colville National Forest (CNF) that can be used in both Forest and project level planning.

Science-management collaboration was initiated on national forests in eastern Washington where resource managers showed a keen interest in science-based options for adapting to climate change. Similar efforts have occurred on other national forests (Peterson et al. in prep.) and guide forest management adaptations in Canada (Ogden and Innes 2009). Our work represents a collaboration of an initial effort to develop specific concepts and applications that could potentially be implemented in management and planning to address climate change. This paper (1) summarizes current climate change science relevant to eastern Washington; (2) describes the collaboration process; (3) describes for the OWNF and CNF the adaptation options for climate change identified from this effort; (4) and recommends development of further strategies that implement the highest identified priority adaptations .

Methods

Over a two-day process, a focus group reviewed climate change information and elicited recommendations for adapting forest management. The first day focused on developing a scientific understanding of climate change and the potential effects to resources relevant to the Okanogan-Wenatchee and Colville National Forests. Scientists made presentations and discussion occurred among scientists and resource management staff. The topics covered during the science presentations included:

Pacific Northwest Climatic Variability: Past, Present, and Future	Dr. David L. Peterson, Research Ecologist, Pacific Northwest Research Station
Introduction to the Concepts of Vulnerability and Adaptation	Dr. Jessica Halofsky, Research Ecologist, Pacific Northwest Research Station

Aquatics: Snow and Stream Hydrology	Dr. Rick Woodsmith, Aquatic Ecologist, Pacific Northwest Research Station
Aquatics: Aquatic Biota	Dr. Karl Polivka, Aquatic Ecologist, Pacific Northwest Research Station
Vegetation	Dr. Dave W. Peterson, Research Forest Ecologist, Pacific Northwest Research Station
Disturbances: Insects and Disease	Ms. Darcy Carlson and Dr. Jim Hadfield, Northeast Washington Zone Forest Pathology and Entomology
Disturbances: Fire	Dr. Dave W. Peterson, Research Forest Ecologist, Pacific Northwest Research Station
Terrestrial Wildlife	Dr. Bill Gaines, Wildlife Ecologist, Okanogan-Wenatchee National Forest, Dr. John Lehmkuhl, Research Wildlife Biologist, Pacific Northwest Research Station
Landscape Perspective	Dr. Paul Hessburg, Landscape Ecologist, Pacific Northwest Research Station

The second day focused on elicitation of feedback from OWNF and CNF resource managers about their concerns regarding climate change and recommendations for strategies and specific actions that would promote adaptation. The following questions were posed to resource managers:

Resource vulnerability questions

- How vulnerable is your resource area to anticipated future climate change?
- Where are the key areas of vulnerability (e.g., roads, invasive plants, lynx habitat, fire behavior in dry forests, loss of campgrounds, regeneration failures)?
- What aspect of future climate change creates the vulnerability (e.g., increased summer temperatures/drought, reduced winter snowpack, rain-on-snow events)?
- What is the level of vulnerability for each key area (e.g., high, medium, low)?
- What are the potential impacts of vulnerability (e.g., resource drain, failure of critical mission, loss of ecosystem service, threat to human health/safety, potential property losses)?

Adaptation and Mitigation Questions

- For each area of vulnerability, what management options exist for reducing vulnerability to future climate change (e.g., managing fuels to modify future wildfire behavior)?

- For each area of vulnerability, what management options exist for assisting the resource area to adjust to changing climate? Would these activities be implemented as part of normal work (proactive) or in response to some event or other trigger (reactive)?

- For the options described above, which of these are “no regrets” options that would be good resource management practices even if climate did not change as predicted?

- What information and/or tools are needed to address identified vulnerabilities? Are there any legal, policy, or management barriers to implementing proposed adaptation strategies?

Although the questions were addressed in the order listed, discussions were far ranging and often digressed to topics that had been discussed earlier. The scientists present (the first three authors of this paper) facilitated discussion and recorded responses from the group sessions. The responses were then summarized by topic and reviewed by OWNF and CNF staff for accuracy. In some cases, detail has been reduced in order to highlight the primary ideas and promote clarity.

Biogeographical Setting and Natural Resources

The Okanogan-Wenatchee and Colville National Forests (Forests) are located in north central and northeastern Washington State. The Forests are bounded on the west by the crest of the Cascade Range, on the north by the Canadian border, and on the east by the Idaho border. This area totals over five million acres of National Forest System lands spanning much of the eastern half of Washington State (figure 1).

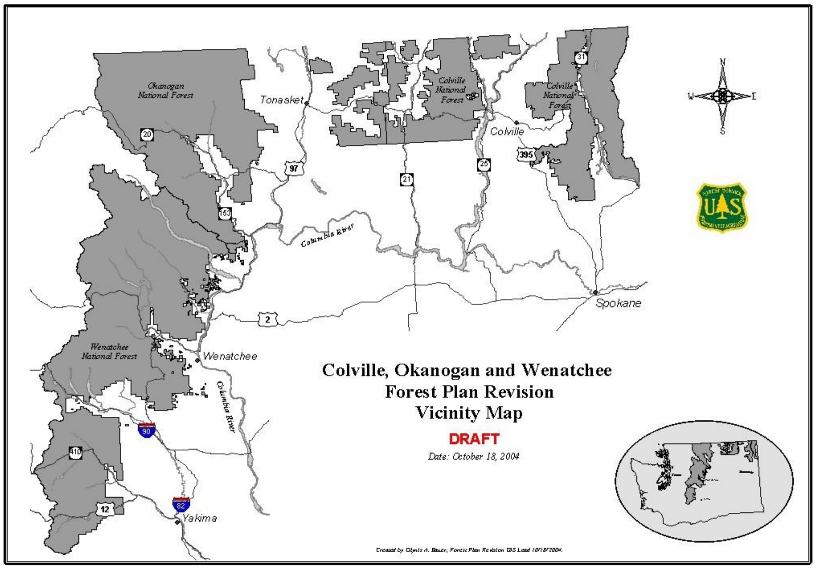

Figure 1. The climate change collaboration case study included the Colville National Forest and the Okanogan-Wenatchee National Forest in northeastern Washington

Dominant forest cover types across the Forests include 668,750 acres of subalpine forest, 1,984,500 acres of cold-moist forest, 342,600 acres of cold-dry forest, 255,900 acres of mesic forests, and 1,593,740 acres of dry forests. Dry and mesic forests have experienced the greatest degree of influence from fire exclusion, resulting in more contiguous fuels, higher risk of uncharacteristically severe wildfire, and forest conditions that are difficult to sustain (Agee 1993, Hessburg et al. 1999, Everett et al. 2000, Wright and Agee 2004, Hessburg et al. 2007).

Colville National Forest

The 1.1-million acre Colville National Forest in northeast Washington is bordered to the north by British Columbia, to the west by the Okanogan National Forest, to the east by the Idaho and Idaho Panhandle National Forests, and to the south by a portion of the

Colville Confederated Tribes Indian Reservation. The Colville Forest has three ranger districts: Republic, Sullivan Lake-Newport, and Three Rivers. The Forest headquarters is located in Colville.

Northeast Washington is geologically complex and includes the Columbia Basin and the Okanogan Highlands, which function as a transition zone between the Cascade and the Rocky Mountain Ranges. The major forest types that comprise the Colville National Forest include 11,900 acres of subalpine forest, 12,900 acres of cold-dry forest, 530,000 acres of cold-moist forest, 492,600 acres of dry forest, and 41,200 acres of mesic forest. About 16,850 acres of the Forest are other non-forest vegetation types. Most of the Colville Forest was burned during the 1920s and 30s, so the current forest is relatively young. Federally listed species include the endangered woodland caribou (*Rangifer tarandus*), threatened grizzly bear (*Ursus arctos*), and Canada lynx (*Lynx Canadensis*). There are currently no federally listed plants on the Colville; however, the moonwart, *Botrychium lineare*, was determined to be warranted but precluded.

Okanogan-Wenatchee National Forest

The Okanogan-Wenatchee National Forest encompasses 3.9 million acres of public land including about 1.4 million acres of designated wilderness. The Okanogan-Wenatchee National Forest includes seven ranger districts, with offices in Naches, Cle Elum, Leavenworth, Entiat, Chelan, Winthrop, and Tonasket. The Forest headquarters office is located in Wenatchee. A Fire Cache and the Wenatchee Valley Rappellers Base are located at Pangborn Airport in East Wenatchee.

The major forest types that comprise the Okanogan-Wenatchee National Forest include 656,800 acres of subalpine forest, 329,700 acres of cold-dry forest, 1,454,400 acres of cold-moist forest, 1,101,100 acres of dry forest, and 214,700 acres of mesic forest. About 17,000 acres are identified as non-forested vegetation.

The Okanogan portion of the Forest is located in north central Washington State, and includes 1.7 million acres of public land, including portions of the Mount Baker-Snoqualmie National Forest. The Okanogan portion of the Forest is comprised of two distinct zones. The western zone includes the Methow Valley. Here, vegetation ranges from sagebrush (*Artemesia spp*.) lowlands, through the dry ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga mensiesii*), western larch (*Larix occidentalis*), and cold-moist subalpine fir (*Abies lasiocarpa*), Engleman spruce (*Picea engelmannii*) forests to timberline where whitebark pine (*Pinus albicaulis*) and mountain hemlock (*Tsuga mertensiana*) share a scattered presence (Williams and Lillybridge 1983). The eastern zone, from the “Meadows” through the Okanogan Highlands, is drier with a far less elevation gradient. Consequently, only the sagebrush and dry forest types are widely represented (Williams and Lillybridge 1983). Federally listed species include the endangered gray wolf (*Canis lupus*), and threatened northern spotted owl (*Strix occidentalis caurina*), grizzly bear, and Canada lynx.

The Okanogan portion of the Forest includes land in several counties including portions of Okanogan, Skagit, Whatcom, and Chelan counties. Okanogan County covers most of the Forest. Forestry, grazing, and recreation are important to local economies and are supported by activities that occur on national forest lands. Water, an important resource provided by the national forest, supports the agricultural industry. Through special use permits, the Loup Loup Ski Bowl and an extensive network of cross-country ski trails provide winter recreation opportunities on national forest lands.

The Wenatchee portion of the Forest includes 2.2 million acres, stretching from Lake Chelan in the north to the Goat Rocks Wilderness in the south. It begins at the crest of the Cascade Range in central Washington and falls sharply to the breaks of the Columbia River. Elevations on the Wenatchee portion range from 800 feet to over 9,500 feet.

Geologic variety and wide differences in amounts of precipitation throughout the Forest result in a diversity in vegetation and an associated richness of wildlife species. The vegetation changes with elevation and moisture as the Forest landscape rises from grassland and shrub-steppe vegetation in the low-lying eastern areas, through stands of ponderosa pine, and into mixed forests of pine, Douglas-fir, and larch (Lillybridge et al. 1995). At higher elevations and closer to the crest of the Cascade Range, subalpine areas support true firs and lodgepole pine, while alpine meadows support stands of alpine firs, larch, and whitebark pine (Lillybridge et al. 1995). Areas near the crest of the Cascade Range receive up to 140 inches of precipitation and as much as 25 feet of snow accumulation each year (Lillybridge et al. 1995). Moisture declines markedly from west to east, with less than 10 inches of precipitation falling annually on the eastern fringes of the Wenatchee portion of the OWNF. Federally listed wildlife species include the grizzly bear, northern spotted owl, Canada lynx, and gray wolf. There are two federally protected plants on the Okanogan-Wenatchee: the Wenatchee Mountains checker-mallow, *Sidalcea oregana* var. *calva*, and the showy stickseed, *Hackelia venusta*.

Policy, Planning, and Management Environments

Two overarching management plans set the standards and guidelines used to manage natural resources on the Okanogan-Wenatchee and Colville National Forests. The Northwest Forest Plan (NWFP, USDA and USDI 1994) amended existing land and resource management plans for national forests that occurred within the range of the northern spotted owl. The NWFP includes all of the Wenatchee portion of the OWNF and the portion of the Okanogan Forest that lies west and south of the Chewuch River. The remainder of the Okanogan portion of the OWNF and all of the Colville Forest are managed under the east-side screens (USDA 1998). Both of these regional management plans recognized the need to protect and restore old growth and late-successional forest habitat, but used two different approaches. The NWFP accomplishes this through a system of reserves, which limit forest management activities to those that either maintain or promote the development of late-successional forest. There are 1,010,286 acres (26 percent) of the OWNF within a system of 27 reserves (USFS 1997, USFS 1998). The east-side screens promote the development of old growth and late-successional forest by managing towards the natural range of variation (Hessburg et al. 1997, Hessburg et al. 1999) and by limiting the cutting of trees to those less than 21 inches in diameter.

Observed and Anticipated Climatic Changes and Effects on Natural Resources

This section briefly summarizes observed and projected changes in atmospheric chemistry, the global climate system, and the climate of Washington State based on a review of current scientific literature. Also discussed are the influences these projected changes are likely to have on natural resources (e.g., water, vegetation, and wildlife) and disturbance regimes managed by national forests.

Regional Climate Change Overview

Atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases have increased rapidly over the past century or more. Records from Mauna Loa Observatory in Hawaii (Keeling et al. 1995) show that global atmospheric concentrations of CO_2 rose by almost 17 percent during the period of 1958 through2005, from about 525 parts per million (ppm) to 380 ppm (IPCC 2007). Atmospheric CO_2 concentrations are expected to continue to rise for the foreseeable future, although future rates of increase may vary with changes in the global economy and the success or failure of international efforts to reduce or limit the growth of greenhouse gas emissions. Although atmospheric CO_2 concentrations are of concern primarily because of their potential to influence global temperatures (i.e., the "greenhouse effect"), higher CO_2 concentrations may also influence vegetation growth and water use efficiency and are therefore linked more directly to forest ecosystem functioning and natural resource management.

Temperatures have been increasing in Washington over the past century. In the last 100 years, temperatures have increased by about 1.5 degrees Fahrenheit (0.8 degrees Celsius) (Mote 2003b). The warming trends have been strongest in the winter months and weakest in the autumn months. Precipitation has also been increasing during the past century with the largest relative increases occurring during the spring in the eastern portion of the state (Mote 2003b).

The Climate Impacts Group at the University of Washington has projected future changes in climate of the Pacific Northwest based on climate projections produced for the Intergovernmental Panel on Climate Change (IPCC) third assessment report (Mote et al. 2005). They predict that temperatures will rise at a rate of 0.2 to 1.0 degree Fahrenheit (0.1 to 0.6 degrees Celsius) per decade over the next century, a potentially much larger increase than experienced in the past 100 years. Predictions are for warming trends to be greater in the eastern part of the state. Precipitation projections for the region are more variable than temperature projections. In general, precipitation is predicted to increase in the winter and decrease in the summer (Mote et al. 2005a).

Winter temperatures play a large role in determining whether precipitation falls as snow or rain. Despite increases in precipitation in eastern Washington, warming temperatures have led to decreases in snowpack. Mote (2003a) reported reductions of 30 to 60 percent in April 1 snowpack from 1920 through 2000 over much of Washington (Fig. 2). The largest decreases in snowpack have been at lower elevations (less than 5900 feet, or 1800 meters). Projected temperature increases for the coming century are expected to increase the proportion of winter precipitation falling as rain, increase the frequency of winter flooding, reduce snowpack, increase winter streamflow, result in earlier peak flows, and decrease late spring and summer flows (Hamlet and Lettenmaier 1999, Mote et al. 2003a,b, Mote et al. 2005a, Hamlet et al. 2007). The snowpack in the Cascades is projected to decrease by 44 percent by 2020 and by 58 percent by 2040 relative to the recent past. Peak runoff is expected to occur 4 to 6 weeks earlier (Climate Impacts Group 2004), while reduced summer streamflows will be more common and widespread (Mote et al. 1999, Miles et al. 2000, Snover et al. 2003, Mote et al. 2003a, 2003b, Climate Impacts Group 2004, Stewart et al. 2004).

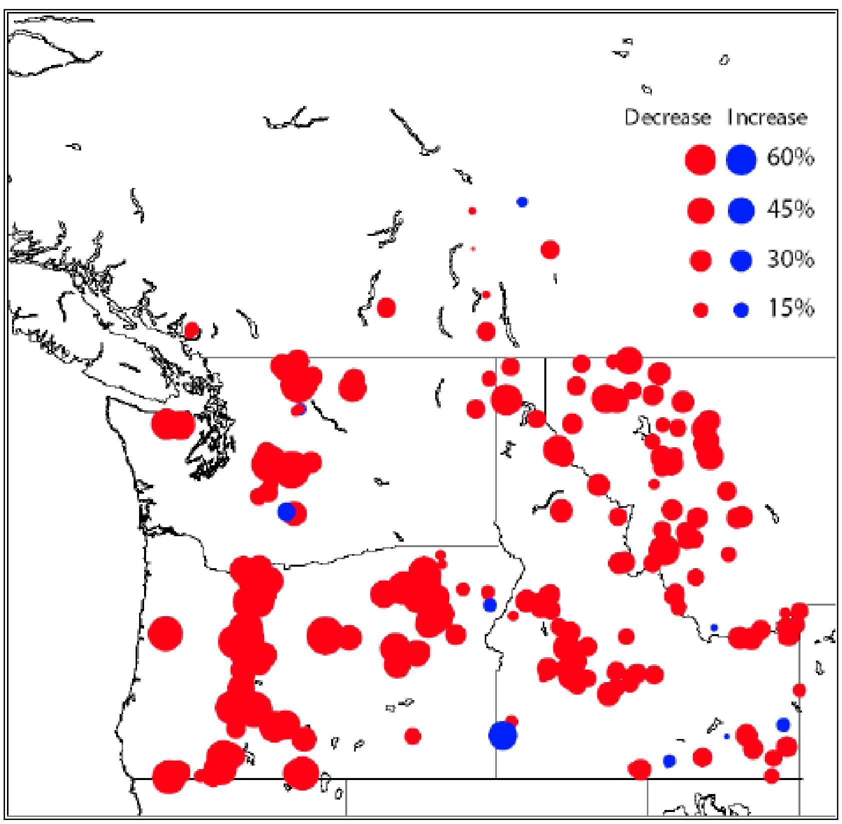

Figure 2. Changes in snowpack within the Pacific Northwest during 1920-2000 (http://cses.washington.edu/cig)

Disturbances

Since the mid 1980s, the size and intensity of large wildfire in the western United States has increased markedly (Westerling et al. 2006). The frequency of large fires has increased four-fold from 1970 through 1986 compared to 1987 through 2003. On average, the length of fire-season has increased by 78 days over the same period. Westerling et al. (2006) attributed increases in large fires to reductions in fuel moisture driven by increased temperatures and lower snowpack. In addition, the increase in fire severity and risk has been driven in part by increased fuel loads because of fire suppression practices (McKenzie et al. 2004).

The predicted increases in spring and summer temperature will exacerbate the frequency and intensity of disturbances such as fire (Wotton and Flannigan 1993, McKenzie et al. 2004) and forest insects (Littell et al. 2009). Some forest insects have already expanded their ranges northward and others have switched from a two-year to a one-year life cycle increasing the probability of large outbreaks (Logan and Powell 2001, Logan et al. 2003). Mountain pine beetle (*Dendroctonus ponderosae*) populations are expected to become more viable at higher elevations leading to increased incidence of mountain pine beetle outbreaks (Littell et al. 2009).

Even under relatively modest greenhouse gas emissions scenarios, there may be a doubling in the area burned in western states (McKenzie et al. 2004). In the interior Columbia Basin, Littell et al. (2009) predicted that the area burned is likely to double or even triple by the end of the 2040s. Models predict an increase in the length of the fire season and in the likelihood of fires east of the Cascade Range (Bachelet et al. 2001, McKenzie et al. 2004). The higher rates of disturbance by fires and insects are likely to be more significant agents of change in forest structure and composition in the 21st century than species turnover or declines in productivity (Littell et al. 2009). This suggests that understanding future disturbance regimes is critical for successful adaptation to climate change.

Hydrology and Fish

Vano et al. (2009) modeled the effects of climate change on water availability within the Yakima River Basin (Fig. 3). They found that water shortages occurred historically in 14 percent of the years. The percentage of years with water shortages was projected to increase to 27 to 32 percent in the 2020s, 33 to 36 percent in the 2040s, and 50 to 77 percent in the 2080s. These projections for reduced water availability are a result of predictions for earlier and reduced spring snowmelt as the century progresses (Vano et al. 2009).

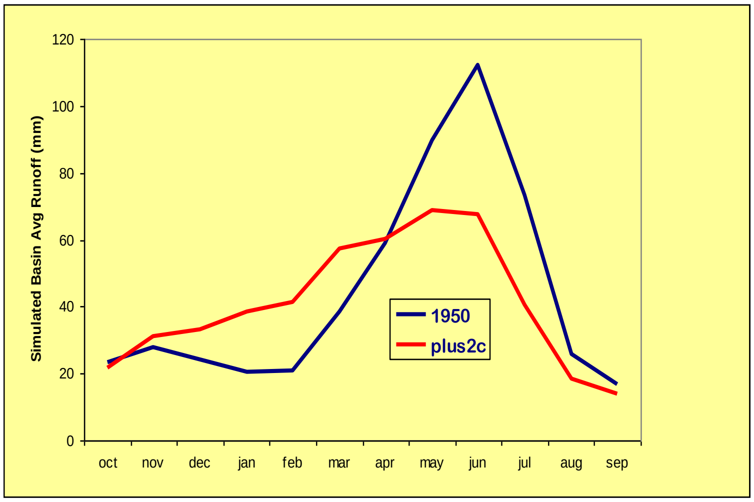

Figure 3. Reduced snowpack and earlier runoff alter peak and base flows in the Naches River Basin (http://cses.washington.edu/cig/)

Climate change is expected to increasingly alter stream function on the Okanogan-Wenatchee and Colville National Forests based on studies that have considered the effects of climate change for the Columbia River Basin. A review of scientific information completed by the Independent Scientific Advisory Board (ISAB 2007) identified numerous consequences. Bisson (2008) summarized expected changes in the ISAB report as follows: 1) warmer temperatures will result in more precipitation falling as rain rather than snow; 2) snowpack will diminish and streamflow timing will be altered; 3) peak river flows will likely increase; and 4) water temperatures will continue to rise.

In addition to an increase in large flood events, wildfires and forest pathogen outbreaks are also expected to increase as noted earlier. Fish habitat in some instances will respond favorably to these events as they are likely to reconnect floodplains and increase large wood accumulations, which, in combination will increase stream channel complexity

(Bisson 2008). Depending on landscape position, stream habitat and dependant species such as trout and salmon may also experience negative consequences resulting from climate change. A higher frequency of severe floods will scour streambeds and reduce spawning success for fall spawning fish (Bisson 2008). Decreased snowpacks and earlier spring runoff will affect migration patterns for salmon that could further affect their survival in the ocean (Mote et al. 2003a, Pearcy 1997). Summer base flows are expected to be lower and last longer, which would shrink available habitat, forcing fish into smaller and less diverse habitat (Battin et al. 2007, Bisson 2008). Additionally, summer temperatures in some stream locations that currently support salmon and trout could rise to a point where they become lethal (Crozier et al. 2008). Higher stream temperatures will likely favor non-salmonid species that are better adapted to warmer water, including potential predators and competitors (Reeves et al. 1987, Sanderson et al. 2009).

Mantua et al. (2009) evaluated the sensitivity of freshwater habitat of Pacific Salmon (*Oncorhynchus spp.*) to climate change. They found that predicted increases in stream temperatures will only slightly increase thermal stress for salmon in eastern Washington for the 2020s, but thermal stress will increase as the century progresses. Streamflow simulations predict that the largest hydrologic sensitivities are for watersheds that currently have a mix of direct runoff from autumn rainfall and springtime snowmelt (transient watersheds). The combined effects of warming stream temperatures and altered streamflows will very likely reduce reproductive success for many salmon populations, but impacts will vary according to different life-history types and watershed types. Salmon populations having a stream-type life history with extended freshwater rearing periods (steelhead, *Oncorhynchus mykiss*; coho, *Oncorhynchus kisutch*; sockeye, *Oncorhynchus nerka*; stream-type Chinook, *Oncorhynchus tshawytscha*; bull trout, *Salvelinus confluentus*) are predicted to experience large increases in hydrologic and thermal stress in summer due to diminishing streamflow and increasing water temperatures. Salmon with an ocean-type life history are predicted to experience the greatest freshwater productivity declines in transient runoff watersheds where future warming is predicted to increase the magnitude and frequency of winter flooding that will reduce egg-to-fry survival rates (Mantua et al. 2009). Habitat restoration and protection can help to mitigate some of the anticipated effects of climate change; however, habitat deterioration associated with climate change will make salmon recovery targets more difficult to attain (Battin et al. 2007).

Vegetation

Climate change is expected to alter the distribution of forests, with a trend that is generally upward in elevation and northerly in latitude. Climate change will likely have the largest effect at forest boundaries, both at the upper and lower elevations of forest distribution. At high elevations, seedling establishment and tree growth may be enhanced by warmer temperatures and decreased snowpack (Franklin et al. 1971, Peterson and Peterson 1994, Woodward et al. 1995, Bachelet et al. 2001, Peterson and Peterson 2001, Peterson et al. 2002, Nakawatase and Peterson 2006). Thus, expansions of forests into the alpine zones should be expected. Conversely, at lower elevations, decreased summer precipitation, decreased snowpack, and increased temperatures have the potential to shift treeline up in elevation (Mote et al. 2003, Neilson et al. 2005).

However, these simple predictions of forest response to climate change do not account for other factors that may influence forests. For example, the upslope contraction of eastern Washington forests in response to warmer and drier conditions may be offset by increased water-use efficiency resulting from increased atmospheric CO_2 concentrations (Bachelet et al. 2001, Krajick 2004). Models that consider this CO_2 effect predict expansions of forests into lower elevations (Neilson and Drapek 1998, Daly et al. 2000).

Littell et al. (2009) studied the potential impacts of climate change on forests of Washington. They predicted that by the mid-21st century some areas of the interior Columbia Basin and eastern Cascade Range are likely to experience substantial declines in climatically suitable areas for Douglas-fir, particularly in the Okanogan Highlands. In addition, they projected increased climatic related stress to pine tree species, and increased susceptibility to mountain pine beetle.

In eastern Washington, there is a strong interaction between climate-induced changes in disturbances and changes to vegetation in fire-prone ecosystems. Climate-driven changes in fire regimes will likely be the dominant driver of change in western U.S. forests over the next century (McKenzie et al. 2004). This is especially true in eastern Washington forests were increased temperatures, reduced snowpack and summer precipitation, and increased fuel loads from fire exclusion create conditions for increased large fire occurrences.

Wildlife

The anticipated climatic changes to eastern Washington environments described in the preceding sections are likely to result in a variety of effects to wildlife populations and their habitats. A striking conclusion reached from reviewed climate change literature was the degree of change to wildlife habitats and populations that has already occurred and been documented (Root et al. 2003, Lawler and Mathias 2007). The remainder of this section is devoted to describing the effects that changing climates are likely to have, or already have had on wildlife populations and habitats. While not all of the studies used to exemplify these effects occurred in eastern Washington, they do address species relevant to eastern Washington and provide insights into the kinds of changes for which planning is needed.

Changes in species distributions

As environments adjust to changing climate, species will shift their distributions in order to find suitable conditions to carry out various life history stages. Birds have been shifting their ranges both poleward in latitude and upward in elevation in response to warming climates (Root 1992, Root 1993, Thomas and Lennon 1999). The most extensive predictions about how species distributions are likely to change because of climate change have been made for landbirds (Price 2002, Wormworth and Mallon 2006). Table 1 shows predicted changes in species distributions for bird species that were commonly detected in studies conducted in the dry and mesic forests of eastern Washington (Gaines et al. 2007, Gaines et al. 2009a, Gaines et al. 2009b).

Gonzalez et al. (2007) provide an example of predicted changes in the habitat distribution for the Canada lynx (*Lynx canadensis*). They modeled lynx habitat based on the distribution of boreal forest and snow cover, and predicted that suitable conditions for lynx habitat may shift as far as 120 miles (200 kilometers) northward. Their analysis suggested that these changes in lynx habitat would affect peninsular populations and predicted that habitat in the Okanogan and Wenatchee mountains, and presumably the Kettle Crest, would be vulnerable to climate change in the long-term.

Table 1--Predicted changes in the distribution of some bird species associated with dry and mesic forests. The species list is based on surveys described in Gaines et al. 2009a. The predicted changes in distribution are based on Price 2002.

May exclude	May contract	Little change
Mountain chickadee	Chipping sparrow	Brown-headed cowbird
Townsend's warbler	Dark-eyed junco	Spotted towhee
Hammond's flycatcher	Nashville warbler	Purple finch
Cassin's finch	MacGillivray's warbler	Western tanager
Red crossbill	Yellow-rumped warbler	
	Cassin's vireo	
	Red-breasted nuthatch	
	Dusky flycatcher	
	Pine siskin	

May exclude	May contract	Little change
	Warbling vireo	

Changes in the timing of breeding and other activities

Blaunstein et al. (2001) studied the onset of breeding by western toads (*Bufo boreas*) and Cascades frogs (*Rana cascadae*). They showed that earlier breeding was related to warmer water temperatures and lower mountain snowpack (Fig. 4). Breeding of tree swallows (*Tachycineta bicolor*) has been documented to begin five to nine days earlier across North America, and is related to increasing average May temperatures (Dunn and Winkler 1999).

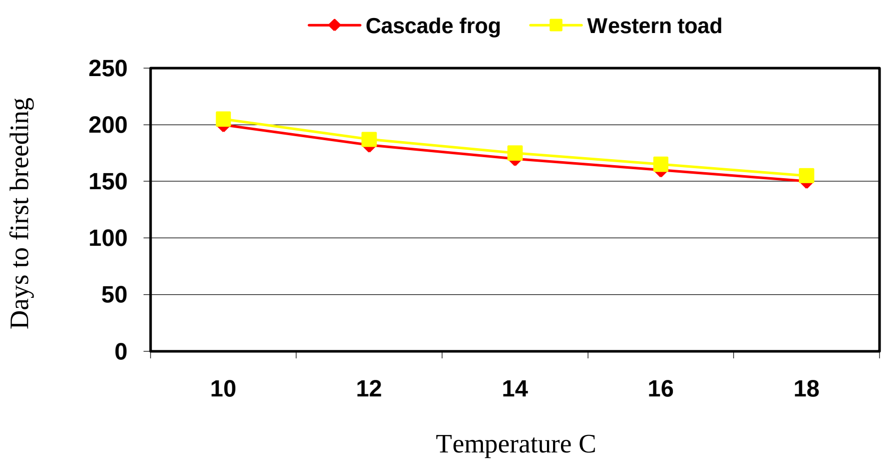

Figure 4. The earlier onset of breeding in Cascade frog and western toad populations as temperature increases (based on Blaunstein et al. 2001)

Changes in pathogens and invasive species distributions

Outbreaks of the pathogen *Saprolegnia ferax* have been documented in western toads and Cascades frogs (Kiesecker et al. 2001). These outbreaks are due to increased UV-B exposure and have been identified as a cause of high mortality in amphibian embryos in the Pacific Northwest. Amphibians, particularly those that breed in shallow montane lakes and ponds, may be quite susceptible to climate-induced changes in UV-B exposure (Kiesecker et al. 2001).

Changes in survival and extinction risks

Some species will be better able to adjust to climate-induced changes to their habitats than others will. In general, species with limited distributions, limited dispersal abilities, highly specialized habitat needs, and with already at-risk populations are likely to be the most vulnerable (Thomas et al. 2004). One of the best-documented examples of increased risk of extinction because of climate change is the American pika (*Ochotona princeps).* Pika populations throughout the inland west have already experienced several extinctions over the last 50 years (Beever et al. 2003, Root et al. 2003). Pikas have characteristics that make them vulnerable to climate change: they do not move large distances (less than 0.62 miles [1 kilometer]); their habitat generally occurs in small, isolated patches; they do not use burrows that could dampen extreme temperatures, and are densely furred so they do not dissipate heat easily. Other species that occur on the Okanogan-Wenatchee or Colville National Forests that may be vulnerable to extirpation due to their limited distributions include the Chelan mountainsnail (*Oreohelix sp.and other Oreohelix spp.*) (Burke 1999, Gaines et al. 2005, Weaver et al. 2009) and mountain caribou (*Rangifer tarandus*) (Apps and McLellan 2006).

Changes in interactions among species

Community level effects and interactions are difficult to study and predict because they have to account for individual responses of many species simultaneously. Resulting from differential species responses, terrestrial communities are likely to be restructured (Graham and Grimm 1990), altering interspecific interactions such as competition, predation, nest parasitism, etc. For example, the complex relationships that occur among species within late-successional forests in eastern Washington are just beginning to be understood. Northern spotted owls (*Strix occidentalis caurina*) compete with barred owls (*Strix varia)* for space and resources (Singleton et al. 2010). The primary prey species of the spotted owl includes the northern flying squirrel (*Glaucomys sabrinus*) whose populations depend on the abundance of lichens and truffles (Lehmkuhl 2004, Lehmkuhl et al. 2004, Lehmkuhl et al. 2006). It is unknown how climate change will affect this chain of interactions, but it is likely that different species within the community will react differently, altering the community structure and our understanding of how the community functions.

To really understand how communities of species are likely to be restructured by climate change, models must include more than just changes in the distribution of habitats. Niche modeling that includes multiple species and multiple interactions will be needed, and this is challenging when little is known about many species (Kickert et al. 1999).

Resource Vulnerabilities

Based on the scientific understanding developed on the first day, participants were asked to identify and rank (high, moderate, and low) resources in relation to perceived vulnerability to climate change (Table 2). Vulnerability was defined as the extent to which a natural or social system is susceptible to sustained damage from weather extremes, climate variability, and change (and other interactive stressors) (Table 3, Binder et al. 2009). Vulnerabilities were categorized into those related to the management of vegetation and habitats, and those related to aquatics and infrastructure. The vulnerabilities identified by the group related to vegetation and habitat management included in two general themes: the conservation of biodiversity, and the restoration of resilient forests and disturbance regimes. The vulnerabilities related to aquatic and infrastructure resources included water quality and quantity, the risk to roads and other facilities from changes to hydrologic regimes, and at-risk aquatic species and habitats. The next section addresses potential adaptations that address these vulnerabilities.

Table 2--Low, moderate, and high vulnerabilities identified by forest employees at the 2008 Climate Change Workshop

Resource vulnerability area	Ranking	Vulnerability
Vegetation and Habitat	High	• Plant migration could reduce the availability of white bark pine and shift the location of other forest types (spruce/fir, western red cedar, grand fir, lodgepole, aspen) reducing the availability of alpine habitats. • Habitat specialists (caribou, lynx, and wolverine denning habitat) will have the

Resource vulnerability area	Ranking	Vulnerability
		most difficult time adjusting. • Riparian and wetland habitats may be particularly vulnerable. • Habitat connectivity will be reduced for some species and may be most detrimental for low mobility habitat specialists. • Stands that have high densities and fuel loads in dry forests are more connected and more susceptible to fire, insects, disease, and drought. • Larger and more frequent disturbances could make it difficult for forests/habitats to recover and cause them to be more susceptible to invasive species. • Old forests have been "managed" in the past and are now susceptible to increased and more severe fires. • Species with narrow ecological amplitude and endemics are more susceptible to changes in environmental conditions.
	Moderate	• Elk and deer may be vulnerable to increased diseases. • Species on the edges of their ranges or with

Resource vulnerability area	Ranking	Vulnerability
		limited mobility need to assessed as to whether or not they are "lost causes" before investing in their conservation.
	Low	• Habitat generalists (grizzly bear, wolves, red squirrel, black bear) that are more mobile may fair better. • Increased CO^2 might increase growth of already overstocked stands.
Aquatic and Infrastructure	High	• The ability to deliver water to municipal/agricultural watersheds may be reduced. • Cold water for fish may be reduced by increasing temperatures causing changes in timing of spawning, ability to spawn, and available habitat. • Roads and other facilities are at risk from increased and more extreme hydrologic events. • Some aquatic species are more susceptible to disease and changes in productivity. • Water availability for ecosystem processes will be altered (timing and quantity).
	Moderate	• Increasing temperatures may reduce

Resource vulnerability area	Ranking	Vulnerability
		snowpack at ski areas. • Riparian areas are harder to manage, and the riparian network may be smaller and less connected. • Grazing patterns may be altered due to changes in water availability. • Cultural sites may be sensitive to increased fire.
	Low	• Roads may need more maintenance and experience increased use. • Facilities may have greater use from increased snow-free season.

Adapting to Climate Change through Management and Planning

The groups of forest managers identified vulnerabilities and adaptive strategies that could be implemented to address the vulnerabilities. The goal of these adaptations is to increase the resiliency of human and natural systems to the impacts of climate change (Millar et al. 2007, Binder et al. 2009). A resilient system is one that has the capacity to absorb and rebound from weather extremes, climate variability, or change while continuing to function (Binder et al. 2009, Turner et al. 2003, IPCC 2007). The concept of a resilient system has been applied to both ecological and social systems (Folke 2006, O'Brien et al.

2009). The identified adaptations were grouped under two major headings: Increasing Ecological Resiliency to Climate Change, and Increasing Social and Economic Resiliency to Climate Change.

Table 3--Basic concepts in adaptation planning (from Binder et al. 2009)

Sensitivity	The degree to which a system is affected, either negatively or positively, by climate variability or change. The effect may be direct or indirect.
Exposure	The nature and degree to which a system is exposed to significant climatic variations. Exposure to climatic stresses may vary by geography, elevation, length of time, and other factors.
Vulnerability	The extent to which a natural or social system is susceptible to sustained damage from weather extremes, climate variability, and change (and other interactive stressors).
Adaptive Capacity	The ability of a system to adjust to climate stresses (including weather extremes, climate variability, and climate change) so that potential damages are reduced, consequences coped with, or opportunities maximized.
Restoration	Putting or bringing back into a former, normal, unimpaired state or condition.

Resilience	The ability of an ecosystem to respond to disturbance. The concept is commonly used and incorporates the idea of resistance to disturbance as well as the time it takes a system to respond.

Increasing Ecological Resiliency to Climate Change

Generally, conservation efforts of the recent past have taken a static approach to conserving biodiversity and protecting ecological systems (Millar 2008). Usually this has involved the delineation of a system of reserves (Spies et al. 2006), or the restoration of the landscape to a historic condition (Landres et al. 1999). Bengtsson et al. (2003) have demonstrated that areas selected to protect ecosystems today will not likely protect ecosystems in a future that is altered by climate change (Pearsons et al. 1992, Hannah and Salm 2004). Increasing ecological resiliency will require landscape planning to determine restoration priorities, restoration of ecosystems in anticipation of future disturbance regimes, better tools to predict climate change effects, and the ability to monitor and adapt strategies relatively quickly as conditions change. Following are the strategies identified by the work groups to increase ecological resiliency:

Restore landscape resiliency

- Use landscape level planning to identify restoration treatment areas, the most effective locations to reduce fire flow, to restore patch sizes, and sustain wildlife habitats (Finney 2004, Agar et al. 2007, Franklin et al. 2008, Spies et al. 2010).
- Use landscape level planning to evaluate the interaction between hydrologic regimes and infrastructure such as roads. Identify significant problem areas(areas

where access is needed for treatments, recreation, etc.) and prioritize road restoration opportunities.

- Conduct landscape planning to occur across ownerships in order to evaluate patterns, processes, and functions (Hessburg et al. 2005, Franklin et al. 2008).
- Use the range of variation (historic and future) to determine where treatments are needed and to restore landscape pattern, functions, and processes (Hessburg et al. 2005, Gartner et al. 2008).
- Match treatment unit sizes with desired patch sizes determined from landscape level planning (Hessburg et al. 2005).

Restore resiliency of forest stands

- Use the range of variation (historic and future) to guide stand-level restoration of species composition, structure, and spatial pattern (Harrod et al. 1999, Franklin et al. 2008, Spies et al. 2010).
- Use thinning (mechanical and through prescribed fire) to reduce biomass, provide more vigorous growing conditions and reduce vulnerability to uncharacteristic wildfire and epidemic insect outbreaks (Hessburg et al. 2005, Franklin et al. 2008, Spies et al. 2010).
- Retain the most fire-tolerant tree species and size classes commensurate with the forest type (Harrod et al. 1999, Franklin et al. 2008).
- Retain and restore old and large tree structure because they are the most difficult to replace and most resilient to disturbances (Harrod et al. 1999, Hessburg et al. 2005, Franklin et al. 2008).

- Minimize soil disturbance and restore soil productivity.

Maintain or restore biological diversity

- Implement the restoration strategy for white-bark pine (Aubry et al. 2008).
- Provide for habitat connectivity (fish, plants, and wildlife) so that species can adjust their ranges to changes brought about by changing climates (Parmesan 2006, Opdam and Wascher 2004, Spies et al. 2010).
- Restore beaver populations to increase water storage and retain wetlands (Brown 2008).
- Protect cold-water areas, as they are important refugia for at-risk fish species (Spies et al. 2010).
- Reduce the impacts of roads on wetland and riparian habitats.

Implement early detection rapid response for invasive species

- Implement integrated pest management to treat existing and new populations.
- Focus on treating small problems before they become large, unsolvable problems. Recognize that proactive management is more effective than delayed implementation (Peterson et al. in prep).

Treat landscape disturbances as management opportunities

- Plan for post-disturbance recovery. Because large fires and other disturbances are expected periodic occurrences, incorporating them into the planning process will encourage post-disturbance management actions that take climate into account, rather than treating disturbance as an anomaly or crisis (Peterson et al. in prep., Spies et al. 2010).
- Develop more dynamic approaches to recovery after a major disturbance as standard post-fire restoration practices are typically not climate-proactive..

Increase social and economic resiliency to climate change

The following strategies are intended to reduce impacts of climate change on forest infrastructure that would cause (and, in some cases, already has caused) expensive repairs, temporary closures, etc. These impacts are anticipated due to changes in the hydrologic regimes brought about by climate change. In addition, these strategies are intended to educate forest employees and the public about climate change and provide support for collaborative learning that facilitates adaptive management.

Match infrastructure to expected future conditions

- Reduce the impacts of roads on water quality, quantity, and flow regimes (Binder et al. 2009).
- Decouple roads, or remove roads to keep water in natural stream channels (Binder et al. 2009).

- Relocate roads and other structures that are at risk from increased peak flows (Woodsmith 2008).

Carbon sequestration and forest management

- Forest restoration and conservation of old growth forests have the potential to reduce emissions and/or create carbon sinks (Schimel et al. 2000). Old growth forests store more carbon than fast growing younger trees (Harmon et al. 1990).

Promote education and awareness about climate change

- Educate employees about climate change science and adaptations (Binder et al. 2009).
- Proactively engage the public in an education program that increases understanding of the need for adaptation (Binder et al. 2009).
- Develop educational materials and programs about climate change.

Collaborate to implement adaptive management strategies

Monitoring and adaptive management will be critical to understanding how strategies are working and if adaptations are needed (Millar et al. 2007, Binder et al. 2009, Spies et al. 2010). A high level of collaboration between research and management will be necessary to integrate evolving science understanding and to design and implement monitoring.

Planning across jurisdictional boundaries and collaboration on projects across boundaries will be vital to successfully adapting to climate change and creating more resilient forest and human systems.

Information and Tool Needs

The primary information and tools that managers identified during the workshop included models to better predict climate change impacts to resources and to evaluate management options. There was considerable discussion concerning how to develop a scientifically credible monitoring program with a concise and realistic set of variables that are important in monitoring climate change.

Managers identified the following tools that would be useful to better predict climate change impacts and understand the effectiveness of management options:

- Tools and expertise to evaluate fire flow over landscapes, and to identify strategic locations on the landscape where treatments are most effective at reducing unwanted fire effects.
- Tools and an approach to evaluate landscapes to determine past, current, and future vegetation patterns (cover types, structure stages), processes (fire, insects), and functions (wildlife habitats).
- Models to predict the movement of plant and animal species, and the potential effects of climate change on species distribution.

- Models to predict the timing and intensity of peak flows, and to determine channel maintenance flows.
- Location of areas that will likely provide refugia for fish.

Managers identified a need to develop a comprehensive monitoring plan to deal with climate change. This plan? would be a collaborative effort between science, management, and stakeholders. Some specific items for monitoring that were identified included:

- Monitor the effectiveness of weed treatments.
- Monitor white-bark pine as it is highly vulnerable to climate change.
- Monitor fish populations and habitat across broad areas.
- Monitor wildlife populations to determine the effectiveness of conservation strategies and recovery plans.
- Identify and monitor key indicators of climate change.

Conclusions

Summarized in this document is the best available science relevant to climate change and the potential effects of climate change on eastern Washington forest environments. With this knowledge base, input from forest managers identified resource vulnerabilities and potential adaptations to management that can address anticipated climate change impacts. Identified were four primary areas of adaptation strategies?: 1) Increase stand and landscape level forest resiliency through aggressive restoration based on understanding of the natural range of variation and projected effects of changing climate on the range of variation; 2) restore hydrologic function and fish passage in priority areas where water interacts with roads and other infrastructure; 3) increase employee and public awareness of the potential impacts of climate change on forest resources and the adaptations being implemented to address them; and, 4) due to the high degree of uncertainty associated with climate change predictions and the effectiveness of adaptations, develop an adaptive management approach that relies of rigorous monitoring and research.

A workshop participant provided a quote that thoughtfully and succinctly defines what lies ahead: “To deal with climate change will require a new level of focus, meaning some things will have to fall off the plate. The scale and immediacy of climate change is different from past challenges.”

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