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KIPZ Climate Change Report

Idaho Panhandle National Forest, Kootenai National Forest

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Introduction

This climate change supplement to the Comprehensive Evaluation Report for revision of the forest plans of the Kootenai and Idaho Panhandle National Forests compiles and synthesizes scientific information on past and projected trends in regional climate and climate-related impacts to forest resources. It also identifies possible management options to reduce ecosystem vulnerability to climate change and to increase ecosystem resilience to both climate and non-climate stressors.

The information contained in this document is a synthesis of currently available scientific information. The Forest Service and other agencies will continue to conduct scientific research on the effects of climate change and monitor actual changes. The adaptive management approach of the forest planning process will allow the Forest Service to update and adjust the forest plan comprehensive evaluations and management options as additional information becomes available.

Observed and Projected Climate Variability and Change

The following information on observed and projected climate trends is derived from two basic sources. First, observed trends from analysis of historical weather observations were obtained from the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Weather Service. We utilized data from the Historic Climate Network database, which has been corrected for obvious errors resulting from changes in weather station locations, surrounding environments, and sensors. Second, projections of future climate trends are based upon analyses of numerous global climate models used in the most recent report of the Intergovernmental Panel on Climate Change.

Observed Climate Trends

Over the last century average annual temperatures in northern Idaho and northwestern Montana have increased about 2° F (0.2° F per decade). Winter temperatures have increased more than other seasons, and daily minimum (nighttime) temperatures have increased more than daily maximums. These local temperature trends are nearly identical to the trends observed for the entire Pacific Northwest and similar to the average trends for North America.

Annual precipitation in northern Idaho and northwestern Montana has increased about 12 percent over the last 100, with greater increases in the spring and summer than autumn and winter. For the entire Pacific Northwest, trends in precipitation have been variable both geographically and decade to decade. Annual precipitation also increased over the U.S. as a whole during the last century.

Projected Climate Trends

Climate models are unanimous in projecting increasing average annual temperatures over the coming decades in the Pacific Northwest. The average of multiple climate model simulations (20 different climate models simulating SRES A1B and 19 simulating SRES B1) projects that annual temperatures will increase 2.2° F by the 2020’s and 3.5° F by the mid 21st century, compared to the average for 1970 to 1999. Temperature increases are projected to occur during all seasons, with the greatest increases projected in summer. Beyond mid-century, model projections diverge substantially in response to differences among scenarios in assumed emissions, with increases in average annual temperature ranging from 5.9° F to 9.7° F in the Pacific Northwest by the end of the 21st century.

Projected changes in Pacific Northwest precipitation are more variable among models, but generally suggest no substantial change in the average annual amount of precipitation from the variability experienced during the 20th century. Given the variability in results among models, projections of precipitation are considered less certain than temperature projections. Most of the models project decreases in summer precipitation, increases in winter, and little change in the annual mean.

The climate observations and projections reported here are long-term trends in average conditions. Climate has varied, and will continue to vary, from year-to-year and decade-to-decade around the long-term trend. The effects of longer term climate trends may be either amplified or moderated by climate variability resulting from the shorter-term El Nino Southern Oscillation and the Pacific Decadal Oscillation.

As a result of changes in long-term average trends, some conditions/events we now consider to be extreme will occur more frequently or with greater magnitude, while others will occur less frequently (e.g., more unusually warm periods and fewer cold spells). In many cases, changes in the frequency and magnitude of extreme events (droughts, severe fires, etc.) will have the most significant and long-lasting consequences for land and resource management.

Potential Impacts on Watershed Processes and Aquatic Ecosystems

Over the last 50 years, average spring snowpack (April 1 snow water equivalent) has declined and average snowmelt runoff is occurring earlier in the spring. These trends are observed for northern Idaho and northwestern Montana, the entire Pacific Northwest, and much of the western U.S. Since the available data is limited to the last 50 years, it is not clear whether these trends are persistent long-term trends or reflect short-term decade-to-decade variability that may reverse in coming years. Several recent studies of the same trends across the entire western U.S. have concluded that natural variability explains some, but not all, of the west-wide trend in decreasing spring snowpack and earlier snowmelt runoff.

Several studies of the Columbia and other river basins in the western U.S. project additional reductions in average snowpack and earlier snowmelt runoff compared to the late 20th century. Until very recently, hydrologic projections for the Pacific Northwest were based on coarse resolution data or consider only a single climate scenario. A new study focused on the Pacific Northwest concludes that April 1 snow water equivalent is projected to decrease by an average of approximately 27-29 percent across the State of Washington by the 2020s, 37-44 percent by the 2040s, and 53-65 percent by the 2080s based on an ensemble of downscaled climate model projections for emissions scenarios B1 and A1B (Elsner et al. 2010). Annual runoff across the State of Washington is projected to increase 0-2 percent by the 2020s, 2-3 percent by the 2040s, and 406 percent by the 2080s. Projected increases in annual runoff are a result primarily of projected increases in winter precipitation (Elsner et al. 2010).

Potential changes in streamflow and rising stream temperatures are likely to increase risks to maintaining existing populations of native cold-water aquatic species. Over the last century, most native fish and amphibians have declined in abundance and distribution throughout the western U.S., including northern Idaho and northwest Montana. It is unknown whether or to what degree these changes are attributable to climate trends. Potential climate-induced trends of altered steamflow timing, lower summer flows, and increased water temperature will likely reduce the amount, quality, and distribution of habitat suitable for native trout, and contribute to fragmentation of existing populations. Climate related impacts are likely to add cumulatively to other stressors on native fish and amphibian species. Non-native trout and other aquatic species better adapted to warm water temperatures may increase in abundance and expand their existing ranges.

Potential Impacts on Forest Vegetation and Disturbance Processes

Climate-induced changes in disturbance regimes such as fire, insect outbreaks, and non-native invasive species, are likely to affect forest vegetation sooner and more dramatically than incremental changes in temperature and precipitation associated with long-term trends. Forests are dynamic ecosystems that constantly change in composition and structure as part of ecological succession, disturbance processes, and climate variability and change. However, climatic changes that are exceptionally rapid or large compared to historic variability could significantly affect forest composition, including the conversion of currently forested areas to non-forest.

Over the 20th century, there have been major changes in the composition of forests in the Northern Rockies, including northern Idaho and northwest Montana. In many areas, extended periods without wildfire, combined with historic timber harvest practices, have resulted in the reduction in abundance of early seral, fire-adapted tree species such as western larch and ponderosa pine. Concurrently, shade-tolerant and less fire resistant species such as Douglas-fir, grand fir, and western cedar have increased in relative abundance. In addition, the introduction of white pine blister rust, a non-native fungus, has led to the decline of western white pine and whitebark pine throughout much of their range. The effects of white pine blister rust have been particularly acute in northern Idaho and northwestern Montana, where about 90 percent of western white pine and whitebark pine have been lost.

Periodic outbreaks of forest insects such as the mountain pine beetle and Douglas-fir beetle have been major agents of change in the forest of the Northern Rockies, occasionally killing a substantial percentage of the trees in a given area in the span of a few years. The survival, life history and potential population growth of these bark beetles are very sensitive to changes in temperature. Entomologists have identified recent climate trends as a contributing factor in the current bark beetle epidemic that extends from the southwest U.S. to central British Columbia.

Although there is considerable uncertainty, recent studies suggest that projected climate changes may increase the likelihood of mountain pine beetle outbreaks in relatively high elevation forests of the Northern Rockies and decrease the likelihood in forests of low and middle elevation. High elevation pine species, particularly whitebark pine, may be the most vulnerable. Projected changes in climate may increase the disturbance severity of forest insects that previously have had a relatively minor role in the forest dynamics of the Northern Rockies. In addition, some species that currently do not occur in the Northern Rockies may expand their range into the region. The amount, distribution and susceptibility of host trees will be a critical factor determining the likelihood of major forest die-backs resulting from aggressive forest insects and pathogens.

Numerous scientific studies suggest that projected climate changes are likely to result in an increasing frequency of large fires in the Northern Rockies and much of the western U.S. During the early and late 20th century, there were periods of one to two decades with a relatively high frequency of large fires and total acres of forest burned in the Northern Rockies. Based on the fire-scar record of the last 400 years in the Northern Rockies, the period from 1937 to 1987 appears to be an unusual extended period with relatively few acres burned. A variety of modeling studies indicate that projected climate changes are likely to result in longer fire seasons, increased number of days with high fire danger, more frequent large fires, and an increase in the average annual area burned in coming decades.

In addition to potential changes in disturbance processes, projected climate changes are likely to significantly stress many forest communities and tree species. A variety of models have been used to evaluate the potential effects of climate change on the distribution of suitable climate habitat for tree species and forest types in the Northern Rockies and western U.S. Although these models do not produce consistent results for individual forest types or tree species, they generally indicate that climatic changes may limit the regeneration ability and increase mortality rates of some tree species within their current ranges.

Projected climate changes are likely to have a substantial impact on rare plant species due to their generally limited dispersal abilities and slow migration rates. Particularly vulnerable are those rare species confined to a very small total area or isolated habitats, such as alpine species. Species that occupy more widespread habitat may expand their ranges, such as those affiliated with grasslands and shrublands. Projected climate changes may also affect locally unique plant communities such as mesic shrubfields and mountain grasslands. For rare plant species and unique communities, changes in fire regimes and non-native invasive species may compound climate related stresses.

Projected changes in climate may also affect the ability of non-native invasive species to expand their ranges in the Northern Rockies, including northern Idaho and northwestern Montana. Although there is considerable uncertainty about the response of individual invasive species, recent modeling studies suggest the potential expansion of Yellow Starthistle, Tamarix, and Cheatgrass. The same study indicates that Spotted Knapweed and Leafy Spurge are less likely to expand their ranges in the Northern Rockies as a result of projected climate changes.

Potential Impacts on Wildlife

The response of wildlife to projected changes in climate is expected to vary by species. Highly mobile species with large geographic ranges and wide physiological tolerances may respond favorably to projected climate changes. However, range shifts may be hampered by habitat fragmentation and movement barriers. Rare, narrowly distributed, and endemic species or those animals with limited dispersal ability are projected to decline under future climate scenarios. Climate-induced changes in the distribution of vegetative communities, distribution and virulence of diseases, disruption of symbiotic and mutualistic relationships with other species, interactions with multiple non-climate stressors, and other sources of uncertainty complicate evaluation of impacts on individual species. Several scientific studies have shown that recent climate trends and non-climate stressors are impacting a variety of terrestrial wildlife species and their habitats in the United States.

Potential Impacts to Special Areas

Projected changes in climate could alter the ability of Research Natural Areas, Botanical Areas, and other special areas to achieve their original conservation objectives. Climate-induced changes in species distribution, disturbance regimes and vegetation structure are likely to affect the ability of these special areas to represent the diverse range of vegetation types and rare species for which they were designated. An addition, rare species may decline in areas where they are currently protected. However, special areas may serve as critical source populations of species as their ranges shift over time.

Potential Social and Economic Impacts

Projected changes in climate may affect social and economic values derived from the National Forests of the Northern Region, including the Kootenai and Idaho Panhandle National Forests. The impacts of projected climate changes may alter the type, location, and seasonality of forest products harvest. New markets may emerge for forest biomass as a source of renewable energy substituting for fossil fuels. Projected climate changes may also alter the season length and timing of various seasonal recreation activities. Depending on the individual preferences of residents and visitors, projected climate changes have the potential to improve or diminish opportunities for and quality of outdoor activities.

Adaptation Options

The adaptation options described below focus on addressing the potential climate change impacts most likely to affect the ability of the Kootenai and Idaho Panhandle National Forests to achieve desired conditions. They emphasize actions that increase the resiliency of watersheds and forests to the changes in disturbance regimes (e.g., fire, insects, and invasive species) that are likely to affect forest vegetation sooner and more dramatically than incremental changes in temperature and precipitation associated with long-term trends.

These adaptation options are drawn from the growing scientific literature on adaptation of temperate forest ecosystems to climate change. We evaluated the applicability of these general and conceptual recommendations to the conditions and trends of the Kootenai and Idaho Panhandle National Forests, including our synthesis of available scientific studies on the potential impacts of climate change on forests of the Northern Rockies.

Even though the largest potential effects of climate change are in future decades, actions taken today can help reduce long-term costs associated with climate change impacts. In addition, consideration of potential climate change impacts and appropriate adaptation options can help to ensure that managers' actions reduce risks, improve resilience and dampen rather than exacerbate the vulnerability of forest resources of value to the public.

Most of the adaptation options identified below can contribute to multiple management objectives in addition to adaptation to climate change. These and many other management practices are designed to reduce effects of existing stressors. However, potential climate change impacts may suggest the need to apply those existing practices sooner, more frequently, or over larger areas.

In sum, the adaptation options discussed below emphasize management actions that address existing stressors, contribute to multiple land management objectives regardless of climate change (win-win), and are likely to be effective at achieving or maintaining desired conditions across a wide range of future climates. Their application in appropriate circumstances may be a critical contribution to sustaining the health, diversity, and productivity of the Kootenai and Idaho Panhandle National Forests to meet the needs of present and future generations.

- **1.** Reduce vulnerability by maintaining and restoring watershed processes and aquatic ecosystems. Improve natural water storage and prolong seasonal water flows by restoration of meadows, wetlands, and floodplains. Protect and restore riparian vegetation to minimize changes in water temperatures. Consider potential climate driven changes in watershed hydrology, including potential for extreme runoff and flood events, when designing, maintaining, or decommissioning infrastructure (roads, bridges, and culverts) and locating facilities (buildings and campgrounds). Increase the resiliency of native fish species by providing large well-connected stream networks, removing migration barriers, managing for aquatic refuges that span elevational gradients. For administrative actions such as issuing special use permits for water developments and filing for instream flow reservation claims, include consideration of potential climate-induced changes in watershed processes.

- **2.** Increase the resilience of forest vegetation by reducing the potential severity of wildfire and insect outbreaks. Managing the density of trees can improve forest resiliency by reducing water stress, decreasing susceptibility to insect and disease mortality, and decreasing the likelihood of stand-replacing wildfires. Management actions that increase the diversity of stand ages, size classes, and tree species in currently homogenous landscapes can reduce the extent and severity of bark beetle outbreaks and wildland fires. Mechanical treatments, prescribed fire, and managing wildland fires for resource benefits are all potential tools for increasing the resiliency of forest vegetation to climate and other stressors. In addition, existing programs to reduce the vulnerability of whitebark pine and western white pine to white pine blister rust will also improve the resistance of these species to the added stresses associated with climate change.
- **3.** Facilitate the adaptation of tree species to changing climate by experimenting with planting trees selected for their potential fitness in anticipated future climates. Provenance testing and modification of existing seed zones is often recommended as means of assisting the dispersal and migration of phenotypes, genotypes, and species of trees into locations likely to provide suitable climatic conditions in the future. Given uncertainties about future site-specific climatic conditions and the need to ensure species become established in the near term, an experimental approach may be an appropriate beginning for this adaptation strategy. Given the large uncertainty in future climate conditions of particular treatment sites, effective application of this experimental strategy will require careful monitoring of seedling survival, development and reproductive success.
- **4.** Reduce the vulnerability of rare plant species by protecting peripheral populations. Populations of rare plant species are particularly vulnerable to climate change. Management actions that may reduce their vulnerability include increasing the number of protected sites, developing conservation strategies that address fire management in occupied habitats, early detection and rapid response of invasive species, storage of propagules in seed banks, and monitoring of known populations.
- **5.** Maintain or enhance the ability of wildlife species to disperse and migrate by promoting connected landscapes. Landscape management practices that enable species movements may allow species to modify their ranges in response to climate change. In addition, local and regional habitat continuity can maintain or increase genetic diversity, thus increasing the resiliency, of wildlife populations.
- **6.** Enhance adaptation by effective response to major disturbances. Although the occurrence of severe drought, wildland fires, and bark beetle outbreaks cannot be precisely predicted, anticipatory planning can identify likely impacts and have guidelines in place to protect sensitive areas and suggest appropriate management responses. Areas such as riparian areas, endangered species habitats, and special areas may require different approaches for reducing disturbance impacts or recovering from damaging events. Lessons learned from previous events, such as observed rates of post-disturbance tree regeneration or conversion to non-forest vegetation can provide guidance for responding severe disturbance events in the future. Planning prior to disruptions can take advantage of disturbances when they

eventually occur to convert vegetation to more resilient and desirable ecosystems and reduce assessment and response time while ensuring sensitive resources that require special responses are protected.

- **7.** Reduce the vulnerability of vegetation types and rare species in special areas. Minimize effects of non-climate stressors by avoiding fragmentation of habitats around special areas, developing fire management strategies for special areas, and detection and control of invasive species. Establish additional special areas to include vegetation types and habitat that are currently unrepresented. Utilize special areas (especially Research Natural Areas) to detect and monitor the effects of climate change.

Chapter 1. Climate Change Implications for Resource Management on the Kootenai and Idaho Panhandle National Forests

Introduction

Climate has always been a dominant influence on the Kootenai and Idaho Panhandle Nation Forests. It is a primary driver of conditions for growing trees and other vegetation, the timing and magnitude of fresh water flows, habitat quality for fish and wildlife, recreation opportunities, and many other goods and services. Climate also plays a significant role in the size and severity of wildfires; forest insect population growth and vulnerability of host trees, the distribution of noxious weeds and other invasive species, floods, and other disturbances.

Changes in climate can affect the conditions and trends of resources and ecosystems on the Kootenai and Idaho Panhandle National Forests, and the feasibility of accomplishing forest plan desired conditions and objectives. The extent to which National Forests may be affected by changes in climate depends upon the amount of change, the sensitivity of natural resources and ecosystems to specific changes, and the availability of practical adaptation options for effective management responses (Julius 2008).

This report presents a synthesis of the best available scientific information on climate change and its potential impacts on the resources and ecosystems of northern Idaho and northwest Montana. It summarizes available information on climate changes that have been observed over the last 100 years and the amount of change projected in the coming decades. It provides an evaluation of the potential implications for those trends for resources and ecosystems of the Kootenai and Idaho Panhandle National Forests. Recent peer-reviewed syntheses by the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Climate Change Science Program provide much of the broad-scale scientific information presented in this report. More regionally and locally specific scientific information is included when available.

The information presented in this report is a “snapshot” of the state of the science on climate change and its potential impacts. The amount of relevant scientific information is growing rapidly. While there is broad scientific consensus on the basic aspects of climate change at global scales, there are many uncertainties regarding projected climate changes at regional and local scales. In addition, much remains to be learned about the potential impacts to communities, specific economic activities, and ecosystems. Thus, responding to the hazards of climate change is fundamentally a risk management problem.

Continuing research activities by the Forest Service, other agencies and universities are expected to help the public and land managers better understand changing conditions and determine appropriate management approaches. The global change research program of Forest Service Research and Development will not only address enhanced sustainability of social, economic, and ecological systems (adaptation) and management of forest carbon (mitigation) but will also provide decision support tools for land managers and facilitate collaboration and technology transfer.

Recent and projected changes in climate suggest significant impacts on the communities, economic activities and ecosystems of the Northern Rockies and the Idaho Panhandle and Kootenai National Forests. This begs the question of what, if anything, can land managers do to ameliorate the potential negative impacts of climate change on the ecosystems of the Kootenai and Idaho Panhandle National Forests and the goods and services those Forests provide the public.

While considerable uncertainty remains regarding the magnitude and timing of projected climate changes, particularly at local-scales, the following chapters of this report document the best available scientific information on how climate change may affect the National Forests of the Northern Rockies, including the Idaho Panhandle and Kootenai National Forests. Sufficient knowledge exists regarding the potential and likely effects of climate change to suggest possible adaptation strategies to reduce the likelihood or magnitude of undesirable impacts. A recent report by the U.S. Climate Change Science Program (Joyce et al. 2008) summarizes adaptation options for national forests. These options are organized in three broad categories:

- No active adaptation. This strategy addresses climate change by reacting to climate induced events, such as a major fire or flood, once they occur. This approach may also apply when scientific uncertainty is considered too great to warrant proactive planning, or when proactive adaptation strategies are considered too costly or difficult in the absence of a strong scientific consensus on vulnerabilities and climate change effects. This strategy may be applicable in low-sensitivity ecosystems and short-term projects or plans.
- Planned responses after a major disturbance. This approach assumes that adjustments to management approaches are needed eventually, and are best made during or after a major climatic event, such as very large fires or insect infestation.
- Proactive steps taken in advance of a changing climate. This management approach uses the best available information about future climate, environmental conditions, and social desires to begin making changes to plans and project proposals now and as future opportunities arise. The goal of proactive or anticipatory management is to facilitate adaptation in the face of changing climate.

Joyce et al. (2008) suggest several concepts that could inform development of proactive management of potential climate change impacts.

- ***1. Create resistance or promote resilience to climate change -*** These concepts encourage consideration of management actions that improve ecosystem defenses against climate change effects and also creating resistance against climate-exacerbated disturbance impacts. Examples of resistance and resilience actions include forest "thinning and fuel abatement treatments at the landscape scale to reduce crown fire potential and risk of insect epidemic, maintaining existing fuelbreaks, strategically placed area treatments that will reduce fuel continuity and drought susceptibility, creating defensible fuel profile zones around high-value areas (such as WUI, critical habitat, or municipal watersheds), and similar treatments." With respect to climate-related insect and disease outbreaks, the authors suggest intensive silvicultural methods. Another adaptation option related to resistance and resilience is the protection of "refugia" that exist in environmentally or climatically buffered, cooler, or unusually mesic conditions. Over time, the ability to "manage for resilience" of current systems in the face of climate change will be limited as temperature thresholds are exceeded, climate impacts become severe and irreversible, and socioeconomic costs of maintaining existing ecosystem components and structures become excessive. At this point, it will be necessary to "manage for change," by shifting to adaptation options that incorporate information on projected ecosystem changes.

- **2. Enable forests to respond to change -** The goal of this set of adaptation options is to enable forest ecosystems to naturally adapt as environmental changes occur. The concept involves assisting transitions, population adjustments, range shifts, and other natural adaptation. Examples include assisted migration of species to areas assumed to become future habitat, avoiding restoration efforts in areas where habitat suitability may be lost due to climate change, modifying rotation lengths, altering thinning prescriptions and other silvicultural treatments, and replanting with different species.
- **3. Increase redundancy and diversity -** This strategy involves creating redundancy and diversity of conditions that "spread the risk" of desired ecosystem components being eliminated by climate change and severe disturbances. Examples include maintaining a diversity of age classes; planting with mixed species across a range of environments; increasing locations, sizes, and range of habitats for landscape-scale vegetation treatments; increasing the number of rare plant populations targeted for restoration, and modifying tree planting guidelines to promote expanded genetic diversity.
- **4. Promote connected landscapes -** This strategy suggests maintaining or developing continuous habitat with few physical or biotic barriers through which species can move or migrate in response to changing habitat conditions.

These adaptation options address ways to maintain ecosystem diversity, productivity, and resilience under uncertain future conditions and imperfect understanding of ecosystem processes. As a result, the appropriateness and potential effectiveness of these options depends on local circumstances. The Forest Service is undertaking substantial efforts to better understand the potential effects of climate change on resource management, and the associated uncertainties. Ongoing national, regional and forest-specific monitoring and scientific research will continue to add to our understanding, and will help to inform evaluations of adjustments in management actions needed to maintain the health, diversity, and productivity of the National Forests and Grasslands, including the Kootenai and Idaho Panhandle National Forests. In coming years, management experience and research activities are expected to help both public and private land managers better understand changing conditions and the potential effectiveness of adaptation options. As issues are better understood, climate change adaptation strategies can be adjusted based on new knowledge and experience.

Chapter 2. Observed and Projected Climate Trends

Introduction

Until recently, most long-term resource management decisions have relied on the assumption of a stationary climate - that future climate conditions will not vary substantially from the range of conditions experienced in the recent past. This assumption is challenged by growing evidence of significant human-induced changes in the earth's climate (IPCC 2007a). A great many scientific studies over the last two decades have linked climate change to significant socioeconomic and ecological impacts (IPCC 2007b; Field et al. 2008). For example, in western North America climate change has been identified as a contributing factor to large scale vegetation die-off (Breshears et al., 2005), increased forest mortality from bark beetles (Logan et al., 2003; Carroll et al., 2004), decreased summer stream flows and fish habitat quality (Field et al. 2008), an increase in the number of large wildfires in the western U.S. from 1950 to 2007 (Gillet et al. 2004; Westerling et al., 2006; Littell et al. 2009), and changes in the distribution of some species (Parmessan, 2006). Many other published studies suggest additional or more severe impacts are possible and perhaps likely in the future (IPCC, 2007b).

These studies raise many questions, including:

- Have there been significant changes in the climate of the Inland Northwest and around the Kootenai and Idaho Panhandle National Forests;
- What are the most credible projections of future climate changes for the next several decades in this area; and
- What are the major sources of uncertainty in these projections?

The following sections attempt to provide a synthesis of the best available scientific information pertaining to these questions.

Observed Climate Trends

Global, North America and the United States

Over the last 100 years, the global surface temperature increased by 1.3 ±0.32 °F (IPCC 2007c) (Figure 1). The IPCC has concluded that it is very likely (>90 percent chance) that most of the increase observed since the mid-20th century is due to increasing atmospheric concentrations of greenhouse gases. Land regions have warmed more than oceans, with the greatest warming during the winter and spring (Solomon et al. 2007). Average annual temperature in the Northern Hemisphere during the period 1950-2000 was warmer than any other 50-year period in the last 500 years, and likely the warmest 50-year period in at least the last 1,300 years (Solomon et al. 2007).

Temperature has also increased in the U.S. over the last 100 years (Arndt et al. 2010). In the continental U.S., temperatures rose at a rate of 0.12°F per decade from 1901 to 2006 (EPA 2008). The rate increased to 0.59°F per decade during the period 1976 to 2006 (EPA 2008). Some regions of the country have warmed more than others (Figure 2). The magnitude of warming was greatest in Alaska and the western U.S. (EPA 2008). Although annual average temperature in the southeast U.S. did not change significantly from 1901 to 2008, annual average temperature has risen about 2˚F since 1970 (Karl et al. 2009).

The greatest warming was in daily minimum (nighttime) temperatures, and spring and winter warmed more than other seasons (Gray et al. 2008). The last 10 years have seen fewer cold snaps than for any other 10-year period in the historical record, which dates back to 1895 (Gray et al. 2008).

The total annual precipitation over the contiguous U.S. increased an average of 6 percent over the period of 1901 to 2005, with significant variability over time and by region (Figure 3). The U.S. has had a statistically significant increase in heavy precipitation (defined generally as the upper 10 percent of all daily precipitation amounts), primarily during the last three decades of the 20th century and over the eastern portions of the country (Karl and Knight 1998; Groisman et al. 2005; CCSP 2008). Analyses of weather station records from 1949 to 2005 reveal that the proportion of winter (November-March) precipitation in the form of snow compared to rainfall has decreased nationwide and in the western U.S. where 75 percent of weather stations experienced snowfall reductions (Knowles et al. 2006; Feng and Hu 2007).

The Pacific Northwest[1], Northern Idaho, and Northwestern Montana

During the period 1920 to 2000, annual mean temperatures in the Pacific Northwest warmed about 1.5°F, more than the global average (Mote 2003). The warming has been generally consistent and widespread throughout the region (Figure 4). An analysis of historical records from nine meteorological stations in western Montana found that average annual temperatures increased 2.4˚F from 1900 to 2006 (Pederson et al. 2010). Winter temperatures increased more than summer (Mote 2003; Hamlet and Lettenmaier 2007; Pederson et al. 2010). Minimum daily temperatures rose faster than maximum daily temperature through the mid-20th century (Mote 2003; Hamlet and Lettenmaier 2007; Pederson et al. 2010).

Annual precipitation in the Pacific Northwest increased 14 percent for the period 1930 to 1995, with considerable year-to-year variability (Mote 2003; Halmet and Lettenmaier 2007) (Figure 5). However, these trends are not statistically significant and depend on the time frame analyzed.

Similar trends are found for the Canadian portion of the Columbia River Basin, an area immediately north of the Idaho Panhandle and Kootenai National Forests. The annual mean temperature there increased 2.5°F from 1913 to 2002, based on the average of five weather stations (Cranbrook, Golden, Castlegar, Kaslo, and Revelstoke) (Murdock et al. 2007). Again, minimum (nighttime) temperatures increased more than the average daily maximum temperature. Annual precipitation increased 26 percent from 1913 to 2002, but changes were highly variable among the five stations.

Analysis of records from seven weather stations in the vicinity of the Kootenai and Idaho Panhandle National Forests (Figure 6) reveals similar trends (Table 1). For the period 1910 to 2006, daily mean temperature increased about 2.0 °F (0.2°F per decade) and annual precipitation increased 12 percent. Winter temperatures increased more than other seasons, and daily minimum (nighttime) temperatures increased more than daily maximums. Spring and summer precipitation increased more than autumn and winter.

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[1] Much of the information presented here pertaining to the Pacific Northwest comes from numerous reports of the Climate Impacts Group of the University of Washington, whose website (http://cses.washington.edu/cig/) provides a wealth of information regarding climate change in the Pacific Northwest.

Weather and Climatic Extremes

The information presented above describes trends in average climatic conditions. The potential significance of climate variability and change extends beyond changes in averages. Small changes in average conditions are likely to result in large changes in the frequency and magnitude of extreme conditions (Figure 7). As a result of changes in long-term average trends, some of what we now consider to be extreme events will occur more frequently, while others will occur less frequently (e.g., more unusually warm periods and fewer cold snaps) (Karl et al. 2008). In many cases, it is the changes to the frequency and magnitude of extreme events that have the most significant and long-lasting consequences for communities, economies and ecosystems (Peterson et al. 2008; Pederson et al. 2010).

Changes in extreme temperatures have been observed around the world and throughout North America over the last 50 years (Trenberth et al. 2008; CCSP 2008). Most of North America is experiencing more unusually hot days, but the heat waves of the 1930s remain the most extreme in the historical record back to 1895 (CCSP 2008). Pederson et al. (2010) report a three-fold increase in the number of days per year with maximum temperatures in excess of 90?F in western Montana over the period 1895 to 2006. There has been a decline in the frequency of unusually cold days the last few decades, and the last 10 years had had a lower number of severe cold days than any other 10-year period in the historical record (CCSP 2008). Western Montana has also experienced a decline in the number of extremely cold days (minimum daily temperature less than 0?F) per year (Pederson et al. 2010). Over the period 1895 to 2000, the average length of the frost-free season (days with minimum temperatures above freezing) in the United States increased by almost two weeks (Kunkel et al. 2004). Averaged over the entire U.S., the number of frost days (daily minimum temperature less than 32?F) decreased by 0.8 days per year during the period 1948-1999, with decreases of 2.6 days per decade occurring in the Pacific Northwest (Easterling 2002). Weather station data reveals a similar decreasing trend in frost days in western Montana (Pederson et al. 2010).

Weather, Climate Variability, and Climate Change

Evaluations of climate trends can be confusing because weather changes constantly and climate changes at different spatial and temporal scales. To reduce this confusion, it is helpful to clearly define the terms and explain the scales that distinguish weather, climate variability, and climate change.

- **Weather** is the hourly, daily, and weekly conditions in temperature, precipitation, wind humidity, and other atmospheric conditions observed at a given place. It changes relatively quickly, and it can change significantly as one moves north or south, east or west, or up and down in elevation. Weather is difficult to predict more than a few days in advance.
- **Climate** is a statistical characterization of the weather, averaged over many years. The World Meteorological Association defines it as the average 30-year weather patterns of a region.
- **Climate variability** is the variation in weather statistics ("climate") over broader regions and over longer periods (Figure 8). For example, the 1960s were cooler and wetter than the last 10 years in the Pacific Northwest. Springs tend to be wetter than summers. Over periods of month, years, and decades, and over broad areas such as the Pacific Northwest or the entire earth, patterns of variation in weather statistics become evident. Climate variability can be caused by internal climatic processes, such as changes in patterns of ocean temperatures. The El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) are two sources of climate variability in western North America. ENSO oscillations occur over two to seven year periods. PDO oscillations occur on a longer cycle (20-50 years). External

forcings also influence climate variability. External forcings include changes in solar radiation, large volcanic eruptions, and changing concentrations of greenhouse gases in the atmosphere.

- **Climate change** is a non-random change in climate that is measured over several decades or longer (Figure 8). It is technically defined as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (decades or longer). Like climate variability, climate change may be due to natural internal processes or to external forcings.

Projected Climate Trends

Global climate models, or GCMs, are the principal tool for evaluating future changes in climate. These highly complex models simulate interactions among atmospheric, oceanic, and land surface processes, as well as sea-ice, land-ice, and other components of the climate system (Randall et al., 2007).

To simulate 21st century climate, GCMs are run with different scenarios of global socioeconomic change (Naki?enovi? and Swart 2000). The different scenarios lead to different levels of greenhouse gas and sulfate aerosol[1] emissions. Over 20 different climate modeling centers around the world have contributed to a set of comparable model experiments using this standardized set of emissions scenarios (Meehl et al. 2007b). These model experiments provide the foundation for projections of future climate.

The information presented below is an abbreviated synthesis of five primary sources: Chapters 8, 9, 10, and 11 of Climate Change 2007: The Physical Science Basis (IPCC 2007a), and a report titled "Scenarios of future climate for the Pacific Northwest" produced by the Climate Impacts Group at the University of Washington (Mote et al. 2008).

Global, North America and the United States

Over the 21st century, the IPCC projects an increase in global average annual surface temperatures of 3.2 to 7.2°F (IPCC 2007c). The range of values reflects the differences among scenarios of greenhouse gas emissions over the course of the 21st century. All models project increased warming, regardless of emission scenarios, and the models project warming everywhere. However, warming is expected to be greatest over land (approximately twice the global average temperature increase) and at high northern latitudes, and increases going from coasts to continental interiors.

For the next two decades, a warming of about 0.36°F per decade is projected for a range of emissions scenarios. Model projections indicate that decadal average warming by 2030 is very likely (>90 percent chance) to be at least twice as large as the natural variability during the 20th century. Even if greenhouse gas concentrations and aerosol emissions had been kept constant at 2000 levels, a further warming of 0.2°F per decade would be expected.

The range of projected global warming through the mid-21st century is narrower than the second half of the century (Figure 9). In the latter half of the century, the difference in emissions levels among scenarios becomes more important for the magnitude of projected warming.

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[1] Aerosols are small particles that affect cloud formation and the amount of solar radiation reflected back into the atmosphere. Aerosols can partly offset greenhouse warming. (See IPCC, 2007 WG1 Chapter 2.4 for further details).

Global mean precipitation is expected to increase, but there is substantial variation among regions and seasons (Meehl et al. 2007). There is greater confidence in changes in temperature than changes in precipitation due to difficulties in modeling precipitation (Randall et al. 2007).

The IPCC concluded that all of North America is very likely (>90 percent chance) to warm during the 21st century, and annual warming will likely exceed the global average in most areas of the continent. Annual precipitation is very likely (>90 percent chance) to increase in Canada and the northeast U.S., and likely to decrease in the southwest U.S. In western regions of the U.S., modest changes in annual mean precipitation are projected, with the majority of GCMs indicating an increase in winter and a decrease in summer.

Pacific Northwest

The Climate Impacts Group at the University of Washington has analyzed the results of twenty GCMs and two emissions scenarios (B1 and A1B) for the Pacific Northwest (Mote et al., 2008). These model results scaled to the Pacific Northwest unanimously project further warming over the 21st century, with the multi-model mean projecting an increase in average annual temperatures of 0.2 to 1.0°F per decade through the mid 21st century, with a best estimate average of 0.5°F per decade (Table2). Temperature increases occur across all seasons with the largest increases in summer (Appendix 1). Average annual temperatures will likely exceed the range of variability observed in the 20th century (Figure 10).

Beyond mid-century, the models begin to diverge substantially in the magnitude of projected increases in average annual temperatures of the Pacific Northwest. The multi-model average for temperature increase by the 2080s is 5.9°F, with a range of +2.8 to +9.7°F (Table 2). The reason for this large range of model results in the later portion of the 21st century is that it takes decades for the differences in emission rates between scenarios to result in large differences in climate.

Projected changes in precipitation are more variable among models and thus less certain. Most of the models project decreases in summer precipitation, increases in winter, and little change in the annual mean (Appendix 1). However, these changes in precipitation are projected to be small compared to the year-to-year and decade-to-decade variability observed in the 20th century (Figure 10).

Key Sources of Uncertainties

Over the last two decades, advances in computational capacity, development of coupled models that combine atmospheric and oceanic models, and improved understanding of specific physical processes have led to a continuous improvement in the performance of climate models, including the ability to simulate observed historical climate (Randall et al. 2007; Reichler and Kim, 2008).

Despite these advances, uncertainties remain in climate projections. Below we briefly describe three principal sources of uncertainty (Randall et al. 2007; UK Climate Impacts Programme, 2009) and how they are addressed in the methods used to produce the information above on projections of 21st century climate in the Pacific Northwest.

Future greenhouse gas emissions - We cannot know with certainty how populations, economies, energy technologies and other social factors that influence greenhouse gas emissions will change in the future. Thus, we don't know with certainty the atmospheric concentrations of greenhouse gases at particular future points in time. To address this uncertainty, climate modelers use a standardized set of "emissions scenarios" that represent a range of plausible ways in which emissions might change. The resulting greenhouse gas concentrations of all scenarios are similar until mid-century. This is primarily due to the inertia (long lifetime) of energy production technologies and most greenhouse gases. This means that for a period up to around 2040, the emissions uncertainty is relatively small. After mid-century, atmospheric greenhouse gas concentrations resulting from different scenarios begin to diverge much more, and as a result so do projected global temperatures.

The projections for the Pacific Northwest summarized in the preceding section are based on consideration of two emissions scenarios: B1 which has a relatively low emissions rate; and A1B, which has a moderate emissions rate compared to the other five SRES marker scenarios (Figure 11). Thus, Pacific Northwest projections do not include scenarios of greater greenhouse gas concentrations and temperature increases later in the 21st century. However, these differences among model projections are not significant until the second half of the 21st century.

Natural variability - Climate will continue to vary from year-to-year and decade-to-decades as it does now. This is due to the chaotic nature of the climate system. For any given future period, natural variability could either exacerbate or dampen changes caused by increasing atmospheric concentrations of greenhouse gases. Although there have been recent advances, the response of some aspects of natural variability, such as the El Niño Southern Oscillation, to increased greenhouse gases remain highly uncertain and therefore add uncertainty to multi-decadal GCMs simulations (Vecchi and Wittenberg 2010).

The Pacific Northwest projections address this source of uncertainty by analyzing the results of an ensemble of twenty different models. In addition, the model results are summarized into thirty-year time slices (2010 to 2039, 2030 to 2069, and 2070 to 2099), which represent the average of future climate simulated for that time period. This reduces the effect of natural variability relative to the long-term climate trend.

Modeling uncertainty - The climate system is very complex as a result of the many interactions and feedbacks, such as clouds, rate of heat uptake by the oceans, and surface albedo. Different models may represent these interactions and feedback differently. As a result, each model will simulate a different global climate change and a different regional response even when based on the same emissions scenario. These differences are the primary reason why different models provide somewhat different results for a given atmospheric concentration of greenhouse gases.

The Pacific Northwest projections address this source uncertainty by considering the results of twenty different models from over a dozen different modeling centers. Moreover, the model results are summarized with a weighted average. The weighting is based on the performance of each model as measured by how well model simulates observed 20th century climate of the Pacific Northwest and how far the individual model's 21st century projections diverge from the multi-model average. In calculating the "reliability ensemble average," greater weights are given to better performing models. (For details of the "Reliability Ensemble Average" methodology, see Mote et al. 2008 and Giorgi and Mearns, 2002).

The methods used to produce the Pacific Northwest climate projections apply the latest Global Climate Models and advanced analysis techniques that address key limitations in climate modeling. The methods used to produce the PNW projections do not eliminate all uncertainties associated with GCMs. However, the methods used explore and manage the key sources of uncertainty in the following ways:

- Emphasizing mid-century projections which reduces the significance of uncertainties associated with the future global trends in greenhouse gas emissions;

- Summarizing results by thirty-year time slices to reduce the significance of uncertainty regarding inter-annual and inter-decadal natural variability;
- Use of a twenty model ensemble to compensate for the modeling biases of individual GCMs; and
- Weighting the influence of individual models based on their performance in simulating observed 20th century climate.

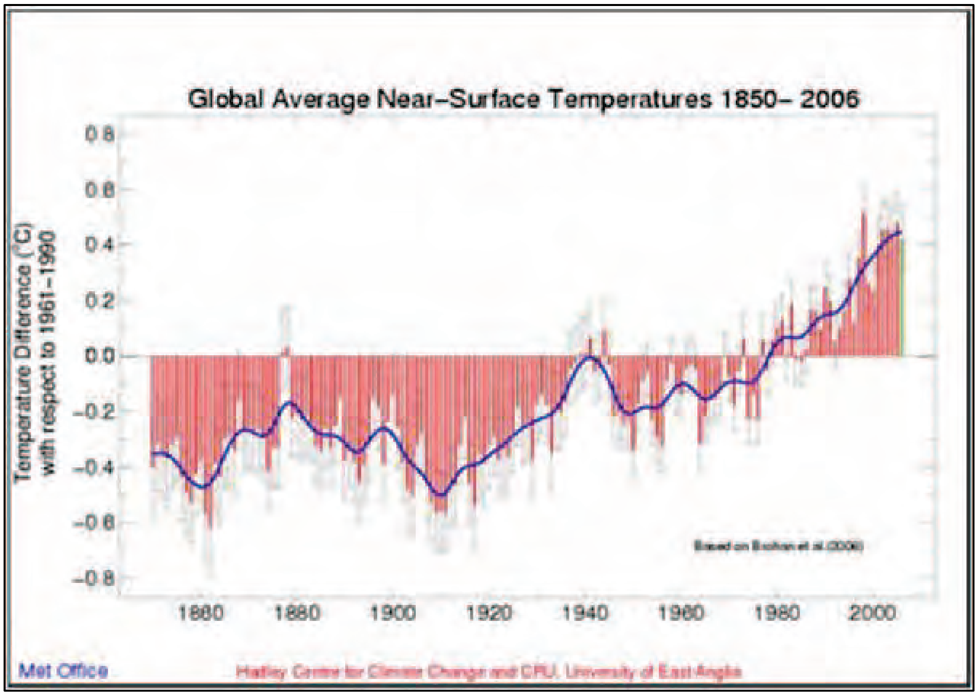


Figure 1. Annual average global mean near-surface temperature (red bars) from 1850-2006, as an anomaly from the average over the 1961-1990 baseline period

The error bars shown for each year indicate the 5 percent to 95 percent confidence range; the true value is more likely to be towards the middle of the error bar. The blue curve shows the data smoothed to emphasize decadal variabitons. Source: Hadley Center for Climate Prediction and Research, University of East Anglia, United Kingdom.

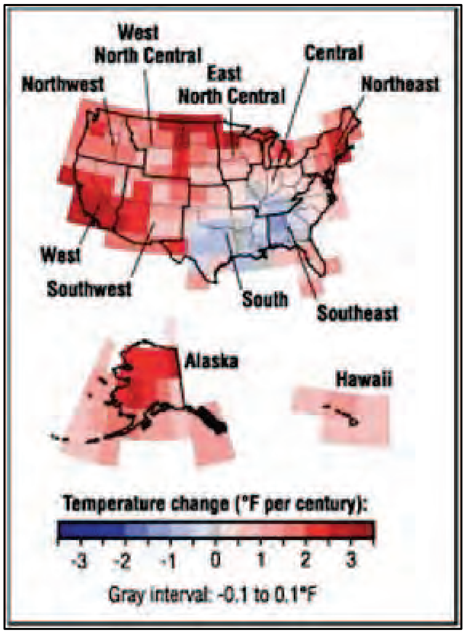


Figure 2. Change in annual average temperature 1901-2006. Red shades indicate warming over the period and blue shades indicate cooling. Source: Janetos et al. 2008; Data Source: NOAA National Climatic Data Center

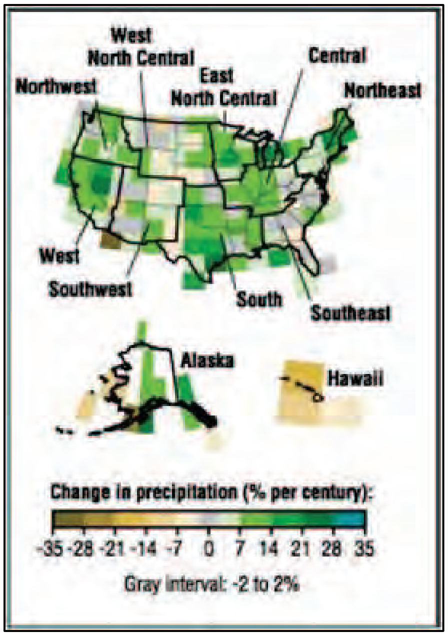


Figure 3. Change in average annual precipitation 1901-2006. Green shades indicate a trend towards wetter conditions over the period and brown shades a trend toward drier conditions. Source: Janetos et al. 2008. Data source: NOAA's National Climatic Data Center

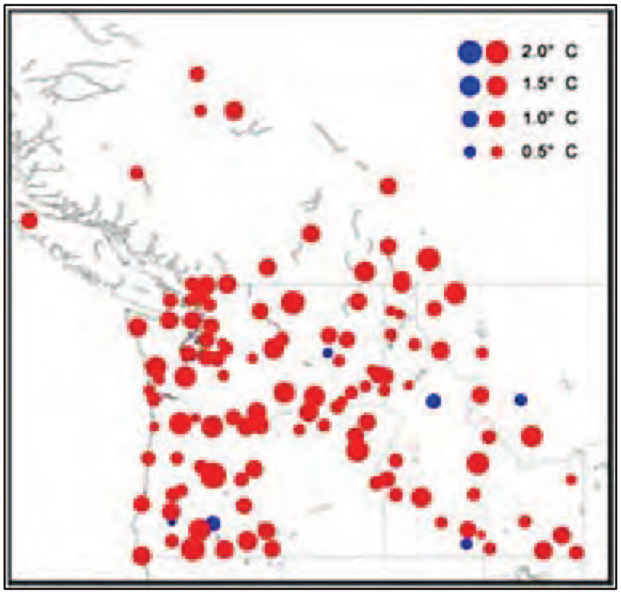


Figure 4. 20th century trends in average annual temperature (1920-2000). Increases (decreases) are indicated with red (blue) dots. The size of the dot corresponds to the magnitude of change. Source: Climate Impacts Group, University of Washington

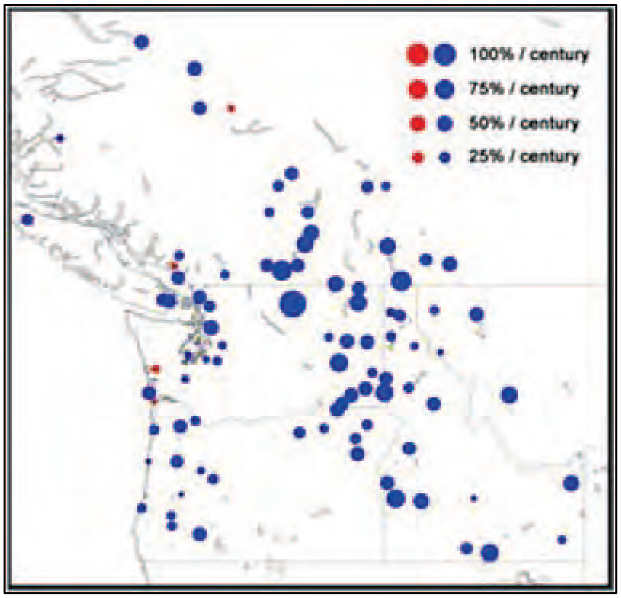


Figure 5. 20th century trends in average annual precipitation (1920-2000). Increases (decreases) are indicated with blue (red) dots. The size of the dot corresponds to the magnitude of change. Source: Climate Impacts Group, University of Washington

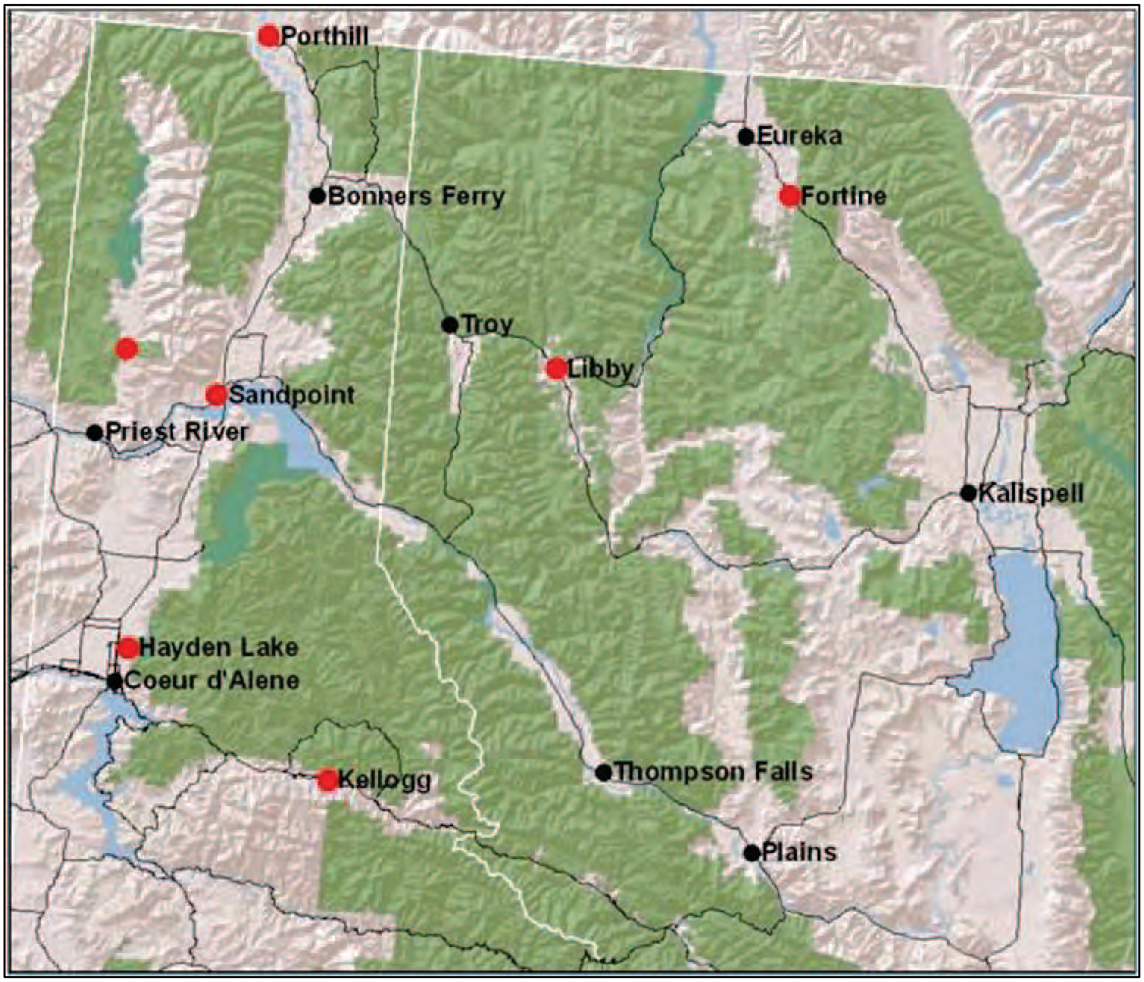


Figure 6. Location of weather stations (red dots) used to estimate 20th century trends in temperature and precipitation for northern Idaho and northwestern Montana

Table 1. Temperature and precipitation trends (1910-2006) from seven weather stations in northern Idaho and northwestern Montana. Data Source: Office of the Washington State Climatologist website

Temperature and Precipitation Trends (1910-2006) for Seven Weather Stations Near Kootenai and Idaho Panhandle National Forests.					
	Tmean Trend per decade	**Tmin Trend per decade**	**Tmax Trend per decade**	**Precipitation Trend per Decade**	**Precipitation Percent Change (1910-2006)**
Annual	+ 0.2 °F	+ 0.44 °F	+ 0.01 °F	+ 0.32”	+ 12%
Winter (DJF)	+ 0.40 °F	+ 0.67 °F	+ 0.22 °F	+0.01”	+ 2%
Spring (MAM)	+ 0.12 °F	+ 0.36 °F	- 0.04 °F	+ 0.13”	+ 28%
Summer (JJA)	+ 0.18 °F	+ 0.27 °F	- 0.11 °F	+ 0.14”	+ 44%
Autumn (SON)	+ 0.10 °F	+ 0.23 °F	- 0.06 °F	+ 0.02”	+ 1%

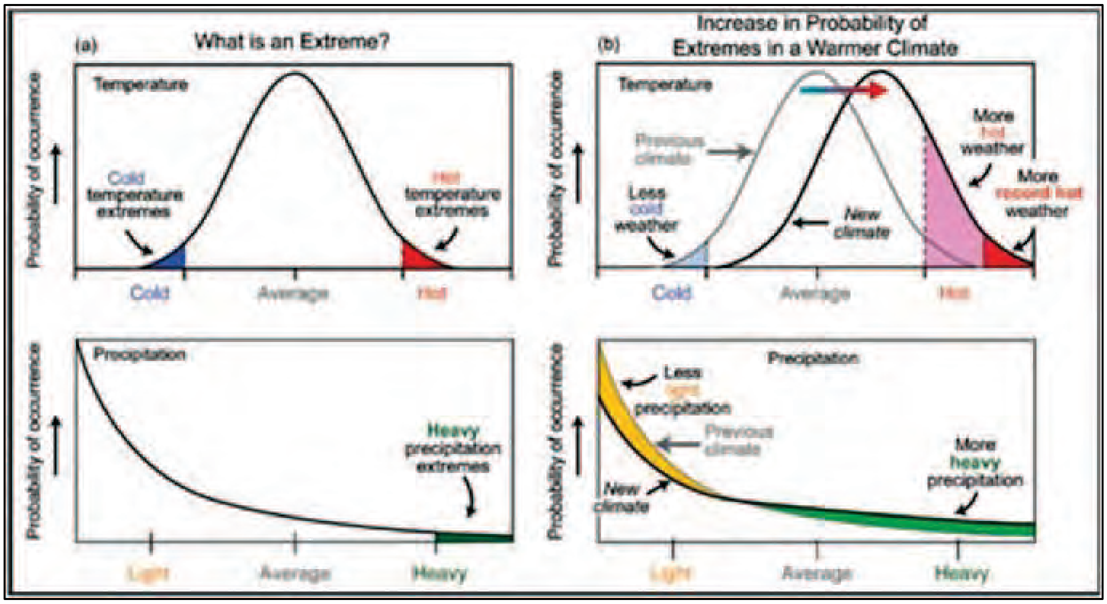


Figure 7. General effects of changes in long-term means on the probability of extreme temperature and precipitation events

The exact threshold for what is classified as an extreme varies from one analysis to another, but would normally be as rare as, or rarer than, the top or bottom 10 percent of all occurrences. A relatively small shift in the mean produces a larger change in the number of extremes for both temperature and precipitation (top right, bottom right). Changes in the shape of the distribution (not shown), such as might occur from the effects of a change in atmospheric circulation, and could also affect changes in extremes. Source: U.S Climate Change Science Program, Synthesis and Assessment Product 3.3 (Karl et al. 2008).

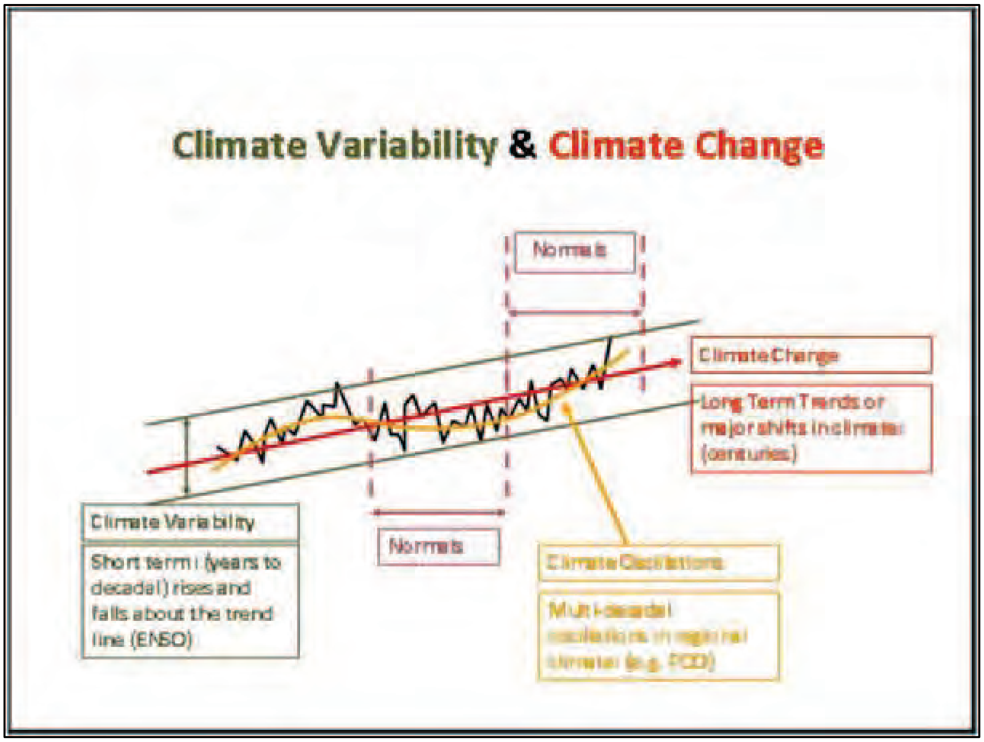


Figure 8. Climate will continue to vary year-to-year and decade-to-decade around long-term climatic trends. The primary large-scale drivers of climate variability in Pacific Northwest and Northern Rockies are the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Source: Rick Lee, Pacific Climate Impacts Consortium, Victoria, British Columbia, Canada

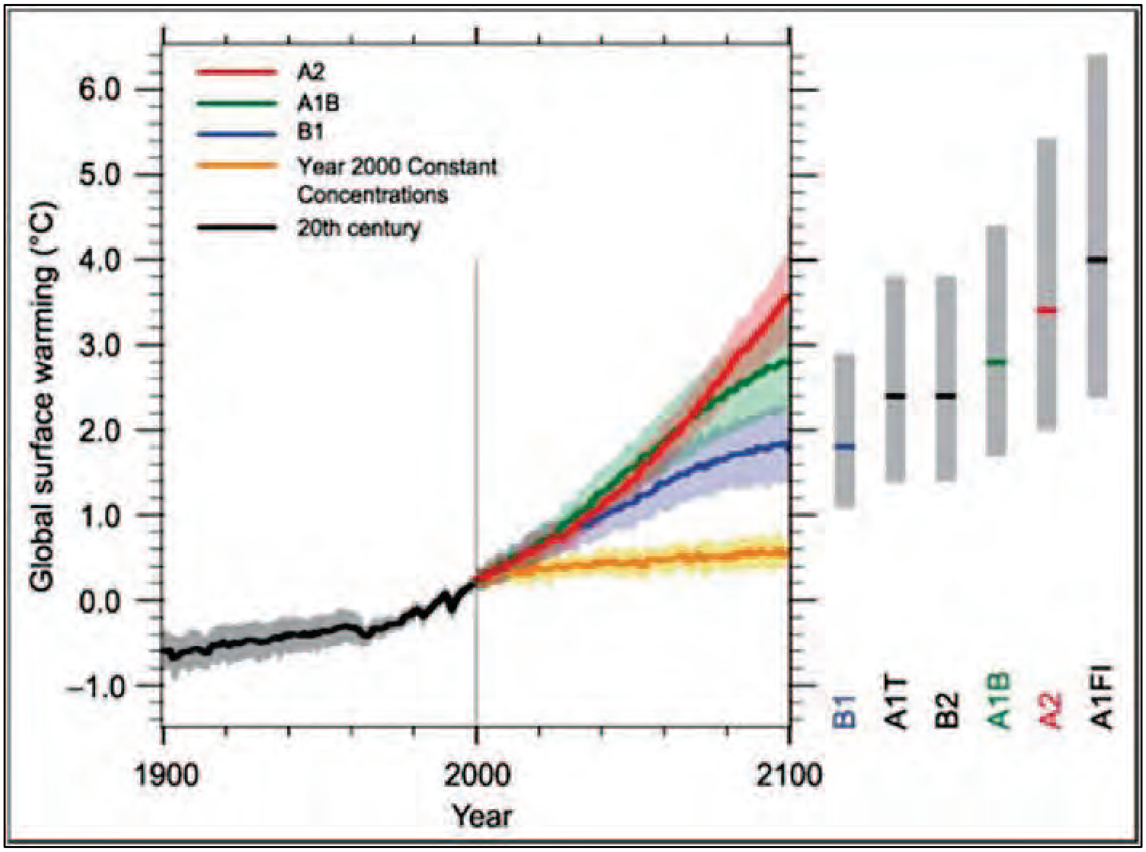


Figure 9. Multi-model averages and assessed ranges for surface warming for IPCC SRES emissions scenarios

Solid lines are multi-model global averages of surface temperature (relative to 1980-1999) for the A2, A1B, and B1 SRES emission scenario families, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where atmospheric concentrations of greenhouse gases were held constant at year 2000 values. The gray bars at right indicate the best estimate (solid line within each bar) and the likely (>66 percent chance) range assessed for the six SRES scenarios. Source: IPCC 2007a.

Table 2. Average projected changes in Pacific Northwest climate from 20 climate models and two greenhouse gas emission scenarios (B1 and A1B) for the 2020s, 2040s, and 2080s. All changes are in relation to average temperature and precipitation for 1970-1999. Model values are weighted to produce the "average." Data source: Mote et al. 2008

Projected Changes in Annual Mean		
2020s	Temperature	Precipitation
Low	1.1°F	- 9%
Average	2.2°F	+ 1%
High	3.4°F	+ 12%
2040s	Temperature	Precipitation
Low	1.6°F	- 11%

Projected Changes in Annual Mean		
Average	3.5°F	+ 2%
High	5.2°F	+ 12%
2080s	Temperature	Precipitation
Low	2.8°F	- 10%
Average	5.9°F	+ 4%
High	9.7°F	+ 20%

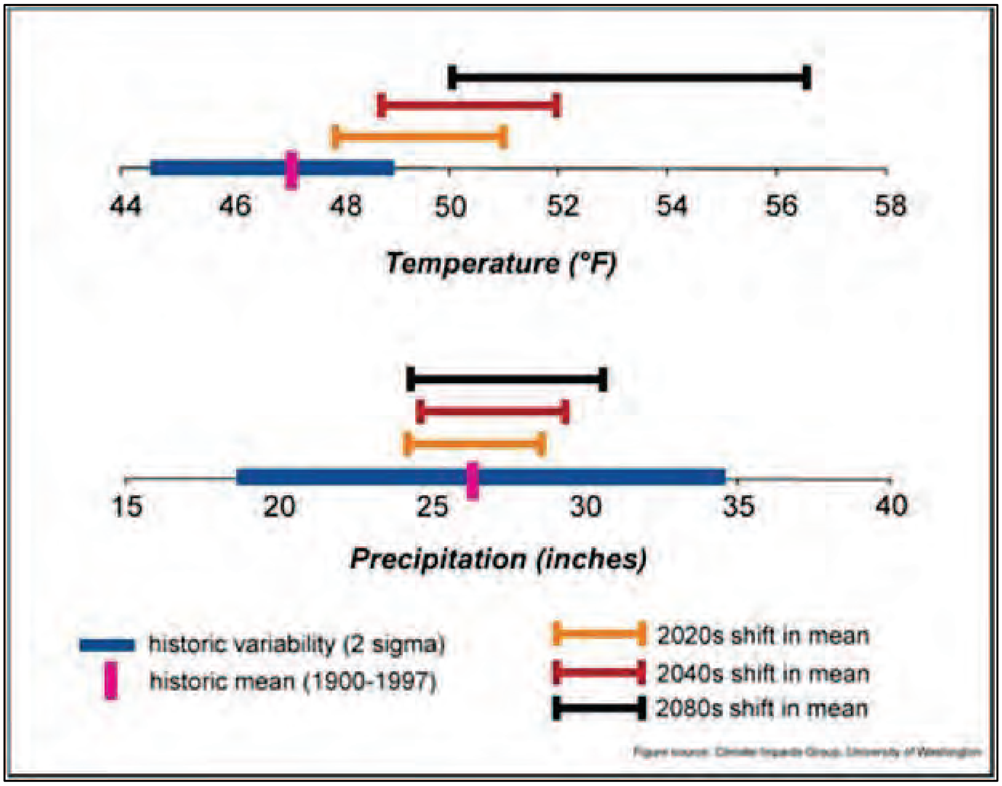


Figure 10. Comparison of observed year-to-year variability and projected shifts in average annual temperature and precipitation for the Pacific Northwest from 20 climate models

The blue bars represent the year-to-year variability in Pacific Northwest temperature and precipitation during the 20th century. The pink bar represents the historic average for the 20th century Pacific Northwest temperature and precipitation. The orange, maroon, and black lines indicate the projected shift in the historic average for the 2020s, 2040s, and 2080s, respectively. Average temperature could exceed the year-to-year variability observed during the 20th century as early as the 2020s, while future projected precipitation falls within the range of past variability. Source: Climate Impacts Group, University of Washington.

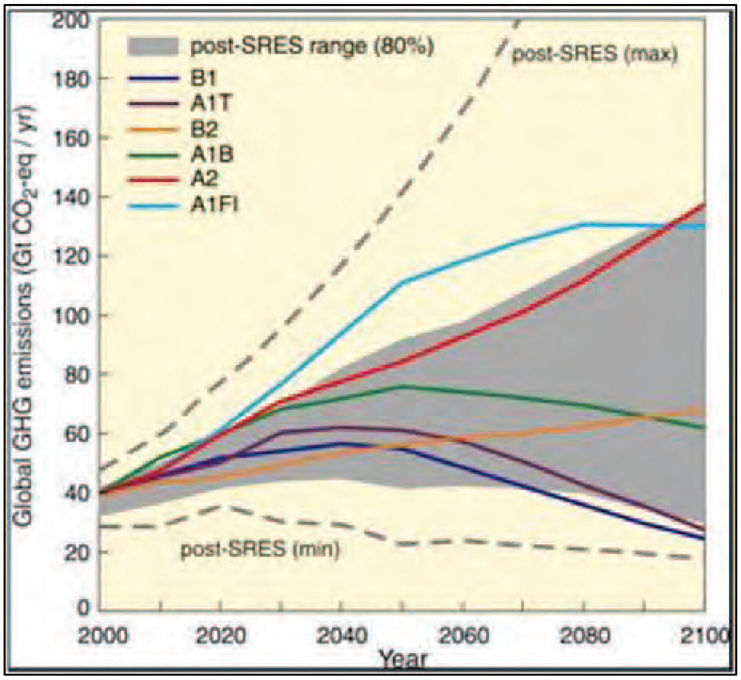


Figure 11. Global GHG emissions (in GtCO2-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (colored lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. (Source: IPCC, 2007c)

Chapter 3. Watershed Hydrology

Introduction

National Forests are the source of 68 percent and 61 percent of all surface water in the States of Idaho and Montana, respectively, and are tremendously important to the communities, economies and ecosystems of those States (Brown et al. 2008). Watersheds of the Idaho Panhandle and Kootenai National Forests are major contributors of water for municipal and domestic drinking supply, irrigation, hydropower production, recreational activities, fisheries, and numerous other public values. Both Forests send and receive water from the Province of British Columbia and play a role in protection of the headwaters of the Columbia River Basin.

More than 60 percent of annual precipitation in northern Idaho and western Montana falls as snow (Serreze et al.1999). Winter snowpack serves as a natural reservoir gradually releasing water to soils and streams in the warmer and drier months of spring and summer. Thus, winter snowpack is the major driver of the watershed hydrology of Idaho Panhandle and Kootenai National Forests, as it is for many of the mountainous areas of the western United States (Stewart 2009). Changes in winter precipitation and temperature can affect streamflows and water supply well beyond the winter season in these snow-dominated watersheds.

Observed Responses to Climate Change

Western United States

Numerous recent studies have examined hydrologic trends over the 20th century in snow-dominated basins of the western United States (see Lettenmaier et al. 2008). Despite using independent data sources and analytical methods, these studies are generally consistent in the following conclusions for the second half of the 20th century:

- April 1 snow water equivalent has declined;
- Snowmelt runoff is occurring earlier in spring;
- Summer base or low flows are decreasing; and
- The proportion of precipitation falling as rain is increasing (Barnett et al. 2008).

Snowpack trends - Over many areas of the western U.S., April 1 snow water equivalent (SWE) declined during the second half of the 20th century (Lettenmaier, et al. 2008). The largest relative declines in April 1 SWE have occurred in western Washington, western Oregon, and northern California (many in excess of 50 percent) with more moderate declines in the northern Rockies (Mote et al. 2005; Regonda et al. 2005; Selkowitz et al. 2002) (Figure 12). The southern Sierra Nevada Mountains and portions of the Southwest U.S. experienced increases in April 1 SWE during this period. In areas where decreases are observed, the largest changes have been lower and mid-elevations. Smaller or no trends generally are found at the highest elevations (often above 8000 feet) and in regions that have experienced increases in winter precipitation (Moore et al. 2007; Regonda et al. 2005; Stewart 2009).

Streamflow - Closely related to the declining trend in April 1 SWE are findings that spring snowmelt are occurring progressively earlier in snow-dominated watersheds over much of the West (Lettenmaier et al. 2008). One study of stream gauge data in the western U.S. and western Canada found a wide-spread trend of earlier peak snowmelt runoff over the period from 1948 to 2002, with peak flows often occurring 1 to 4 weeks earlier (Stewart et al. 2005). A separate analysis of peak flow timing on 84 rivers in the western U.S. found a trend of earlier peak flows on 79 of the rivers for the period 1950 to 2003, although the trends were statistically significant at only 33 of the sites (McCabe and Clark, 2005). Regonda et al. (2005) found very similar results in an analysis of data from 89 stream gauges from snow-melt dominated streams in the western U.S (Figure 13). All three of these studies found that trends of earlier spring snowmelt were greatest at low and mid-elevation sites while generally high-elevation sites where temperatures generally remain sufficiently cold longer into the spring to limit snowmelt show little change. Lastly, an analysis of 20th century seasonal streamflow patterns from 14 free-flowing rivers draining both east and west sides of the Continental Divide between Yellowstone National Park, eastern British Columbia and western Alberta found that 10 of the 14 rivers exhibited an increasing trend in winter flows, and 13 of 14 had a trend of decreasing late summer flows (Rood et al. 2008).

Pacific Northwest and Kootenai/Idaho Panhandle

Snowpack - The trends described above for the entire western United States are even stronger for the Pacific Northwest. April 1 snow water equivalent (SWE) declined at nearly all sites in the Pacific Northwest between 1950 and 2000 (Mote et al. 2003; Hamlet et al. 2005, Mote 2006). The strongest declines occurred in western Oregon and western Washington where many sites declined by 50 percent or more. Decreases in the northern Rockies, including the region of the Idaho Panhandle and Kootenai National Forests, ranged from 15 percent to 30 percent (Mote et al. 2005; Mote 2003) (Figure 14). As is generally the case throughout the western U.S., declining trends are greatest at low and mid-elevation (Regonda et al. 2005). However, declining April 1 SWE has also been documented for relatively high elevation snow survey sites in and around Glacier National Park in Montana (Selkowitz et al. 2002). The trends in April 1 SWE are attributable to observed region-wide increases in temperature over the same period (Mote et al. 2006; Mote et al. 2008; Casola et al. 2009).

Streamflow - Trends toward earlier snowmelt runoff are also stronger in the Pacific Northwest than the western U.S. generally (Stewart et al. 2005) (Figure 15). Regonda et al. (2005) and McCabe and Clark (2005) also found that while the majority of stream gauges from the western U.S. included in their analysis showed the peak snowmelt runoff was occurring earlier, those trends are statistically significant only in the Pacific Northwest, including northern Idaho and western Montana (Figure 12). A recent analysis of spring runoff timing in the Canadian portion of the Columbia River Basin - an area immediately north of the Kootenai and Idaho Panhandle National Forests - reaches similar conclusions (Murdock et al. 2007). Further verifying this strong trend for northern Idaho and western Montana, an analysis of snowmelt runoff timing in the headwaters of the Columbia and Missouri Rivers in Idaho and Montana also found significant trends toward earlier runoff and lower peak flows from 1951 to 2005, although the trends are small compared to the year-to-year variability (Moore et al. 2007). These findings are corroborated by modeling studies which show similar changes in runoff timing (Hamlet et al. 2007).

We analyzed hydrologic trends from 1951 to 2006 observed at six stream gauge stations on or near the Idaho Panhandle and Kootenai National Forests. The sites were selected from the Hydroclimatic Data Network, which includes streamflow measurements for streams without reservoirs and water diversions. Five of the six gauges show statistically significant trends in flow timing, indicating either earlier runoff or decreased winter precipitation (Figure 16). At the 90 percent confidence level, three of the six gauges show statistically significant declines in total annual flow, and only one gauge shows statistically significant trends in summer flow between July 15th and September 15th (Appendix 2).

Potential Causes of Observed Trends in Snowpack and Runoff Timing

The majority of studies cited above are based upon field-collected monitoring data, particularly USGS stream gauges and USDA snow course and SNOTEL data. In most cases, these data only go back five or six decades. Further complicating our interpretation of these data is the high range of year-to-year variability. As a result, it is not clear whether the trends revealed by these data represent persistent long-term trends, or reflect the decade-to-decade variability around a consistent longer-term average. If the observed trends in spring snowpack and snowmelt runoff timing are attributable to natural cycles of variability such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), it would be expected that trends would reverse at some point with the oscillations of natural cycles toward trends of more snowpack, later spring runoff and higher late-summer flows. On the other hand, if the observed trends are at least partly the result of increasing atmospheric concentrations of greenhouse gases, the decreases in spring snowpack, timing of spring runoff, and late-summer flows would become progressively stronger as changes in the atmosphere become more acute.

Several studies have evaluated this question, and many conclude that the major patterns of natural hydroclimatic variability - the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) - explain some, but not all, of the observed trends of decreasing spring snowpack and earlier snowmelt runoff (McCabe and Dettinger, 2002; Stewart et al. 2005; Hamlet et al. 2005; Mote 2006; Knowles et al. 2006; Stewart 2009). Three recent studies focused specifically on the question of attribution, and concluded that, while observed changes in precipitation are indistinguishable from natural variability, up to 60 percent of the trends of timing of snowmelt runoff, winter air temperature, and snowpack in the western U.S. between 1950 and 1999 are human-induced (Barnett et al. 2008; Pierce et al. 2008; Bonfils et al. 2008).

A recent synthesis by the U.S. Climate Change Science Program (CCSP) concluded that 20th century trends of declining spring snowpack and earlier spring runoff are "very likely attributable, at least in part, to long-term warming, although some part may have been played by decadal scale variability, including shift in the Pacific Decadal Oscillation in the late 1970s. Where shifts to earlier snowmelt peaks and reduced summer and fall low flows have already been detected; continuing shifts in this direction are very likely"(Lettenmaier et al. 2008, pg 149).

Projected Trends Related to Climate Change

As discussed above, snow accumulation and runoff in mountainous regions are strongly influenced by seasonal temperature and precipitation, and elevation. Higher winter and spring temperatures can cause decreases in snow water equivalent and earlier snowmelt runoff. These changes are most pronounced at mid and lower elevations where temperatures are closer to freezing than higher elevations. Based on these well-established findings, it is reasonable to infer that if snowfall does not increase additional warming in the future could result in increasingly early snowmelt timing and further reductions in April and May snowpack. Through time these effects would extend further upwards in elevation. However, the influence of complex topography (elevation, slope angle, exposure to prevailing winds, aspect, and vegetative cover) complicates assessment of how this general inference might apply in particular watersheds.

In the last few years, advances have been made in climate model downscaling methods necessary to simulate relatively fine-scale hydrologic processes such as the distribution of rainfall and snowfall, snowmelt, and streamflows. As a result, several studies of potential future changes in the hydrology of the western United States and individual river basins have been completed (Lettenmaier et al. 2008).

Milly et al. (2005) evaluated projected runoff for 165 large river basins based on 24 simulations produced by 12 GCMs applying the IPCC's A1B emissions scenario. The A1B scenario reflects relatively moderate greenhouse gas emission trends. The results from this study include calculations of the number of simulations showing increases and decreases (2041-2060 relative to 1901-1970) in projected annual runoff for each of 18 water resource regions in the United States (Figure 17). The results show that most simulations project increased annual runoff in the eastern U.S., little change in the Missouri and Lower Mississippi regions, and decreased runoff in the Pacific Northwest and California. More than 80 percent of the simulations project substantial decreases (median decreases approaching 20 percent) in annual runoff in the interior West and Southwest. For the Pacific Northwest, 16 of the 24 simulations project decreases in annual runoff, while 8 of the 24 simulations showed runoff increases (Lettenmaier et al. 2008).

The simulations used in the analysis by Milly et al. (2005) have a very coarse spatial resolution, with grid cell sizes of thousands of square miles. Such coarse-grained analysis is unable to incorporate finer-scale topographic and airmass circulation features that have a large influence on the hydrologic characteristics of snow-dominated watersheds. Other recent studies downscale the coarse-grained results of GCMs to produced finer-scale projections.

There have been several studies of projected hydrological changes in the Pacific Northwest. Payne et al. (2004) down scaled results of a single GCM (the Parallel Climate Model) and a "business as usual" emissions scenario to simulate hydrologic changes in the Columbia River basin. Their simulations project progressive reductions in basin-wide averages for spring snow water equivalent over the 21st century. Average annual runoff changed little when averaged over the entire basin. However, the simulations projected relatively large decreases in annual runoff from mountainous headwater regions of Idaho and western Montana. Across the basin, their simulations projected increases in winter flows, and reductions in summer and fall flows.

Using the same GCM and emissions scenario as Payne et al (2004), but an additional regional climate model, Leung et al. (2004) also simulated mid-21st century hydrologic trends for the Columbia River basin. Their simulations projected significant reductions in snowpack, with greater reductions in the coastal ranges (60-70 percent) compared to the Northern Rockies (20 percent reduction). The contrast in snowpack reductions in the coastal mountains and the Northern Rockies was due to differences in winter temperatures between maritime and continental climate. In the Northern Rockies, warming has a much smaller effect on snow dynamics because winter temperatures are much below freezing over a larger proportion of the area. The simulations of Leung et al. also projected for the mid-century Columbia River basin an increased proportion of rainfall over snowfall, more rapid snowmelt due to warmer temperatures, increased winter runoff, and declines in summer runoff.

A third study used a high-resolution regional climate model, driven by a single GCM (NASA's Finite volume atmospheric model) and emissions scenario, to simulate projected runoff timing in snow-dominated basins of the western U.S. (Rauscher et al. 2008). Based on simulations of the effects of the A2 emissions scenario (a relatively high emissions rate compared to most other IPCC SRES scenarios), simulations for the late 21st century (2071-2099) indicate that increases in temperature resulting from increasing greenhouse gas concentrations could cause snowmelt runoff to occur much earlier than present. Some of the greatest simulated changes occur in the Pacific Northwest, including northern Idaho and western Montana where snowmelt runoff is simulated to occur one to two months earlier. These large changes result from an amplified snow-albedo feedback where broader scale temperature increases reduce the extent of snow cover and thus surface albedo (reflectivity). The reduced albedo causes an increase in the solar radiation absorbed by the land surface, which amplifies further warming and additional melting, resulting in a positive feedback (known as the snow-albedo feedback). A recent investigation of projections with a very high resolution (15km) regional climate model also reveals the significant influence of snow-albedo feedback on regional and local temperature in the Pacific Northwest (Salathé et al. 2008).

The three studies described above were based upon a single GCM and emissions scenario, and thus have a greater degree of uncertainty than analyses of multiple GCMs and emissions scenarios. A very recent study by Elsner et al. (2010) used an ensemble of 20 GCMs driven by two emissions scenarios (B1 and A1B) to evaluate projected changes in snow water equivalent (SWE), soil moisture, runoff, and streamflow over the State of Washington and the Columbia River Basin. Their analysis concluded that April 1 SWE is projected to decrease by 28 to 30 percent across the State of Washington by the 2020s, 38 to 46 percent by the 2040s and 56 to 70 percent by the 2080s. The largest decreases occur in areas below 3,280 feet elevation, with declines of 38 to 40 percent by the 2020s to 68 to 80 percent by the 2080s. In mid-elevation areas (3,280ft-6,559ft), April 1 SWE is projected to decrease 25-27 percent by the 2020s, 35-43 percent by the 2040s, and 53-67 percent by the 2080s. Projected decreases in April 1 SWE are less in higher elevation areas. Elsner et al. (2010) also conclude that under most scenarios annual runoff annual runoff is projected to increase from 2.1 to 6.2 percent in the State of Washington through the 21st century. Their simulations of changes in monthly streamflow hydrographs project that snow-dominant watersheds are likely to have reduced peak flow in the late spring and early summer and increased cool season flow compared to historical observations. Transient rain-snow watersheds are projected to shift to a streamflow pattern characteristic of rain-dominant watersheds, with significantly increased winter streamflows, and substantially reduced peak flow in the late spring and early summer.

In addition to projected changes in snowpack, streamflow, and runoff, projected changes in fire frequency and severity (see Chapter 5.6) could have significant effects on geomorphic and watershed processes. Recent post-fire studies have shown dramatic changes in watershed runoff response. A recent study conducted following the Montana fires of 2000 documented increased peak runoff volumes, short duration convectional summer rainstorms produced extreme flood and debris flow volumes far in excess of anticipated runoff from storm events with similar recurrence intervals (Pratt et al. 2004). In periods when drought persists following wildfires, post-fire vegetative re-growth may be slow due to moisture stress. This biogeomorphic response coupled with increased acres burned will result in reduced water infiltration, greater hill-slope erosion, and increased sediment yield (Bull 1979; Bull 1991; Meyer and Pierce 2003). This negative feedback process may alter site productivity and watershed processes for many decades or longer.

Key Sources of Uncertainty

In addition to the uncertainty associated with future greenhouse gas emissions, global climate model simulations, and downscaling methods, estimating hydrologic responses of individual sub-basins and watersheds to projected climate changes poses additional challenges.

- Hydrologic models often rely on output from global and regional climate models to evaluate potential hydrologic effects. Global climate models have relatively poor skill in simulating regional and local-scale precipitation, due in part to their coarse spatial resolution and limited ability to account for local topographic influences on the hydrologic processes of small to medium sized watersheds (e.g., 6th and 5th hydrologic unit codes).

- There is limited availability of locally-specific field data and analyses on the relative influence of temperature, precipitation, elevation, dust, and black soot on observed snowmelt and runoff trends in mountainous areas.
- We currently lack multiple, high-resolution regional climate models that can resolve fine-scale circulation patterns, snow-albedo feedback, and other environmental features that influence hydrologic processes.
- The effects of climate change on major patterns of inter-annual and inter-decadal variability (e.g., ENSO and PDO) are uncertain.
- Most commonly used meso-scale hydrologic response models assume vegetation and land use remain constant during the simulation period, even though changes in vegetation (e.g., large fires) and land use are nearly certain and will significantly affect hydrologic processes at the watershed scale.
- Hydrologic monitoring programs (e.g., snow course sampling, SNOTEL, stream gauges, soil moisture sampling networks are often not in sufficient numbers or in the appropriate locations to parameterize and validate hydrologic simulation models (Lettenmaier et al. 2008).

Although there are uncertainties associated with projections of potential hydrologic impacts of climate change particularly at finer spatial scales, this does not imply that the potential impacts are unknown or that recent studies are not useful to decision making. The numerous studies reviewed are generally consistent in their projections of some fundamental hydrologic changes. From these studies it appears likely that projected changes in climate in the Northern Rockies and Pacific Northwest will result in reduced mountain snowpack, earlier spring peak runoff, reduced summer and fall streamflows, and higher winter streamflows. The potential hydrologic effects of climate change add substantial risks to numerous environmental assets, particularly when combined with other stressors on watershed processes (e.g., wildfire impacts, changes in land use, and increasing consumptive demands). Adaptation actions can reduce these risks.

Potential Adaptation Options

The projected hydrologic changes described above could have substantial impacts on communities, economic activities, and ecosystems of the northern Idaho and northwestern Montana. The fundamental challenge of adapting to projected hydrologic changes will be maintaining conditions of summer and fall water flows sufficient to sustain aquatic ecosystems and native fish species while satisfying to the extent possible water needs of downstream users. A variety of actions might be applied. The following options might be considered where locally appropriate:

- Increase reservoir capacity where consistent with other watershed values and objectives could help compensate for earlier spring snow melt runoff and lower late summer flows.
- Reintroduce beaver to appropriate watersheds and adopt management policies that ensure population persistence once established to help compensate for earlier spring snow melt runoff.
- Where consistent with State and Federal laws and effective at reducing vulnerability of aquatic ecosystems, file for instream flow water reservation claims.

- Consider potential effects of climate driven changes in watershed hydrology when authorizing and renewing Special Use Permits for water developments, including possible permit conditions to ensure adequate by-pass flows.
- Consider potential climate driven changes in watershed hydrology, including potential for extreme runoff and flood events, when planning and designing infrastructure (roads, bridges, culverts) and locating facilities (buildings and campgrounds). Road drainage structures may need to be larger with additional rolling dips to handle more frequent and higher peak flows.
- Consider reducing the amount of transpiration and interception losses from overstocked forests by reducing stand densities where consistent with other forest management objectives. Recognize that reducing stand density may reduce shading, increase solar radiation, and contribute to accelerated snow melt.
- Increase monitoring efforts so that reasoned adjustments in management (adaptive management) can be made. These data will be critical in understanding the rate and magnitude of changes in watershed response. Some long-term USGS and USFS stream flow monitoring sites have been abandoned in recent years due to funding limitations. Several key stations within or adjacent to the Kootenai and Idaho Panhandle National Forests are candidates for reactivation.

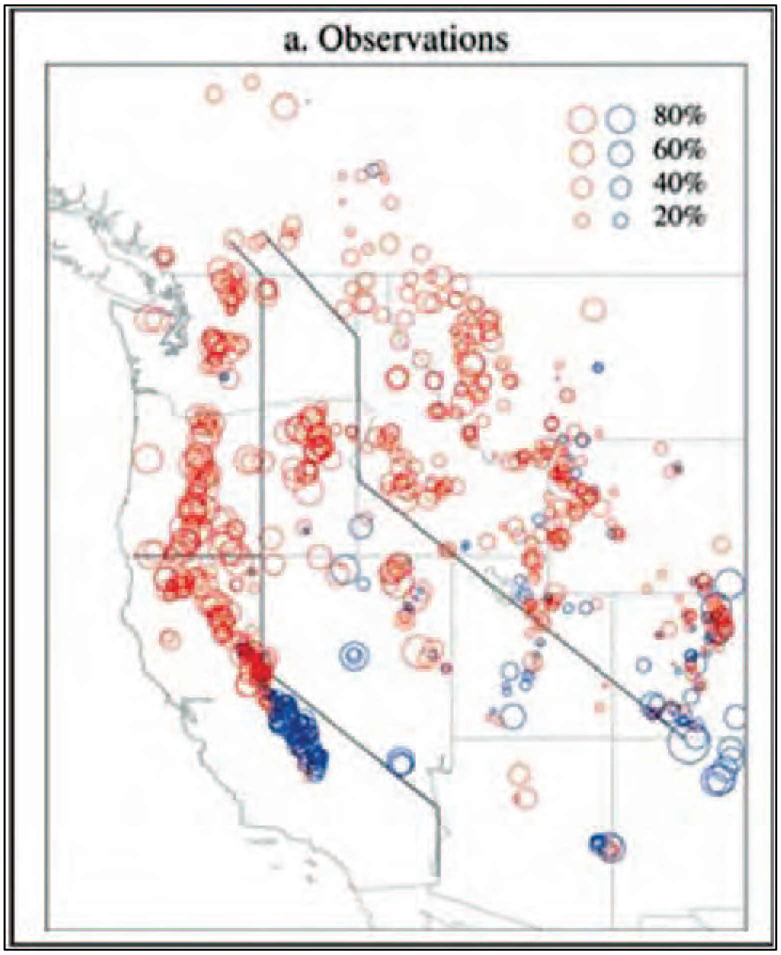


Figure 12. Linear trends in April 1 Snow Water Equivalent for 824 snow data stations from 1950 to 1997

Negative trends are shown by red circles and positive trends with blue circles. Circle size is proportional to trend size. Lines on the map divide the West into four regions for more geographically specific analysis. Source: Mote el al. (2005).

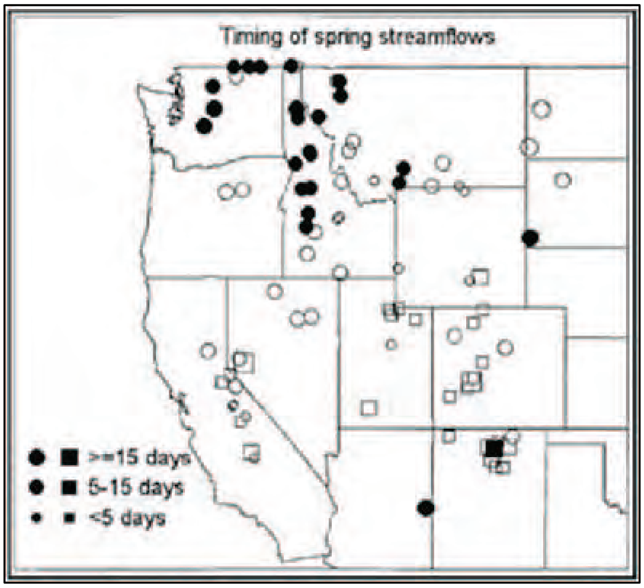


Figure 13. Changes in the center of mass of annual streamflow timing in days for 89 USGS HCDN gages from 1950 to 1999. A circle indicates earlier runoff, squares later runoff, with filled shapes statistically significant, and shape size proportional to trend. Source: Regonda et al. 2005

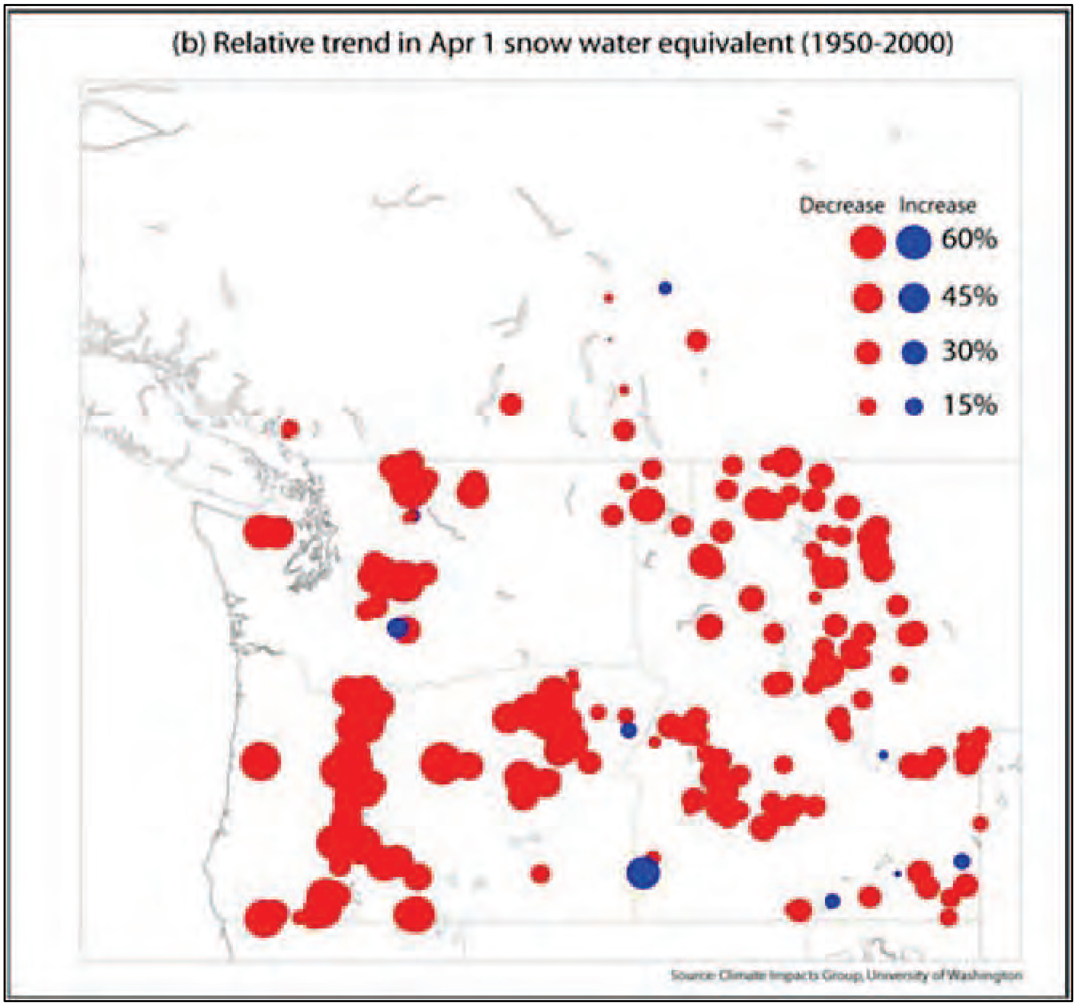


Figure 14. Trend in April 1 snow water equivalent (SWE) 1950-2000. Red dots indicate a decreasing trend. Blue dots represent increasing trend. The size of the dot corresponds to the magnitude of the change. Source: Climate Impacts Group, University of Washington

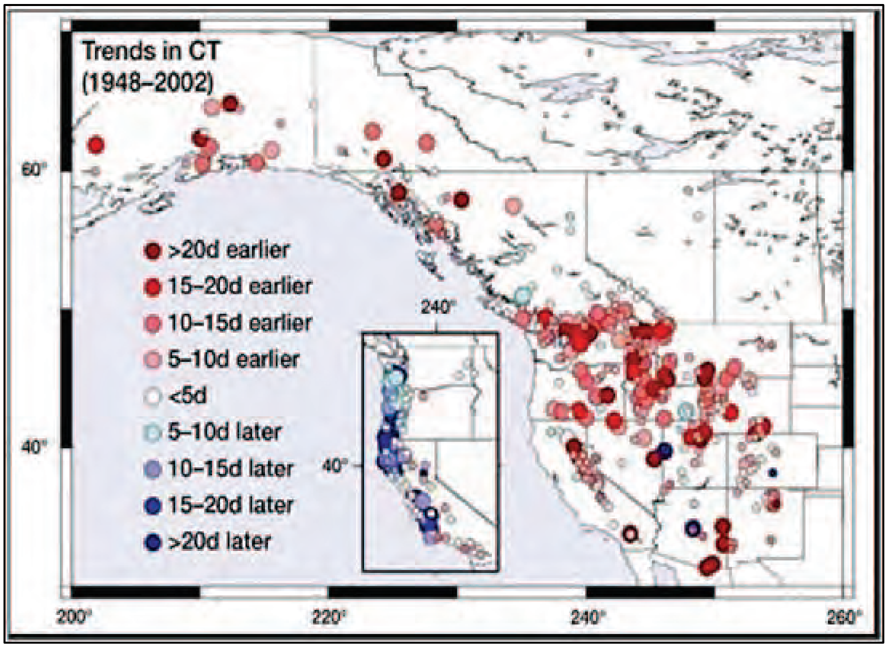
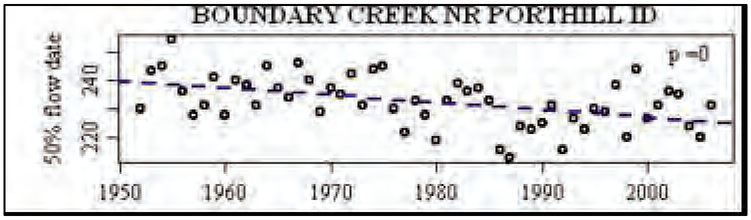
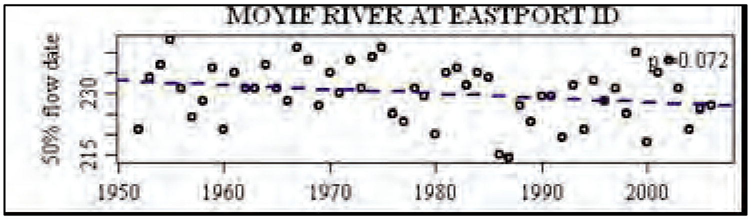
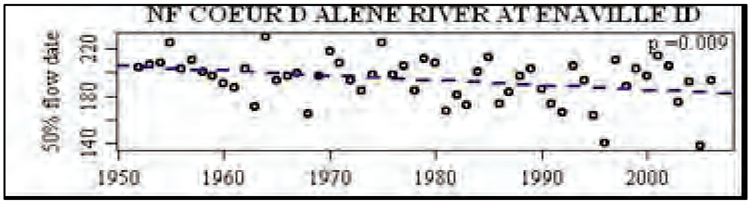
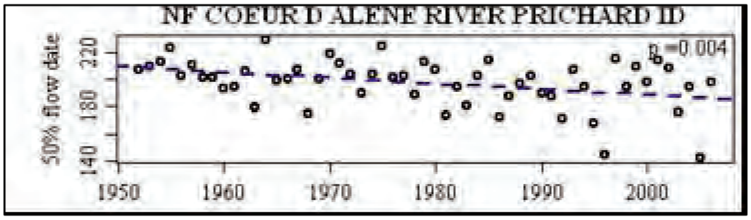


Figure 15. Trend in April 1 snow water equivalent (SWE) 1950-2000. Red dots indicate a decreasing trend. Blue dots represent increasing trend. The size of the dot corresponds to the magnitude of the change. Source: Climate Impacts Group, University of Washington









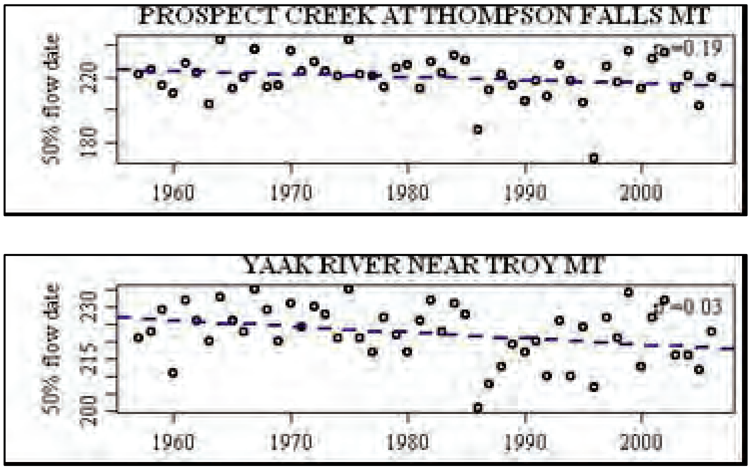


Figure 16. Trends in date of 50th percentile flow for 6 stream gauges in Northern Idaho and western Montana (1951-2006)

Blue line denotes the trend in flow timing during this time period. P-values (upper right corner) indicate the statistical significance of trends in mean annual flow. Values less than 0.10 are considered statistically significant at the 90 percent confidence level. Five of the six gauges show statistically significant trends in flow timing, indicating that either earlier runoff or decreased winter precipitation has led to earlier 50th percentile flows at these gauges.

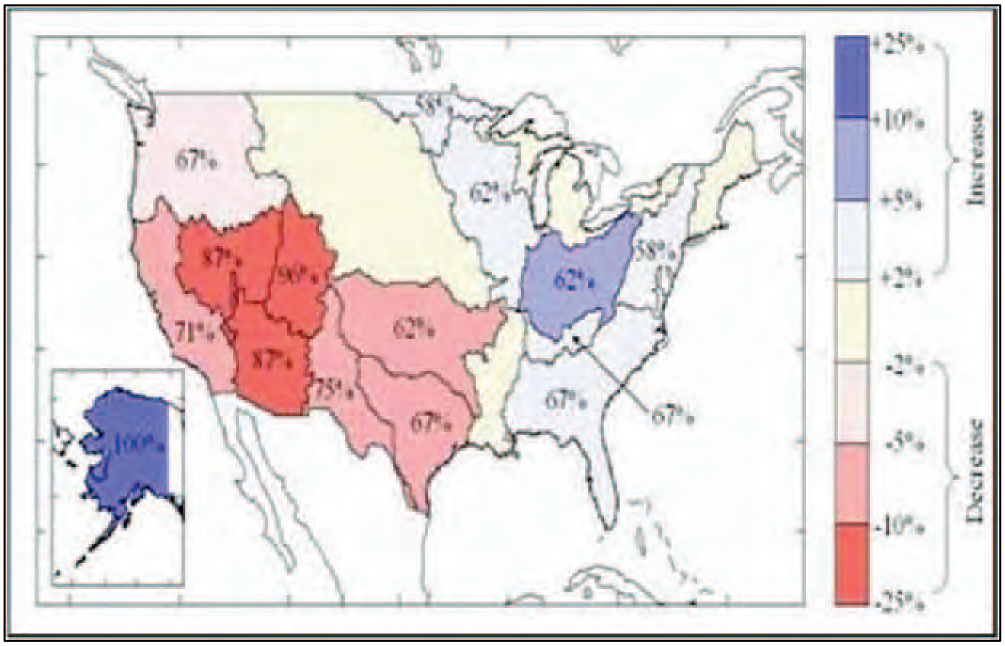


Figure 17. Median changes in runoff interpolated to USGS water resources regions from Milly et al. (2005) from 24 pairs of GCM simulations for 2041-2060 relative to 1901-1970. Percentages are fraction of 24 runs for which differences had same sign as the 24-run median. Results were replotted from Milly et al. (2205) by Dr. P.C.D. Milly, USGS. Source: Lettenmaier et al. (2008)

Chapter 4. Climate Change Related Trends in Aquatic Ecosystems

Introduction

Observational records and climate projections provide abundant evidence that freshwater resources may be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems (Bates et al. 2008). Climate change is altering hydrologic processes and amplifying the risk of extinction for many plants and animals, and threatening the integrity of the living systems that are vital to human well-being (IPCC 2007).

Aquatic ecosystems in the Western U.S. may be particularly vulnerable climate change because of the high percent of cold-water-dependent species (ISAB 2007, O'Neal 2002, Preston 2006). Climate change has the potential to affect most freshwater life history stages of trout and salmon (ISAB 2007). It is likely that most native aquatic species in the Western U.S. will be adversely affected by climate change since changes will potentially result in less snowpack, more precipitation as rain and less snow, earlier snowpack runoff, lower summer baseflows, and warmer water temperatures (Chapter 3).

Water quality, water quantity and aquatic biodiversity are important ecosystem services provided by the national forests. Climate change will affect the ability of the national forests to provide water and other aquatic ecosystem services. While some uncertainty exists regarding the extent, location, or timing of climate change impacts, land managers can anticipate aquatic ecosystem changes and respond with flexible and adaptive management strategies.

Observed Trends in Aquatic Ecosystem

The Idaho Panhandle and Kootenai National Forest support a variety of aquatic-dependent species including fish, amphibians, and aquatic invertebrates. Many of these species are cold-water dependent, in other words they require cold water temperatures for all or a portion of their life cycles.

Human activities since the late 1800s have altered much of the landscape across the Idaho Panhandle and Kootenai National Forests. Milling of logs downstream reduced habitat complexity and the connection between streams and their floodplains (Lee et al. 1997). Dams and diversions resulted in dramatic changes to stream conditions and the passage of aquatic species upstream and downstream. Ground disturbing activities such as mining, road building, and logging have resulted in higher sediment loading to streams and channel alterations that often have resulted in unfavorable conditions for aquatic species (Rieman et al. 2003). In the Interior Columbia Basin, which includes the Idaho Panhandle and Kootenai National Forests, the ecological integrity of streams, lakes, and wetlands was significantly compromised by the late 1920s (Lee et al. 1997). Increasing human population, technological advances (for example, centrifugal pumps), and availability of heavy equipment after World War II greatly accelerated the development of new irrigation projects, timber harvest, livestock grazing, dam construction, and road building (Lee et al. 1997). Individually and in combination, these activities continued to fragment and compromise the aquatic ecosystems (Lee et al. 1997).

Features of altered ecosystems include changes (generally reductions) in species diversity, changes in species distributions, and losses of habitat types or ecosystem states (Reeves et al.

1995). Of particular concern for native salmonids is the fragmentation of aquatic habitat that impedes or prevents recolonization of an area disturbance, such as flood or fire, cause a local population to be extirpated. In addition, habitat fragmentation prevents fish from moving into upstream areas, which under a warming climate scenario would most likely provide cooler water temperatures. Also of concern to native fish and amphibians is the introduction of non-native species which has occurred on both the Idaho Panhandle and Kootenai National Forests.

Most, if not all, of the native fish and amphibian species on the Idaho Panhandle and Kootenai National Forests have declined in abundance and distribution over the last century (Lee et al. 1997; Rieman et al. 1997; Thurow et al. 1997). Throughout the Columbia River Basin, these declines have been attributed to a variety of causes including construction of dams, reservoirs and other instream structures that block fish migration and fragment populations; introduction and expansion of nonnative species that displace native fish through competition, predation, and hybridization; and degradation of instream habitat that resulted from some types of mining, timber harvesting, road construction, and other development activities (Lee et al. 1997; Rieman et al. 1997; Thurow et al. 1997; Shepard et al. 2005).

Chapter 3 of this report summarizes observed climatic and hydrologic trends over the western U.S., and northern Idaho and northwestern Montana. Trends potentially consequential for aquatic ecosystems include:

- Declining snowpack, especially at mid-and low-elevations;
- Earlier snowmelt and peak runoff;
- Decreasing summer stream flows; and
- Increasing proportion of annual precipitation falling as rain compared to snow.

In addition, observed increases in temperature and changes in the timing and intensity of precipitation have increased the probability of flood events in some watersheds of the western U.S. from 1915 to 2003 (Hamlet and Lettenmaier 2007). Modeling analysis indicate that relatively low elevation watersheds of northern Idaho and northwestern Montana with winter temperatures generally near freezing have experienced an increasing likelihood of rain-on-snow events resulting in an increased frequency of winter floods during the 20th century (Hamlet and Lettenmaier 2007). Higher elevation watersheds where winter temperatures are more consistently below freezing showed a decreasing flood risk (Figure 18).

These climatic and hydrologic trends, combined with climate-related trends in wildfires (Chapter 10) and forest mortality from insects and diseases (Chapter 9), can significantly affect aquatic ecosystems and species (Dunham et al. 2003; Casola et al. 2005; Dunham et al. 2007; Williams et al. 2009; Isaak et al. 2010). A growing body of literature has linked these hydrologic trends with impacts to aquatic ecosystems and species in the western North America, often as a result of climate-related factors affecting stream temperatures and the distribution of thermally suitable habitat (Peterson and Kitchell 2001; Morrison et al. 2002; Bartholow 2005; Kaushal et al. 2010; Isaak et al. 2010). Lower summer streamflows and higher air temperatures, as observed over recent decades in northern Idaho and northwestern Montanta, are generally expected to result in increased stream temperatures. However, stream temperatures are controlled by a complex set of site-specific variables including shading from riparian vegetation, wind velocity, relative humidity, geomorphic factors, groundwater inflow, and hyporheic flow (Caissie 2006). Long-term stream temperature trend data are not available for most streams in northern Idaho and northwestern Montana streams. As a result, it is unclear whether or to what extent observed climatic and hydrologic trends have affected stream temperatures and the distribution of thermally suitable habitat for fish species in this area. Similarly, stream gage-based analyses of observed trends in flood occurrence and magnitude, and resulting effects on aquatic habitats, is not available for northern Idaho and northwestern Montana.

The effects of observed climate trends on amphibian species are unclear, with only two published analyses specific to the Northern Rockies. McMenamin et al. (2008) report that over the period from 1992 to 2008 wetland amphibian habitat in Yellowstone National Park declined significantly, resulting in the loss of more than half the sampled amphibian populations. The authors partly attribute these changes in amphibian habitat and populations to observe climatic and hydrologic trends, including increasing maximum annual temperature, decreased yearly and winter precipitation, and declining spring snowpack. In contrast, a recent 9-year study of Columbia spotted frogs in the Bitterroot Mountains of westcentral Montana documented an increase in survival and breeding probability associated with decreasing winter severity (an index combining peak snow water equivalent, duration of snow cover, and date of last day with snow cover) (McCaffery and Maxell 2010).

Projected Trends in Aquatic Ecosystem

As described in Chapters 2 and 3 of this report, climate and hydrologic model simulations for the Northern Rockies project:

- Warmer air temperatures;
- Decreased winter snowpack;
- Increasing proportion of annual precipitation in the form of rain, and decreasing proportion as snow;
- Earlier snowmelt;
- Lower summer stream flows; and
- Increasing potential for rain-on-snow events and extreme flooding.

These projected climatic and hydrologic changes will affect the amount, type, quality, and distribution of aquatic habitats, species, and communities. Projected changes in thermal and hydrologic conditions have the potential to affect salmonid fishes during all their freshwater life history stages (ISAB 2007). These potential impacts include:

- *Egg incubation and fry emergence* may be adversely affected due to flood flows, dewatering, and/or water temperatures. Shifts in the timing and magnitude of natural runoff will likely introduce new selection pressures that may cause changes in the most productive timing or areas for spawning.
- *Spring/summer rearing* may be adversely affected due to reduction in stream flow and higher water temperatures.
- *Overwinter survival* may be positively affected by higher winter water temperatures enabling fish to feed more actively, potentially increasing growth rates if sufficient food is available. If food is limited, the elevated metabolic demands could reduce winter growth and survival.

In addition to direct effects on aquatic species, projected climatic and hydrologic changes may also result in indirect effects on aquatic ecosystems by increasing the extent or severity of terrestrial disturbance processes, such as wildfires (see Chapter 10), tree mortality from insects and pathogens (see Chapter 9), and riparian vegetation. These projected direct and indirect impacts will likely affect aquatic ecosystems and species by altering stream temperature and the distribution of thermally suitable habitat, stream hydrology, and production of sediment and coarse wood inputs to streams.

Stream Temperatures and Thermally Suitable Habitat

Fish and most other aquatic organisms are ectothermic (cold blooded) and incapable of independently regulating their metabolic rates. Most ectothermic species are adapted to specific temperature ranges. Stream temperatures near or outside the range of thermally suitable habitat may be lethal, reduce growth and productivity rates, and affect other life history traits (Rieman and Isaak 2010). As a consequence, stream temperature regimes are often a dominant factor shaping species distribution and relative abundance of fish and other aquatic species, aquatic community composition, and competitive interactions among species. Stream temperatures are affected by a variety of factors in addition to air temperature, such as solar radiation and shading from riparian vegetation, stream flow volume and timing, valley shape and orientation, and groundwater inflow (Caissie 2006; Tague et al. 2008; Isaak et al. 2010). Wildfires and loss or conversion of riparian vegetation can significantly affect stream temperatures and distribution of fish species (Dunham et al. 2007; Rieman and Isaak 2010).

Bull trout is the native trout species most vulnerable to potential increases in stream temperatures because it has the coldest range of thermally suitable habitat among native salmonids in the Northern Rockies. For this species, increasing stream temperatures may cause a net loss of habitat because areas are not available further upstream to replace those that become unsuitably warm. For rainbow trout, which tolerates warmer stream temperatures that bull trout and is often limited by upstream temperatures that are too cold, warming may only shift suitable habitats toward higher elevation stream reaches with little or no net change in total amount of thermally suitable habitat (Rieman and Isaak 2010). Cutthroat trout in high-elevation streams currently are commonly limited by low water temperatures and short growing seasons (Coleman and Fausch 2007; Harig and Fausch 2002). These populations may benefit from climate-induced increases in thermally suitable habitat in higher elevation stream reaches (Rieman and Isaak 2010). However, warmer stream temperatures may also lead to nonnative fish and other aquatic species moving into previously unsuitable upstream areas where they will compete with native species (Rieman et al. 2007; Rahel and Olden 2008; Fausch et al. 2009; Haak et al. 2010)

Projected increases in air temperatures, along with projected decreases in summer stream flows, will likely lead to warmer stream temperatures in the Columbia River basin, particularly during summer low flow periods (Casola et al. 2005). Recent scientific publications suggest that projected air temperature changes are likely to reduce the distribution of thermally suitable natal habitat for bull trout, fragment existing populations, and increase risk of local extirpation (Rieman et al. 2007; Isaak et al. 2010) (Figure 19). However, the risk of climate-induced extirpation in subbasins of northern Idaho and northwestern Montana may be less than other, relatively drier and warmer, subbasins in the Columbia River basin (Rieman et al. 2007).

Other recent publications conclude that westslope cutthroat trout, which can generally tolerate warmer stream temperatures than bull trout, is at a low risk for increasing summer stream temperatures in most basins within its range, including the Clark Fork, Coeur d'Alene, and Kootenai basin of northern Idaho and northwestern Montana (Williams et al. 2009; Haak et al. 2010). These studies also conclude that stream temperature impacts resulting from projected climate-change-induced increases in wildfire extent and severity posed a moderate or high risk of cutthroat trout extirpation in 46 percent of occupied subwatersheds throughout the species' occupied range. However, wildfire posed a moderate or high risk to cutthroat trout in only 3 percent of subwatersheds in the Coeur d'Alene and Kootenai basins, but 45 percent of subwatersheds in the Clark Fork Basin (Haak et al. 2010).

Kootenai River white sturgeon, spawn in May or June in water temperatures around 8-9oC and cease to spawn at 12oC (Paragamian et al. 2001). Under future scenarios of warming water temperatures and reduced summer flows there is a possibility that the white sturgeon may be stimulated to spawn earlier that May-June period. This may actually be advantageous for white sturgeon for both egg incubation/survival as well as flow/velocity requirements for successful recruitment (ISAB 2007).

Stream Hydrology

Projected reductions in summer low flows and increased winter flood risks may have negative effects on native salmonids and other aquatic species. Continuation or acceleration of the observed trend in declining summer low flows will reduce the volume of habitat for aquatic species within individual reaches, and reduce availability of food resources, due to reduce terrestrial interactions (Baxter et al. 2005) and lower drift rates associated with decreased flow velocities (Harvey and White 2006). In addition, the upper extent of perennial flow in some streams will likely become intermittent more regularly, which could reduce the total amount and quality of available habitat (Clair and Ehrman 1996). These same reductions may also start to preclude upstream access to traditional spawning areas by fall spawning fish at some point.

Changes in flood risks are generally expected to be greatest in watersheds with midwinter air temperatures near or slightly below freezing, which characterizes many of the watersheds in northern Idaho and northwestern Montana (Hamlet and Lettenmaier 2007). These watersheds are especially vulnerable to increasing frequency of rain-on-snow events and associated flooding as a result of warming temperatures during late fall, winter, and spring. An increased frequency or severity of mid-winter flood events would negatively affect fall spawning fish species - such as bull trout, brook trout, and brown trout - because bed scour could easily destroy eggs incubating in the gravel and eliminate yearly recruitment (Tonina et al. 2008). Haak et al. (2010) conclude that risks to native trout resulting from projected increases in winter flood risk in north Idaho and northwestern Montana are greater than risks associated with climate-induced changes in wildfire, drought, or stream temperatures. They estimate that cutthroat trout in most subwatersheds in the Clark Fork, Couer d'Alene, and Kootenai basins face high to moderate risk of increased winter flooding (Haak et al. 2010; Williams et al. 2009).

Sedimentation and coarse wood recruitment to streams

Altered stream hydrologies may also affect the way that sediment and wood are transported through stream networks. If this altered transport capacity is accompanied by increases in wildfire activity (as appears to be occurring across much of the western US;

Westerling et al. 2006; see Chapter 10), supplies of sediment and wood delivered to the stream network could increase, which has several implications for aquatic organisms (Rieman et al. 2003; Dunham et al. 2007). Because most fire related sediment is delivered to and through channels in episodic, postfire pulses, populations isolated in small, steep headwater tributaries may become more susceptible to catastrophic debris flows that could cause local extirpations (Dunham et al. 2003; Wondzell and King 2003). Larger, mainstem stream channels or lower gradient areas on smaller streams could start to aggrade as they adjust to the influxes of additional materials (Minshall et al. 1997; Benda et al. 2003). Depending on the frequency and intensity of larger flood events relative to sediment supplies, channel morphologies could widen to handle flashier runoffs and higher peak flows (Benda et al. 2003; Miller et al. 2003). Habitat diversity and structural complexity may also increase over time due to the additional inputs of sediment and wood (Minshall et al. 1997; Benda et al. 2003; Dunham et al. 2003; Rieman et al.

2003). Although wildfires and other disturbances processes are not unusual for most watersheds in the Northern Rockies, climate change projections indicate that they may increase in frequency and severity in coming decades (see Chapters 9 and 10 of this report). Fish and other aquatic species with narrow habitat requirements and isolated populations in currently fragmented habitat will be most susceptible to negative impacts from these projected changes since they will be unable to re-populate a stream reach after disturbance (Dunham et al. 2003). Many stream habitats on the Idaho Panhandle and Kootenai National Forests are currently fragmented by road culverts and other barriers (Hendrickson et al. 2008).

Amphibians

For amphibians, responses to climate change will be influenced by the following primary factors (Lind 2008, Climate Change Resource Center):

- Expected changes and variability in local environmental and habitat conditions;
- The phenology (timing) of life -requisite activities;
- Interactions with emerging pathogens and invasive species; and
- Interactions with other environmental stressors (e.g. chemicals).

Amphibian populations are sensitive to changes and variability in air and water temperatures, precipitation, and hydroperiod (length of time and seasonality of water presence) of their environments (Carey and Alexander 2003). Amphibians are ectothermic; their body temperatures and activity cycles are dependent on environmental conditions because they are unable to regulate their body temperature internally. Many of the amphibians found on the Idaho Panhandle and Kootenai National Forests require aquatic habitats for egg laying and larval development and moist environments for post-metamorphic life stages (Maxell 2000).

Species associated with shallow ponds and intermittent streams and springs, may be particularly vulnerable to altered precipitation patterns; changes in the timing of spring runoff; and the duration and severity of droughts (McMenamin et al. 2008). On the other hand, amphibians occurring in relatively high elevation and wet environments may benefit from warmer temperatures and shorter winters (McCaffery and Maxell 2010). As water temperatures increase and the availability of water in aquatic habitats becomes more variable, amphibians are likely to experience lower rates of survival to metamorphosis (Lind 2008, CCRC). In addition, air and water temperature outside of a species' thermal optima is likely to result in physiological stresses. Recent research on amphibian declines has documented the role of emerging pathogens and in some cases epidemic outbreaks of particular infections and diseases (Daszak et al. 2003, Wake and Vredenburg 2008). Changes in climate regimes are likely to increase pathogen virulence and amphibian susceptibility for pathogens (Pounds et al. 2006, Lind 2008, CCRC). Similarly, warm water invasive species (e.g., bull frogs, sunfishes) may expand their ranges given warming trends, increase predation of native amphibians, and cause additional stresses from inter-specific competition.

Key Sources of Uncertainty

As described in Chapters 2 and 3 of this report, there is considerable uncertainty surrounding projected changes in precipitation, which has a strong influence on stream hydrology and aquatic ecosystems.

Although stream temperatures are likely to increase with projected increases in air temperature, stream temperature trends may only generally track air temperature increases because of the numerous factors in addition to air temperature that influence stream temperature, such as solar radiation and shading from riparian vegetation, stream flow volume and timing, valley shape and orientation, and groundwater inflow (Caissie 2006; Tague et al. 2008; Isaak et al. 2010). Thus, although stream temperatures are likely to increase with projected increases in air temperature, stream temperature trends may only generally track air temperature increases, and will in some locales be more strongly affected by the secondary effects of climate change manifest through wildfires or conversion of riparian vegetation types (Rieman and Isaak 2010). Thus, there is considerable uncertainty, especially at local scales, regarding the effect of projected climatic changes on thermally suitable habitat for aquatic species.

There is considerable uncertainty regarding the potential effects of climate change on parasites and pathogens on aquatic species. Many fish pathogens and parasites do not become injurious until their host becomes thermally stressed (ISAB 2007). Although there is some general evidence that the virulence of some pathogens and parasites may increase with climate change (Marcogliese 2008), little scientific research available specific to aquatic ecosystems of the Northern Rockies.

Synergistic effects of multiple stressors are uncertain. Climate change will occur concurrently with other impacts to aquatic ecosystems. Studies that have examined the simultaneous effects of more than a single stressor (e.g., climate and land use; climate, land use, and human population growth) generally conclude that the effects of more than a single stressor are not easily predictable, but may often be more severe than simple combination of the single-factor outcomes (ISAB 2007, Hansen et al. 2001).

Potential Adaptation Options

Adaptation here is in the context of the policies and management measures that land managers might undertake to increase the likelihood that aquatic ecosystems and species may persist despite potential climate-related impacts. The following section includes some possible proactive adaptation actions.

Use existing information to identify watersheds and aquatic resources that are most vulnerable and/or sensitive to adverse changes. Planning for change and priority-setting will need to begin with identifying the vulnerability and sensitivity of areas with the highest aquatic resource values. An example of an area of very high aquatic resource value would be a watershed or stream reach supporting federally listed fish species.

Implement broad-scale inventories, assessments, and monitoring (e.g., stream temperature monitoring) that can help managers identify trends, anticipate effects, and act quickly to limit reduction in critical aquatic resources.

Another option is to Implement best management practices to protect aquatic resources that are actively managed and implement restoration actions to reestablish aquatic ecosystem components and processes that have been lost or at risk.

Actively manage for resilience and resistance of aquatic ecosystems including:

- Providing refuges across the landscape that spans elevation and altitudinal boundaries, so that aquatic-dependent species can disperse into environments with suitable habitat conditions.
- Provide larger (>10,000 ha) stream networks for native fish.

- Reduce the effects of other factors that have negative influences on aquatic species (e.g. habitat alteration, pollutants, and toxins) to decrease stresses on individuals and populations.
- Remove migration barriers and reestablish habitat connectivity to help aquatic species adapt to changing conditions.
- Maintain or restore instream flows by restoration of meadows, wetlands, and floodplains to improve natural storage, reduce flood hazards, and prolong seasonal flows.
- Control or eradicate non-native species.
- Protect and restore riparian forests to moderate changes in water temperate.
- Restore patchiness or heterogeneity to forests and streams to make them less susceptible to large disturbances synchronized across broad areas, and that would simultaneously affect many populations of aquatic species.
- Improve or decommission roads to reduce adverse impacts during precipitation events.
- Assisted migrations may be considered for species and populations in isolated and fragmented habitats that will not be able to respond to changes in the distribution of suitable habitat.

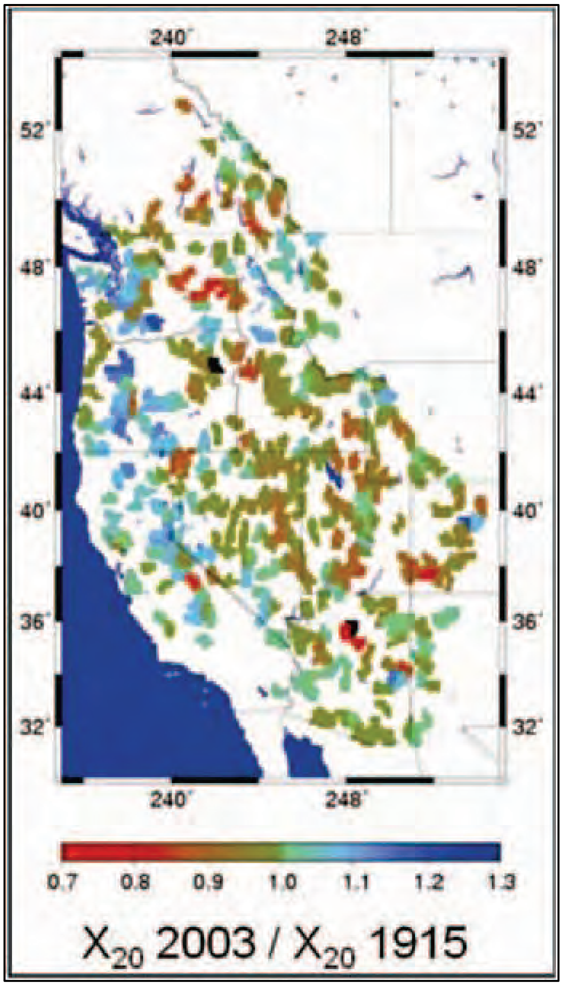


Figure 18. Relative changes in 20-year flood probability from 1915 to 2003 west of the Continental Divide modeled using the Variable Infiltration Capacity hydrologic model. Watersheds in blue had increased probabilities while those in brown or red had reduced probabilities (Rieman and Isaak (2010) from Hamlet and Lettenmaier 2007)

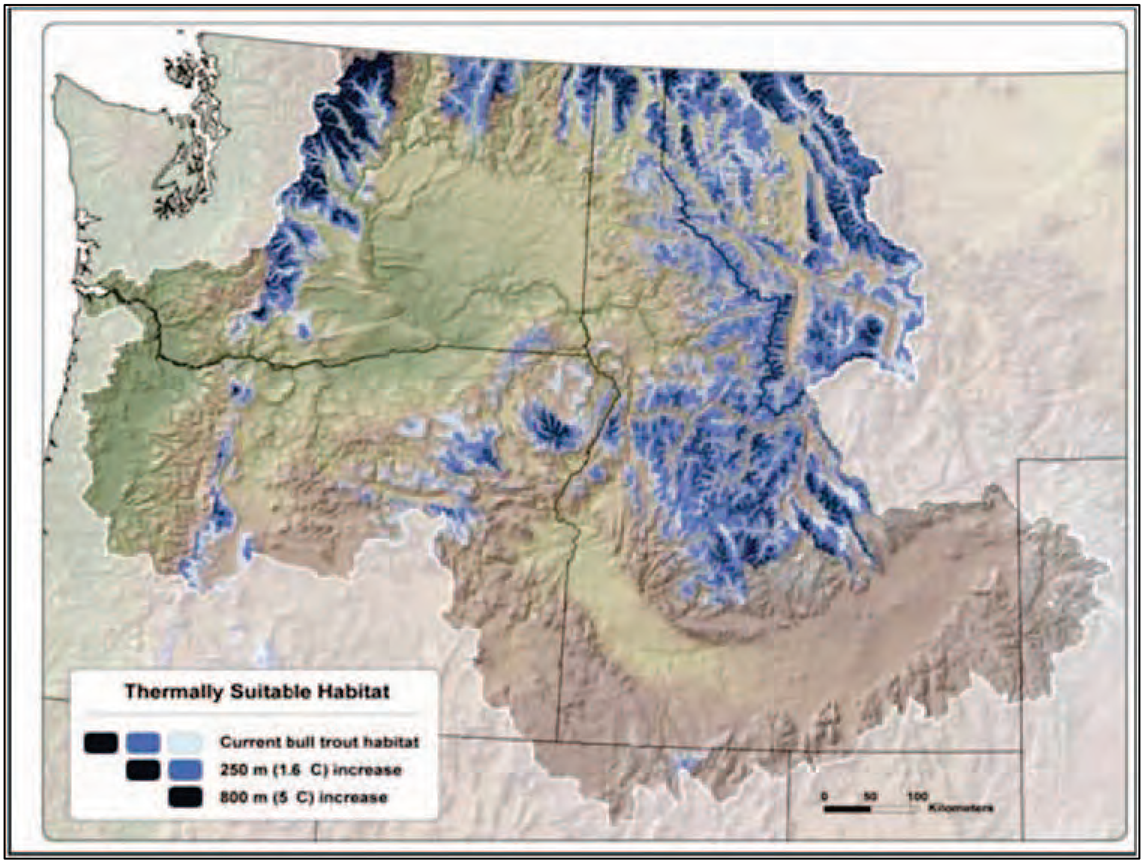


Figure 19. Changes in thermally suitable habitat under different air temperature increases for bull trout spawning and juvenile rearing within the Interior Columbia River basin predicted by a bioclimatic model. All shades of blue indicate historically suitable habitats; whereas lighter shades of blue indicate habitats that could be lost with future air temperature warming of 1.6 oC to 5 oC (Rieman and Isaak (2010) from Rieman and others 2007)

Chapter 5 Climate Related Trends in Forest Composition

Introduction

Over many thousands of years, the vegetation of the North America has changed in response to long-term changes in climate (Delcourt and Delcourt 1991; Thompson and Anderson 2000; Williams 2002). On shorter time scales of years and decades, climate variability, drought, insect outbreaks, wildfires and other disturbances have caused significant changes in the distribution and abundance of trees and other plant species (Dale et al. 2001). The composition of the Kootenai and Idaho Panhandle National Forests, like all forests, is constantly changing. Climate plays a fundamental role in these changes (Woodward 1987).

Recent and projected trends in global climate have led many scientists to suggest that the distribution of tree and other plant species should be expected to migrate up in elevation and up in latitude toward the poles (Janetos et al. 2008). There is increasing evidence from a variety of locations to support this hypothesis (Parmesan and Yohe 2003; Lenoir et al. 2008). Several studies have documented the movement of the alpine tree line upward in elevation and “in filling” of high elevation meadows in western North America during the 20th century (Rochefort and Peterson 1996; Hessl and Baker 1997; Luckman and Kavanagh 2000; Roush et al. 2007; Fagre et al. 2003). In the Green Mountains of Vermont, researchers have found that the northern hardwood-boreal forest ecotone shifted approximately 300 feet upslope over the last 40 years, with hardwood species advancing and boreal conifer species retreating upslope (Beckage et al. 2008). The authors attributed these observed increases in average annual temperature and precipitation. A recent study of tree species’ seedling distributions in relation to latitude in the eastern United States concluded that many northern tree species are migrating northward in response to climate trends (Woodall et al. 2009).

Observed Trends in Forest Composition

Over the last 100 years, forest management activities, fire suppression, forest succession, and the introduction of non-native pathogens have had a major influence on forest composition of the Kootenai and Idaho Panhandle National Forests (Quigley and Arbelbide, 1997; USDA Forest Service 2003). Climate variability, through its effects on wildfire occurrence and extent, appears to also have played a substantial role during the 20th century and throughout the Holocene (Morgan et al. 2008; Whitlock et al. 2003; see Chapter 5.8). As a general pattern, there has been a pronounced shift from early to late seral cover species in northwestern Montana and northern Idaho (Hessburg et al. 1999; Hann et al. 1997; Hessburg et al. 2000; Hessburg and Agee 2003). Forest structure has also changed with decreases in stand initiation, young multi-story structures while intermediate forest structures have increased in area (Hessburg et al. 2000; Hann et al. 1997) (Figure 20).

Perhaps the most well-known change has been the near elimination of the western white pine cover type as a result of the introduced pathogen white pine blister rust, mountain pine beetle mortality, and selective harvesting, (Hessburg et al. 2000; Neuenschwander et al. 1999; Harvey et al. 2008; Kendall and Keane 2001). There has also been a significant decrease in the percent of area occupied by Ponderosa pine (15 percent decrease) and western larch (23 percent decrease) (Hessburg et al. 1999; Hessburg et al. 2000). Concurrently, the percentage of area occupied by grand fir, Engelmann spruce-subalpine fir, and western hemlock-western red cedar cover types has increased (Hessburg et al. 1999; Hessburg et al. 2000). At higher elevations, the occurrence of whitebark pine has declined, while Engelmann spruce and subalpine fir have increased (Hessburg et al. 2000; Kendall and Keane 2001; Tomback and Kendall 2001).

The shift toward increasing dominance of shade tolerant cover types has been accompanied by a shift in structure to stands that are more dense forest conditions with has increased susceptibility to bark beetles, root disease, and wildfire (Hessburg et al. 1999; Hessburg et al. 2000). In all forest habitat type groups the relative abundance of medium size classes and mid-successional stages have increased significantly over the last 100 years, while large, very large, old growth, seedling/sapling, or small sizes classes have declined in relative abundance (Hessburg et al. 1999; Hessburg et al. 2000). In some areas, the changes in forest structure and landscape patterns have created conditions more susceptible than historically to drought stress, mortality from insects, diseases, and severe wildfires (Hann et al. 1997; Hessburg et al. 1999; Hessburg et al. 2000).

These observed changes in forest composition are the result of multiple factors, including climate variability (Morgan et al. 2008). It is unknown whether natural climate variability, including the Pacific Decadal Oscillation, has caused widespread changes in the distribution of trees and other plants in the Northern Rockies and the Kootenai and Idaho Panhandle National Forests. The only scientific evidence of climate-induced shifts in the distribution of tree species in the U.S. Northern Rockies is limited to localized changes in the alpine tree line elevation and the in-filling of high elevation meadows (Malanson et al. 2007). However, the lack of published scientific studies is not conclusive evidence that such changes are not occurring (Janetos et al. 2008).

Projected Trends in Forest Composition

Research scientists have used several types of simulation models to examine the potential effects of climate change on forest composition. These models differ in their basic analytical approach, biological resolution (e.g., biomes vs. species), and ecological processes simulated (Peterson et al. 2005; Betts and Shugart 2005; Cushman et al. 2007). The three most common types of models used to simulate effects of climate change on vegetation distribution are dynamic global vegetation models, landscape disturbance/succession models, and statistical species distribution models. Each type of model has strengths and limitations (Thuiller et al. 2008; Iverson and Prassad 2001; Peterson et al. 2005; Betts and Shugart 2005).

Dynamic global vegetation models (DGVMs) integrate physiological, biogeochemical, biogeographical, and fire processes to simulate changes in the distribution of vegetation types; movement of carbon, nitrogen and water through ecosystems; and fire disturbance (Betts and Shugart 2005; Prentice et al. 2007; Lavorel et al 2007). They are most commonly used for global, continental and regional-scale simulations. Given the complexity of processes modeled, DGVMs do not simulate changes in individual species. Rather, they simulate changes in broad classes of vegetation types such as biomes or plant functional types (e.g., temperate coniferous forest). Most DGVMs have a coarse spatial resolution (≥50 km2 grid cell size), although some recent DGVM simulations have a spatial resolution of 1 km2 or higher.

Landscape disturbance/succession models simulate the interactions of vegetation succession, disturbance, and climate (Keane et al. 2007). As the name implies, landscape models are typically used for regional and landscape-scale simulations. Some landscape models are able to simulate spatial processes such as fire spread. Because they model vegetation succession, landscape models typically simulate changes in the distribution of potential vegetation types, not individual species.

Statistical species distribution models, sometimes referred to as climate envelope models, typically use statistical regression analyses to identify the climatic or environmental conditions most strongly correlated with the current distribution of a species, then map the location of those conditions under modeled climate projections. They are typically applied at continental, regional, and finer analysis areas. Given the fine-grained pattern of distribution of most species, particularly in areas of diverse topography, statistical species distribution models are improved by high spatial resolution data for historic and projected climate, and accurate observations of species presence, absence, and age. Statistical species distribution models typically project the future distribution of climatically suitable habitat for an individual species, not the actual occurrence or range of a species.

The following text summarizes results from applications of these different types of models to simulate the effects of climate change on forest composition in the U.S. Northern Rockies.

DGVM Simulations — The DGVM model known as MC1 has been used for more than a decade to simulate the effect of different climate scenarios on the distribution of broad vegetation classes in the conterminous United States (Bachelet et al. 2001; Bachelet et al. 2003; Lenihan et al. 2008a. Recent experiments project the widespread reduction in subalpine forests in the western U.S (Lenihan et al. 2008a). The distribution of temperate conifer forests expands in the Pacific Northwest and Northern Rockies, especially when the models simulate fire suppression success continuing at historical levels. In simulations of no fire suppression, woodland/savanna vegetation types replace most shrubland areas in the interior west, especially if vegetation growth response to elevated CO2 is assumed to be high (Lenihan et al. 2008b; Bachelet et al. 2008). These coarse-grained simulations of vegetation change provide only general indications of potential climate-induced change in forest composition in the Northern Rockies.

Landscape Simulation Models — Research scientists have used the landscape model known as LANDSUM to simulate potential effects of climate change on vegetation in two sample landscapes, one mountainous and one relatively flat, in western Montana (Keane et al. 2008). This modeling experiment simulated the changes in potential vegetation types (PVTs) under three climate scenarios: current climate; warm and moist; and hot and dry. Under the warm-moist scenario, seasonal temperatures increased 1.8° to 3.6°F, and spring and summer precipitation increased about 25 percent over current climate (1980-1997). Under the hot-dry scenario, increased 4.5°F in winter, 5.4° F in spring, 12°F in summer, and 8.3°F in autumn; precipitation increased 11 percent in winter and decreased 34 percent in summer compared to 1980-1997.

Simulations of the warm-moist scenario projected substantial declines in bluebunch wheatgrass (flat landscape), mountain big sagebrush (mountainous landscape), Douglas fir/ponderosa pine, Douglas-fir, and subalpine spruce-fir potential vegetation types (PVTs). This simulations of this scenario also project increases in the distribution of Wyoming Basin big sagebrush (flat landscape), montane spruce-fir, timberline spruce-fir, timberline whitebark pine, lodgepole pine, and Douglas-fir lodgepole pine (flat landscape only).

Simulations of the hot-dry scenario projected substantial declines in bluebunch wheatgrass (flat landscape), mountain big sagebrush (mountainous landscape), Douglas-fir/ponderosa pine. The Douglas-fir/Douglas-fir declines in the mountainous landscape but not the flat landscape.

Subalpine spruce-fir increases in the flat landscape but declines in the mountainous landscape. Lodgepole pine expands its distribution in the flat landscape but remains stable in the mountainous landscape. The montane spruce-fir and Douglas-fir/lodgepole pine PVTs increase substantially in both landscapes. Timberline spruce-fir and whitebark pine PVTs remain stable in both landscapes.

The results of these landscape succession model simulations reveal the significant influence of changing fire regimes on the composition of future landscapes and highlight the relative and interacting effects of temperature and precipitation on the distribution of potential vegetation types (Keane et al. 2008). However, the authors note that “more research is needed to evaluate if our results are in the realm of ecological possibility or a side-effect of our statistical model” (Keane et al. 2008 pg. 11).

Statistical species distribution models — Recently two modeling groups have developed statistical species distribution models to evaluate the effects of climate change on the distribution of tree species in western North America (Rehfeldt et al. 2006; McKenney et al. 2007). One group is affiliated with Natural Resources Canada (NRCan), and the other with the U.S. Forest Service Rocky Mountain Research Station (RMRS). Although there are many similarities in the methods of the two modeling groups, the most notable difference is the use of different climate variables to define suitable habitat for the species modeled. In addition, the two modeling groups differed in the GCMs used to project future climate. The NRCan group projected the distribution of suitable climate habitat of 130 North American tree species using four GCMs (CGCM2, HadCM3, CSIRO, NCAR) each running two emissions scenarios (A2 and B2) (McKenney et al. 2007). The RMRS projected the distribution of “climate profiles” for numerous tree species in the western U.S. using three GCMs (CGCM3, HadCM3, and GFDL) each simulating the A2 and B1 emissions scenarios. The methods used by RMRS were published by Rehfeldt et al. 2006. Both modeling groups have produced websites[1] where detailed descriptions of their data sources, methods and simulation results are available, including maps of suitable habitat projected by multiple GCM/emission scenarios.

Examination of the mid-21st century simulations from both modeling groups reveals that simulation of future tree species distributions differ more between GCMs than between emissions scenarios. Multiple simulations from both modeling groups consistently project extensive reductions in suitable climate habitat of western larch, whitebark pine, and lodgepole pine in the U.S. Northern Rockies, including northern Idaho and northwestern Montana. Projections of changes in suitable climate habitat for ponderosa pine vary among models and are spatially complex for the western U.S. However, the majority of models project reductions in suitable habitat for ponderosa pine in northern Idaho and western Montana. Douglas-fir, model projections range from little change to substantial reductions in suitable habitat (see also Littell et al. 2010 for similar analysis specific to the State of Washington). Projections of suitable habitat for western red cedar and mountain hemlock are even more variable, with some models projecting increases in suitable habitat and other projecting moderate to substantial reductions. Appendix 5.2.2 provides a more complete comparative summary of statistical species distribution model projections from these two modeling groups.

Summary of Projected Trends in Forest Composition — The future distribution of trees and other species in the Northern Rockies will be determined by interactions of climate variability, climate change, disturbance processes, land use changes, nonnative and invasive species, inter-

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[1] http://forest.moscowfsl.wsu.edu/climate/
http://planthardiness.gc.ca/ph_futurehabitat.pl?lang=en.

specific competition, species dispersal and migration processes, phenotypic and genetic responses of species, forest management actions, and other influences. The models summarized above consider only a small subset of these factors. Thus, they should be viewed as estimates of potential changes in climatically suitable habitat, rather than quantitative predictions of the future distribution of tree species and forest types (Janetos et al. 2008).

Even though the different model simulations described above do not produce consistent results, collectively they indicate that projected changes in climate are likely to significantly stress many forest communities and tree species. Climate stress will combine with other stressors to influence the composition tree species on the Kootenai and Idaho Panhandle National Forests, and the entire Northern Rockies.

Key Sources of Uncertainty

Lack of model validation — It is impossible to validate model projections for events that have not yet occurred. However, rigorous comparison of results from independent models can improve confidence in consensus results among independent experiments and reveal the sources of uncertainty that have the most significant impact on model results (Araújo et al. 2005). In reviewing the model results summarized above, greater confidence might apply to projected changes that are broadly consistent across multiple simulations.

Climate means vs. variability — Inter-annual variability in weather may have a greater impact on tree species recruitment and mortality than shifts in long-term means of temperature and precipitation. For example, a few relatively cool or moist years per decade within an otherwise warming and drying trend may make a large difference in the distribution of species whose range is limited by water availability. In addition, climate variability also strongly influences disturbance processes and mortality rates of trees. However, most vegetation response models address changes in climate means, and not inter-annual variability (Keane et al. 2007).

Influence of multiple stressors — Models used to project the future composition of forests consider only a few of the likely influences on tree species' distribution. Every model omits influences that may be significant. For example, none of the models reviewed above consider land management practices that may dampen or amplify the potential effects of changing climate. Estimation of the effects of climate change on forest composition requires the consideration of multiple stressors (McKenzie et al. 2009).

Effects of increased concentrations of CO2 — CO2 concentrations can have substantial impacts on the physiology of trees and other plant species (Körner et al. 2007). For example, it may increase the water use efficiency of plants and thus increase tolerance to water stress. Such physiological changes may alter the climatic conditions under which tree species are able to regenerate and become established (Bachelet et al. 2008). The simulations with the MC1 model summarized above assume that elevated CO2 increases water use efficiency in trees. The landscape simulation and statistical species distribution models do not incorporate potential physiological responses to elevated CO2 concentrations. Considerable uncertainty persists regarding the effects of increased CO2 concentration on the water use efficiency of tree species (Körner et al. 2007; Hyvönen et al. 2007).

Inter-specific competition — None of the simulation models summarized above directly simulates competitive interactions among species, which may play a critical role in the current and projected distribution of tree species (Thuiller et al. 2008).

Dispersal and migration — The future distribution of trees and other species depends in large part on their ability to migrate into suitable habitat conditions. The rates of climate change may exceed the migration rates of many plant species. However, some tree species with long-distance wind or animal-assisted seed dispersal may more able to migrate long enough distances and quickly enough to colonize newly suitable habitat. Most simulations models do not include consideration of seed dispersal and species migration (Midgley et al. 2007; Neilson et al. 2005).

Phenotypic and genetic adaptation — Climate change is likely to impose strong selective pressures on populations including those of tree species and other plants. Phenotypic and genetic variation within populations will determine the ability of species to persist in the face of a changing environment. Species with wide-spread and well connected populations with a relatively high degree of genetic diversity may successfully adapt to changing conditions. Rare species and small, isolated populations may be more vulnerable. There is insufficient knowledge of the phenotypic and genetic diversity of most trees and other species to estimate their ability to adapt to a changing climate (Aitken et al. 2008; Jump and Peñuelas 2005).

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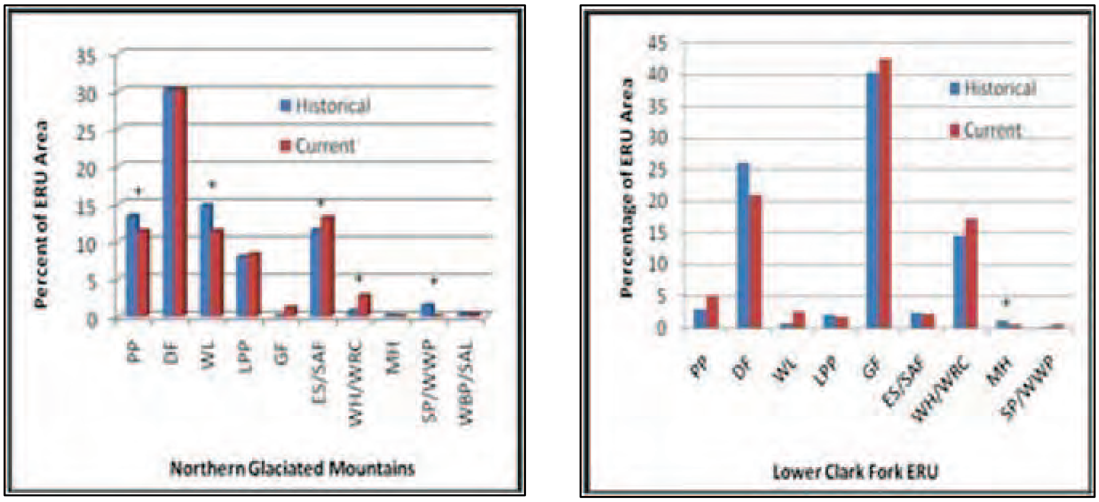

Figure 20. Change in percentage of area in forest cover types of the Northern Glaciated Mountains and Lower Clark Fork Ecological Reporting Units (ERUs)

These two ERUs encompass the Kootenai and Idaho Panhandle National Forests. Historical period is years 1932-1966. Current period is 1981 to 1993. Asterik (*) denotes significant difference at $p \leq 0.2$. (Source: Hessburg et al. 2000.)

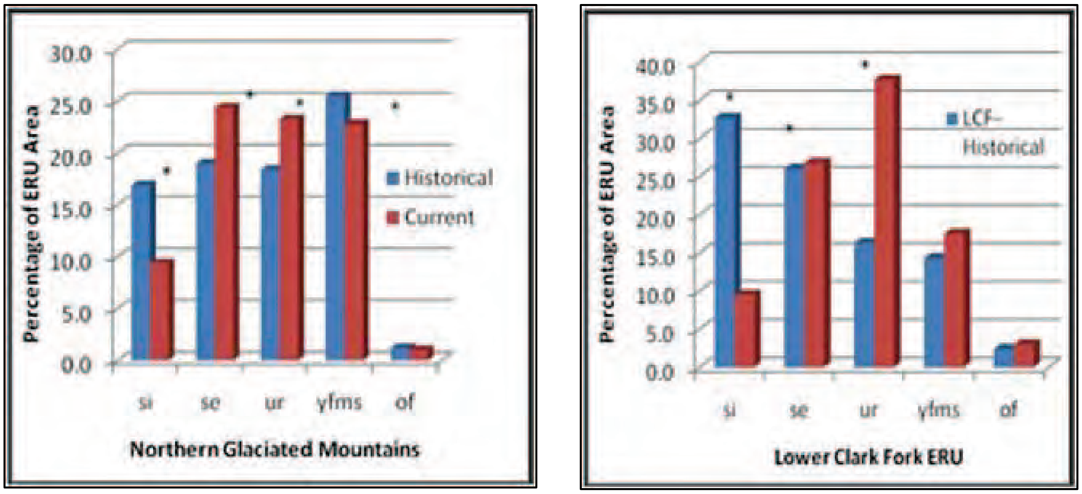

Figure 21. Change in percentage of area in forest structure classes (stand initiation, stem exclusion, understory reinitiating, young forest multi-story, and old forest multi- and single story) of the Northern Glaciated Mountains and Lower Clark Fork Ecological Reporting Units (ERUs)

These two ERUs encompass the Kootenai and Idaho Panhandle National Forests. Historical period is years 1932-1966. Current period is 1981 to 1993. Asterik (*) denotes significant difference at $p \leq 0.2$. (Source: Hessburg et al. 2000.)

Chapter 6. Rare Plants

Introduction

Plant species, including both vascular and non-vascular taxa, are susceptible to a wide range of effects resulting from climate change. Precipitation and temperature regimes control many aspects of species' distribution patterns and population biology, and effects of changes in those regimes have already been observed (Janetos et al. 2008; Root et al. 2003).

There are currently 205 plant species designated as sensitive, and four species federally listed as threatened, in Region 1 of the USDA Forest Service. On the Kootenai and Idaho Panhandle national forests, 80 sensitive plant species have been documented, but none of the threatened species are currently known to be present (USDA Forest Service, 2004). These rare plants are affiliated with five broad habitats (Figure 22). The diverse vegetation types occurring in these habitats, and the plant species they contain, are likely to be affected to varying degrees, and in different ways, by climate change.

The geographic distribution patterns of rare plant species are also a key consideration when evaluating the potential impacts of climate change, as species with certain distribution patterns are likely to be more vulnerable to climate change than others (Ohlemuller et al. 2008; Schwartz et al. 2006). For example, narrowly endemic plants that are restricted to alpine habitats are among the most threatened by climate change, since such habitat can only decrease with a warming climate (Hawkins et al. 2008). Conversely, species that occupy more widespread habitats may expand their ranges, such as those affiliated with grasslands and shrublands (Rehfeldt et al. 2006). The geographic distribution patterns of sensitive plant species on the Kootenai and Idaho Panhandle national forests are summarized in Figure 23, and the differential impacts to these patterns are discussed below. The distribution types are defined as follows (Lesica and Shelly 1991):

- **Narrow endemic -** species confined to a very small total range, and also typically confined to uncommon or isolated habitats (such as alpine endemics).
- **Regional endemic -** species restricted to a relatively small range, such as portions of two adjacent states, or several major watersheds within a state.
- **Disjunct -** populations are widely separated from the main range of the species.
- **Peripheral -** populations occur on the geographical margins of a species' contiguous range.
- **Scattered -** species sparsely distributed across a wide geographic range, with relatively few individuals per population, or few populations, or both.

Observed trends and responses to climate change

The geographical distribution of plant species is determined in large part by climatic conditions (Janetos et al. 2008). Thus, it is not surprising that climate change has a profound influence as an "ecosystem architect," and has been influencing the distribution and abundance of plant species over very long periods of time (Millar 2004). At annual and decadal scales, vegetation responses include changes in productivity, abundance, and local shifts in community composition; at century and millennial scales, major colonization and extirpation events, through migration and range shifts, have occurred (Millar 2004).

The direct biological and ecological effects that climate change has on plants include alterations to reproductive biology, physiology, and life history, as well as physical changes to their habitats. These effects can then lead to changes in the distribution ranges and abundance of species. Influences on the distribution and abundance at range margins, both in latitude and elevation, have been documented (Lenoir et al. 2008). Shifts of species ranges poleward, and upward along elevation gradients, is expected (Parmesan 2006). A significant upward shift in species optimum elevation has been observed in west Europe; the shift is larger for species restricted to mountain habitats (Lenoir et al. 2008). In a study of seven alpine plant species in Glacier National Park, Lesica and McCune (2004) found that four species demonstrated declines in abundance, and none increased, after a decade of increasing average summer temperatures; their observations cannot infer causality, but are consistent with predictions of climate-induced extirpation of high-elevation floras.

Other extreme events that have been shown to influence plant populations include earlier snowmelt. Inouye (2008) documented increased damage to flower buds of three subalpine perennial forb species over an eight-year period in Colorado as a consequence of earlier snowmelt and increased exposure of the plants to killing frosts. The lack of seed production in such cases could lead to demographic changes in the populations.

Disruption or uncoupling of species interactions, such as obligate pollination mutualisms, may also result from climatically driven changes in phenology, owing to potentially different responses of the obligate species. Such disruptions have been observed for endangered plant species (Wall et al. 2003).

Precipitation is also a key driver of plant population dynamics, and possibly more so in some cases than temperature (Parmesan and Galbraith 2004).

Projected responses to climate change

Reproductive biology and life history (including pollination and other mutualisms); Observed responses were described above, and can be expected to continue under changing temperature and precipitation regimes. A high degree of variation in response, among species, is to be expected (Post et al. 2008).

Habitat changes; Changes in precipitation and temperature patterns will lead to alterations in various habitats. Wetlands, aquatic habitats, and riparian zones, in particular, are likely to be influenced directly by changes in snowpack patterns and run-off (Rood et al. 2008). Also of major importance in the Kootenai-Idaho Panhandle Planning Zone (KIPZ) are the habitat refugia (cool air drainages; moist low-elevation sites) that contain numerous plant species that are rare locally or rangewide, many of which are disjunct from their primary ranges in the Cascade Mountains of Oregon and Washington. Changes in temperature regimes and precipitation patterns could alter the microsites associated with these habitats.

Geographic range shifts; The species that are considered most vulnerable to climate change are those with narrow geographic ranges; such range restrictions are typically associated with specialized habitats that are limited by climatic factors (e.g., alpine zones) or unique ecological characteristics (e.g., uncommon soil types or other spatially limited substrates) (Hawkins et al. 2008; Loarie et al. 2008). In the case of climatically restricted species, the physiological tolerances of the species may be exceeded as warming occurs. In the case of ecologically restricted species, changing climatic patterns may extirpate populations that are unable to migrate to other suitable habitats.

Interaction with land use patterns; Populations of rare plants that occur in isolated habitat patches as a result of habitat fragmentation may be extirpated under changing climate patterns, again as a result of inability to disperse to other suitable habitats.

Fire effects; Climate change (especially warming and earlier onset of spring) in the western United States has lead to an increase in wildfires (Westerling et al. 2006). Rare plant species that are vulnerable to extreme wildfire events are likely to be increasingly impacted.

Key sources of uncertainty

Numerous sources of uncertainty exist regarding the continuing and potential effects of climate change on the distribution and viability of rare plant species, including:

- A high degree of variation among species in their life history strategies, physiological tolerances, and dispersal abilities, which underlie the high variability in species responses to climate change (Janetos et al. 2008, Post et al. 2008). This variation makes generalization about potential effects difficult.
- Interaction of temperature changes with other regional to global drivers of changes affecting species distributions, such as variation in precipitation regime, nitrogen (N) deposition, land-use changes, invasive species, and CO2 increases (Lenoir et al. 2008).
- Uncertainty in climate projection models.

Potential Adaptation Opportunities

A range of adaptation options for conservation of rare plant species are available for consideration. These include:

- Focused conservation of "rear edge" populations (e.g., peripheral populations occurring at the lowest latitudes or southern range margins in the northern hemisphere). This could include detection and maintenance of the greatest possible number of local populations, regardless of their size or performance (Hampe and Petit 2005). The majority of the sensitive plant species on the Kootenai and Idaho Panhandle national forests are peripheral to their geographic distributions as a whole (Figure 23), and populations of these species would be targets for this approach. This approach has already been used for one sensitive plant species on the Kootenai National Forest (Phegopteris connectilis), in which a series of populations have been inventoried and protected in Botanical Special Interest Areas (SIAs). Protection of such peripheral populations does not necessarily ensure long-term persistence of all of them under changing climate regimes, but the redundancy of protected sites may offset local population losses to the degree that the species will at least persist in the planning zone.
- Fire use and control. Identify species or populations that are sensitive to increased fire and develop specific conservation strategies for them that address fire management in occupied habitats (Peterson and McKenzie 2008).
- Invasive species control (especially new introductions).
- Ex situ conservation (storage of propagules in permanent seed banks).
- Assisted migration. This involves translocation of seeds or plants to climatically suitable habitats, in order to expand or augment the range of the species. Assisted migration is a hotly debated approach that has both positive and negative aspects (McLachlan et al. 2007; Hunter 2007), and will need careful consideration if it is contemplated for any species, including rare plants. A framework for determining, prioritizing, and developing collection strategies for potential target species for assisted migration is proposed by Vitt et al. (2010).

- Wetland and riparian rare plants. Habitat management in or near riparian areas and wetlands may be beneficial, especially in cases where drying of the sites might be occurring. Examples may include tree removal where trees have encroached in wet meadows; restoration of stream beds that have down cut; and encouragement of beavers.
- Monitoring of known populations. This should include populations in protected sites such as Research Natural Areas and Special Interest Areas, as well as in project areas within managed landscapes.

The Gran Canaria Declaration II on Climate Change and Plant Conservation (Botanic Gardens Conservation International 2006) suggests the following priority species for adaptation actions:

- Taxa with "nowhere to go" (e.g., alpine species)
- Plants with restricted ranges (endemic species)
- Taxa with poor dispersal capabilities and/or long generation times
- Species that are susceptible to extreme conditions such as flood or drought
- Plants with extreme habitat/niche specialization
- Taxa with co-evolved relationships with other species (an example in KIPZ is whitebark pine, which depends on Clark's nutcrackers for seed dispersal)
- Species with inflexible physiological responses to climate variables
- Keystone taxa important in primary production or ecosystem processes or function
- Taxa with direct value for humans or with potential for future use

On the KIPZ planning zone, all of the sensitive plant species are worthy of monitoring and conservation planning, but the species associated with wetlands, grasslands, alpine areas, and specialized habitats (Figure 22) could be considered high priorities for adaptation actions. In addition, the regional endemic and disjunctive species (Figure 23) would also represent reasonable priorities for such actions.

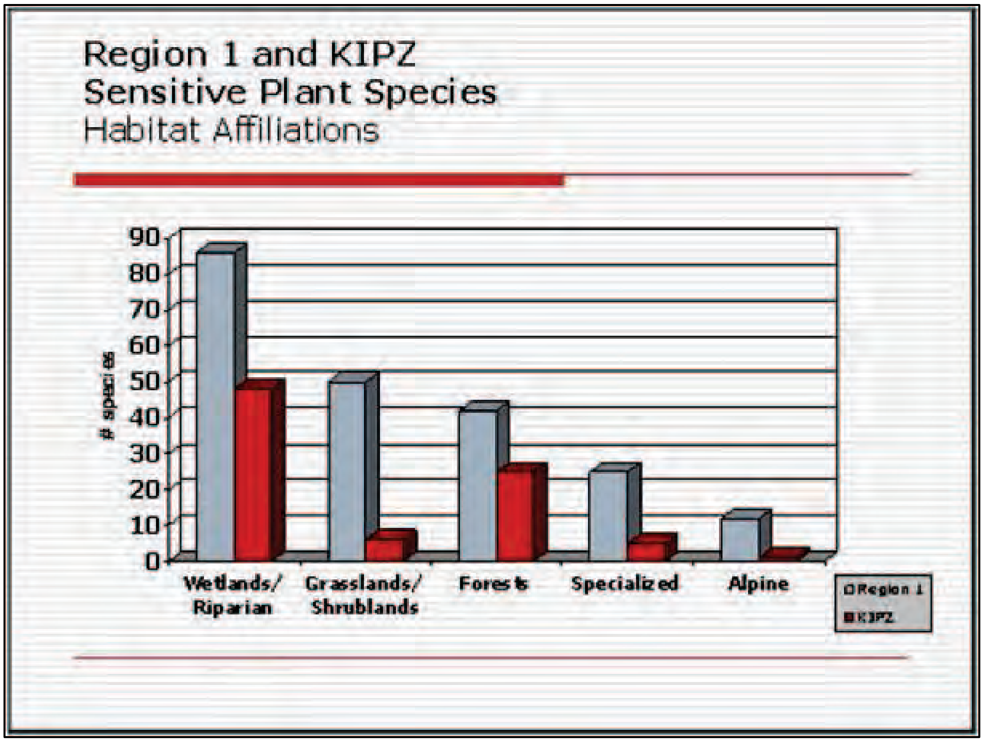

Figure 22. Broad habitat affiliations of sensitive plant species in Region 1 and in the Kootenai and Idaho Panhandle forest planning zone (KIPZ). "Specialized" habitats include cliffs, rocky outcrops, vernally moist sites, and other unique ecological settings

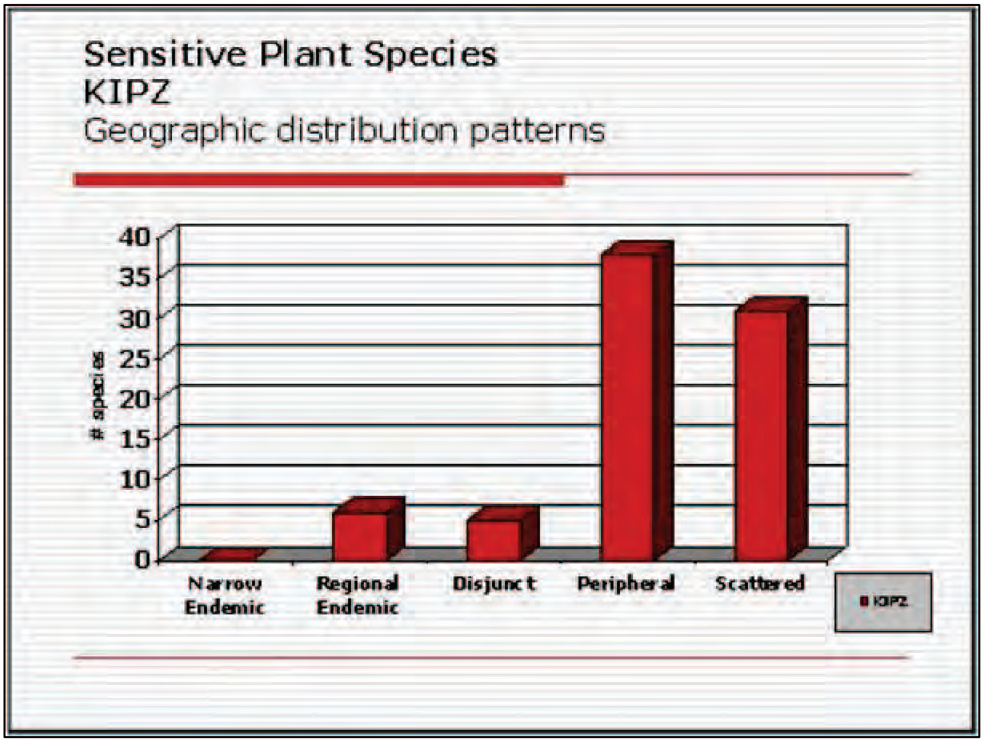

Figure 23. Geographic distribution patterns for 80 sensitive plant species in the Kootenai and Idaho Panhandle forest planning zone (KIPZ)

Chapter 7. Climate Related Trends in Forest Productivity and Carbon

Introduction

Forests have a substantial influence on the global climate by removing CO2 from the atmosphere and storing carbon as biomass. From 1990 to 2006, terrestrial vegetation absorbed approximately one third of the annual global carbon emissions from fossil fuel combustion and land use change (Bonan 2008; Canadell et al. 2007a; Denman et al. 2007). The feedback of carbon between the atmosphere and terrestrial ecosystems has a significant impact on rates of climate change.

Forests remove carbon from the atmosphere through the process of photosynthesis and convert it into sugars used to grow leaves, wood, and roots. Forests also release carbon dioxide to the atmosphere as a result of respiration and decay of dead wood, litter, and organic matter in soils. In addition, forest fires release some stored carbon to the atmosphere; fires, insect outbreaks, pathogens, drought stress, and wind storms kill trees and increase the amount of biomass available for decomposition by microorganisms; and timber harvesting removes carbon from the forest, although some of it is stored in wood products or used to produce energy – displacing fossil fuel use (Ryan et al. 2010) (Figure 24).

The rate of forest carbon gains and losses, and total forest carbon stocks, vary over a forest’s life cycle. When forests are disturbed by fire, harvest, insect outbreaks, and other perturbations, forest carbon stocks will usually recover fully over the life-cycle of the forest (Kashian et al. 2006). Thus, over time, the net carbon change is often zero. However, over large areas of forest comprised of a multitude of stands of different ages, carbon storage and sequestration rates are more stable because stands are in different stages of recovery from disturbance, with some stands providing a carbon “sink”, while others act as net “sources” releasing more greenhouse gases than they sequester (Ryan et al. 2010). Changes in the frequency or severity of disturbance regimes over large areas compared to the historical baseline can increase or lower the average carbon stocks in forests over time (Kashian et al. 2006, Smithwick et al. 2007, McKinley et al. in press). Over time, these processes can significantly affect the amount of CO2 in the atmosphere, and thus global climate (Bonan 2008, Canadell et al. 2007; Denman et al. 2007; Sabine et al. 2004).

Most studies estimate that the terrestrial biosphere is currently a net sink, removing more carbon from the atmosphere than it is emitting, and thus mitigating the effects of CO2 emissions from fossil fuel combustion and land use change (Denman et al. 2007). Terrestrial ecosystems are estimated to have removed approximately 10,300 Mt (million metric tons) of CO2 per year from the atmosphere from 200 to 2006 (Canadell et al. 2007a). Forests, particularly those at northern and mid-latitudes, are a large portion of this sink, sequestering more carbon per unit area than other vegetation types (Houghton 2007).

It is clear that forests currently play a key role in mitigating global CO2 emissions, and thus the rate of climate change (Nabuurs et al. 2007). However, the future of this ecosystem service is uncertain. Conversion of forests to non-forest, particularly in the tropics, and the potential effects of climate changes on forests raise questions about the future strength of the global forest carbon sink, and whether it may convert to an additional source of carbon to the atmosphere. Ultimately, the answers to these questions will have a significant impact on global climate.

Observed Trends in Forest Carbon: United States and U.S. Northern Rockies

Reconstructions of the terrestrial carbon budget of the conterminous U.S. over the last three centuries indicate that changes in land use have produced oscillations from a generally neutral carbon budget in the 17th and 18th centuries to an increasing net carbon emission to the atmosphere in the 19th century (Pacala et al. 2007a; Pacala et al. 2007b; Birdsey et al. 2007; Birdsey et al. 2006; Smith and Heath 2004; Birdsey and Lewis 2003; Hurtt et al. 2002; Pacala 2001; Houghton and Hackler 2000; Houghton et al. 2000; Houghton et al. 1999) (Figure 25). Increasing net carbon emissions of the 19th century were the result of the conversion of forests to croplands, primarily in the eastern U.S. This trend in the U.S. carbon budget reversed in the 20th century as some croplands were abandoned and reverted to forests and as fire exclusion and suppression became widespread throughout the U.S. (Pacala et al. 2007a; Pacala et al. 2007b; Birdsey et al. 2007; Birdsey et al. 2006; Smith and Heath 2004; Birdsey and Lewis 2003; Hurtt et al. 2002; Pacala 2001; Houghton and Hackler 2000a; Houghton et al. 2000b; Houghton et al. 1999). These conclusions are derived from evaluations of land use changes, and do not explicitly consider the potential role of climate variability, which may have periodically amplified or moderated the effects of land use changes (Bachelet et al. 2004).

Analyses of trends in North American terrestrial ecosystem productivity during the late 20th century based on satellite imagery generally confirm a net carbon sink for the North American continent, although there is considerable year-to-year and geographical variation (Figure 26) (Potter et al. 2007; Running et al. 2004; Nemani et al. 2003; Potter et al. 2003; Slayback et al. 2003; Hicke et al. 2002; Myneni et al. 2001). The inter-annual and spatial variability of productivity are commonly attributed to anomalies in seasonal temperature and precipitation, and ecosystem disturbances such as drought, fire, and insect outbreaks (Potter et al. 2008a; Piao et al. 2007; Potter et al. 2007; Boisvenue and Running 2006; Angert et al. 2005; Potter et al. 2005; Goetz et al. 2005; Running et al. 2004; Nemai et al. 2003; Nemani et al. 2002; Hicke et al. 2002a).

Recent estimates find that the terrestrial ecosystems of the United States remove approximately 505 million metric tons (Mt) of carbon per year (± 50 percent) from the atmosphere and store it as plant material and soil organic matter (King et al. 2007; Pacala et al. 2007). Estimates of the net sink from forests, forest soils and wood products range from 203 to 293 Mt C per year, or roughly half of the total sink (US EPA 2008; Birdsey et al. 2007). Wood products account for approximately 6 to 12 percent (30 to 57 Mt per year) of the total U.S. carbon sink (US EPA 2008; Birdsey et al. 2007). Forests and wood products offset approximately 10 to 20 percent of U.S. fossil fuel emissions (US EPA 2008; Pacala et al. 2007).

The reservoir of stored carbon in U.S. forests is approximately 42,700 to 66,600 Mt (US EPA 2008; Birdsey et al. 2007). Public forestlands contain approximately 37 percent of this carbon reservoir (Smith and Heath 2004). National Forests store an estimated 8,900 Mt of carbon, or from 13 to 21 percent of all forest carbon of the United States (Smith and Heath 2004). Carbon stocks of the Kootenai and Idaho Panhandle National Forests contribute approximately six tenths (0.0058) to eight tenths (0.008) of one percent of the total U.S. forest carbon reservoir.

Trends in carbon stocks and flux on the Kootenai and Idaho Panhandle National Forests can be inferred from 20th century trends in forest age and structure classes. Recent scientific literature documents the general pattern of changes in carbon stocks and net ecosystem productivity (NEP)[1] over the period of stand development in coniferous forests of the interior western United States (Smithwick et al. 2008; Bradford et al 2008; Dore et al. 2008; Luyssaert et al. 2008; Irvine et al. 2007; Hall et al. 2006; Law et al. 2003; Kashian et al. 2006; Law et al. 2001; Carey et al. 2001). Total carbon stocks decline as a result of disturbance and then increase, rapidly during intermediate years and then at a declining rate, over time until another significant disturbance (regeneration timber harvest or tree mortality resulting from drought, fire, insects, disease or other causes) kills large numbers of trees (Figure 27) (Canadell et al. 2007; Pregitzer and Euskirchen 2004). Carbon flux and NEP are lowest, and usually negative (a carbon source to the atmosphere) in young stands (0-30 years) following disturbance because carbon emissions from decay of dead biomass exceed the amount of carbon removed from the atmosphere by photosynthesis within the stand. As the stand develops, NEP increases and the stand becomes a carbon sink. NEP and carbon sink strength generally peak at the intermediate stage of stand development, then decline with age but often remain positive (Canadell et al. 2007; Pregitzer and Euskirchen 2004) (Figure 27). Over the long-term (centuries) net carbon storage is often zero, if stands regenerate after disturbance, because re-growth of trees recovers the carbon lost in the disturbance and subsequent decomposition of trees killed by the disturbance (Kashian et al. 2006).

On the Kootenai and Idaho Panhandle National Forests, the distribution of forest age and structure classes has changed substantially since the early 20th century (USDA Forest Service 2003). Intermediate age classes (40-100 years of age) have increased in area, while the amount of young stands has decreased. In most forest types, the abundance of older, late successional stands has declined. The cause of these changes varies by forest type and geographic location, but the most wide-spread agents of change are root disease, white pine blister rust, timber harvest, and the substantial decline in acres burned since 1940 (see Chapter 10). A significant portion of the increase in intermediate age classes is the result of forest re-growth following large stand-replacing fires in the late 19th and early 20th centuries (see Chapter 10). Figure 28 displays the current age class distributions of the Kootenai and Idaho Panhandle National Forests.

These observed trends in age and structure classes on the Kootenai and Idaho Panhandle National Forests generally mirror those identified for much of the Inland Northwest (Hessburg and Agee 2003). Hessburg et al. (2000) constructed historical and current vegetation maps from 1932 to 1966 and 1981 to 1993 aerial photographs, respectively for sample sub-basins within the interior Columbia River basin. Comparing historic and current vegetation maps, they found that forests of northeastern Washington, northern Idaho, and northwestern Montana experienced a significant increase in area of intermediate structural classes. Stand initiation structures (new forests) declined significantly due to fire exclusion, despite timber harvest activity. This analysis found no significant change in the amount old forest structures (both single and multi-storied) in the Northern Glaciated Mountains and Lower Clark Fork “ecological reporting units” (ERU’s) that contain the Kootenai and Idaho Panhandle National Forests (Hessburg et al. 2000; Hessburg et al. 1999). However, they noted that timber harvest activities reduced the abundance of medium- and large-sized trees distributed in other forest structures as remnants of stand-replacing fires.

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[1] Net ecosystem productivity, or NEP, is defined as gross primary productivity (GPP) minus ecosystem respiration (ER) (Chapin et al. 2006). It reflects the balance between (1) absorbing CO2 from the atmosphere through photosynthesis (GPP) and (2) the release of carbon into the atmosphere through respiration by live plants, decomposition of dead organic matter, and burning of biomass (ER). When NEP is positive, carbon accumulates in biomass. Ecosystems with positive NEP are referred to as a carbon sink. When NEP is negative, ecosystems emit more carbon than they absorb. Ecosystem with negative NEP is referred to as a carbon source.

Currently the Kootenai and Idaho Panhandle National Forests store an estimated 384.1 million metric tons (Mt) of carbon (Table 3). This represents about eight tenths of one percent of the total of approximately 42,654 Mt of carbon in forests of the coterminous United States (US Environmental Protection Agency 2008). The average density of forest carbon is 181.85 (± 4.1) Mg of carbon per hectare (Mg C/ha) (approximately 200 US tons) on the Kootenai National Forest and 186.54 (± 5.1) Mg C/ha (approximately 206 US tons) on the Idaho Panhandle National Forests. The average carbon density of these National Forests is among the highest in the Northern Rockies and interior western U.S. (Hicke et al. 2007; Potter et al. 2008). Preliminary[1] estimates indicate that the Kootenai and Idaho National Forests is a net carbon sink, removing approximately 27 to 31 metric tons of carbon per acre per year. Harvested wood products increase the net sequestration on these forests by an undetermined amount.

Projected Trends in Forest Carbon Stocks and Flux

The future of the terrestrial carbon sink of the U.S. is highly uncertain due to the uncertainty associated with the multiple interacting factors that influence carbon stocks and fluxes (Lenihan et al. 2008a; Ryan et al. 2008; King et al. 2007; Pacala et al. 2007; Birdsey et al. 2007). These factors include: climate variability and change; potential positive effects of increased atmospheric CO2 concentrations on plant productivity; frequency, duration and severity of moisture stress; natural disturbance rates; land-use changes; and land management practices (Canadell et al. 2007).

Projections of the future of the U.S. carbon sink based on national trends in land-use change and fire suppression indicate that the U.S. carbon sink will decline over the 21st century due a slowing of ecosystem recovery from 19th century land-use and vegetation response to 20th century fire suppression (Hurtt et al. 2002). This analysis, which does not include projected climate changes, also concluded that the U.S. converts to a large carbon source if fire suppression is ineffective in the 21st century.

Modeling experiments based on projected changes in climate, but not land use, suggest that the future strength of the U.S. carbon sink is very sensitive to the degree of change in climate, particularly precipitation, and fire regimes (Bachelet et al. 2001, Lenihan et al. 2008a; Lenihan et al. 2008b). If precipitation increases and temperature increases are small or moderate, net ecosystem productivity and carbon stocks are expected to increase. Conversely, if climate changes result in decreased precipitation and soil moisture during the growing season, net ecosystem productivity is expected to decline due to drought stress, and may result in a net carbon source to the atmosphere (Lenihan et al. 2008a; Lenihan et al. 2008b). Increasing concentrations of atmospheric CO2 may moderate these impacts by enhancing vegetation

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[1] These estimates are preliminary because two or more directly comparable forest surveys are not yet available for these National Forests. In the late 1990's the Forest Inventory and Analysis Program switched from periodic sampling to annual sampling, and established a nationally consistent sampling and plot design (Gillespie 1999; Bechtold and Patterson 2005). A complete cycle of annualized inventory has not been completed yet for these National Forests. The reported estimates are calculated by the GForest software program of the National Council of Air and Stream Improvement, Inc., based upon comparison of the annual inventory "panels." The values reported are changes in carbon contained in above ground live trees for the years 2003 to 2007, based sample sizes ranging from 32.5 to 41.1 plots per year on the Idaho Panhandle National Forest, and 32.8 to 38.9 on the Kootenai National Forest. The standard error varies by year, and ranges from 2.09 to 2.95 on the Idaho Panhandle National Forests and from 1.37 to 2.56 on the Kootenai National Forest. The GForest software program can be accessed at http://ncasi.uml.edu. These estimates are expected to change over the next 5 to 10 years with the completion of repeat inventory of individual plots.

productivity and water use efficiency (Bachelet et al. 2001; Joyce and Nungesser 2000; Lenihan 2008a; Lenihan 2008b), at least up to a point where increasing temperatures overwhelm the beneficial effects of CO2 concentrations (Fishlin et al. 2007). Increases in annual area burned may further reduce net ecosystem productivity and carbon stocks despite the potentially positive effects of increasing CO2 concentrations (Lenihan et al. 2008a; Lenihan 2008b).

Empirical analyses the growth rates of trees in the Pacific Northwest demonstrate the potential impacts of climate change on forest productivity, and reveal that high elevation and low elevation forests respond differently to climate variability. Seasonal photosynthesis (“carbon uptake period”) and annual growth rates of high elevation forests (e.g., subalpine fir, mountain hemlock, and high elevation lodgepole pine and Douglas-fir) are commonly limited by a relatively short growing season, low soil temperatures, and long periods of snowcover (Littell et al. 2008; Chinn et al. 2008; Case and Peterson 2007; Case and Peterson 2005; Peterson et al. 2002). Growth rates increase in these high elevation forests during years with earlier spring snowmelt, abnormally warm annual temperatures, and longer growing seasons. These results suggest that projected changes in regional climate (see Chapter 2) will likely result in increased productivity and carbon stocks of high elevation forests.

Conversely, growth rates of lower and mid-elevation ponderosa pine, Douglas-fir, and lodgepole pine forests of the Pacific Northwest and Northern Rockies tend to be limited by low growing season precipitation and high growing season temperatures (Littell et al. 2008; Case and Peterson 2007; Case and Peterson 2005; Watson and Luckman 2002). During these conditions, the rate of water loss from evapotranspiration is greater than the rate of water absorption by roots, resulting in water stress (Case and Peterson 2007 citing Larcher 2003). Prolonged periods of water stress significantly reduce a tree’s ability to photosynthesize (Kozlowskie and Pallardy 1997). As a result, climate projections with increased frequency of reduced snowpack, earlier spring snowmelt, increased temperatures during the growing season, and little or no significant increase in summer precipitation (see Chapters 2 and 3) likely will result in reduced forest productivity and carbon sequestration in low and mid-elevation forests of the Pacific Northwest and Northern Rockies (Boisvenue 2007; Boisvenue and Running 2010). Recent research suggests that regional warming and water balance deficit trends over the late 20th century are contributing to rapid and widespread increases in mortality rates, and slight decreases in forest density and basal area, in old growth forest throughout the western U.S. (van Mantgem et al. 2009).

In addition to the gradual changes in forest productivity and carbon stocks resulting from directional climate change, episodic events such as large high severity fires and large-scale insect outbreaks can significantly affect carbon stocks and flux of forest ecosystems. In the short-term (decades), disturbances can convert regional carbon sinks to a carbon source (Kurz et al. 2008; Kurz et al 2008a; Kurz et al. 2008b). Over the long-term (centuries), the effects of disturbances on the regional carbon balance are neutral assuming (1) similar vegetation re-grows on the disturbed area and (2) the long-term frequency and severity of disturbances does not change (Canadell et al. 2007; Kashian et al. 2006; see Chapters 5, 9, and10). The potential fertilization effect of atmospheric CO2 concentrations may influence the rate of terrestrial carbon recovery (Balshi et al. 2009; Lenihan et al. 2008).

On the Kootenai and Idaho Panhandle National Forests, carbon stocks and flux rates of will vary over coming decades in response to complex and uncertain interactions between climate variability and change, age structure, disturbance-recovery processes, and possible effects of CO2 concentrations on forest productivity (Smithwick et al. 2008; Hyvonen et al. 2007). The contribution of forest re-growth from past disturbances is expected to decline as the maturing forests grow more slowly and take up less CO2 from the atmosphere. Projected climate changes for the region suggest that relatively high-elevation forests may increase in productivity and carbon sequestration, whereas these processes may decline in low elevation forests and mid-elevation forests with south and southwesterly aspects. Potential increases in the frequency and size of high severity fires (see Chapter 10), bark beetle outbreaks and pathogens (see Chapter 9) could also have a significant impact on the carbon budgets of these forests over the 21st century. Extensive high severity fires or large scale tree mortality from bark beetles could convert the Kootenai and Idaho Panhandle National Forests from a net carbon sink to a carbon source for several decades (Kurz et al. 2008a; Kurz et al. 2008b; Bond-Lamberty et al. 2007). In addition, timber harvesting will affect amount of ecosystem carbon stored and the short-term net flux of carbon with the atmosphere. However, the net contribution to atmospheric CO2 concentrations resulting from these disturbances (fire, insect-caused tree mortality, and timber harvest) is expected to be approximately zero over the long-term so long as disturbed areas regenerate with similarly productive species and the disturbance frequency and intensity does not change (Kashian et al. 2006). Utilization of harvested forest biomass for will continue to store a substantial percentage of the carbon in wood products and landfills (US EPA 2008; Skog 2008; Skog and Nicholson 2000; Skog and Nicholson 1998) and may reduce the demand for more fossil-fuel intensive products such as steel and cement (Malmsheimer et al. 2008; Perez-Garcia et al. 2005). In addition, emerging markets in forest biomass for use in energy production could offset fossil fuel emissions (Nichols et al. 2009; Malmsheimer et al. 2008).

Key Sources of Uncertainty

Changes in Climate

Net ecosystem productivity is very sensitive to changes in temperature, precipitation, soil moisture and other climate characteristics (Angert et al. 2005, Paio et al. 2009; Paio et al. 2008). Seasonal changes in these variables can convert an area of forest from a carbon sink to a carbon source, and vice versa (Figure 26) (Ciais et al. 2005; Paio et al. 2009; Paio et al. 2008). But scientific confidence in projections of future changes in seasonal climatic characteristics is limited. Projections of changes in precipitation are more uncertain than temperature, with models producing a relatively wide range of projections for annual and seasonal precipitation, including increases and decreases (see Chapter 2). This is a major source of uncertainty in projecting future changes in forest carbon flux.

Disturbance Regimes

High severity disturbance events have a substantial and rapid impact on forest carbon stocks and flux. Persistent changes in the frequency, magnitude, and severity of disturbances can alter long-term (decades or longer) regional net carbon balances. Yet knowledge of the future trajectory of wildfires, insect outbreaks, drought severity and duration, and other major forest disturbances is limited (See Chapter 9 and 10). The available scientific evidence suggests that wildfires are likely to increase in coming decades in portions of the western U.S. However, there is greater uncertainty in these projections at finer spatial scales.

CO2 Fertilization

CO2 is a fundamental building block of photosynthesis. Trees and other plants grown in elevated CO2 environments have increased growth rates, productivity and water use efficiency compared to controls (Norby et al. 2005). Thus, there is some evidence that increasing atmospheric concentrations of CO2 may increase forest productivity. However, the results of these controlled experiments have not been widely confirmed in natural environments. Additional studies have suggested that the potential CO2 fertilization effect is limited to young plants and by water and nutrient availability (particularly nitrogen) (Norby et al. 2010). In addition, there is some evidence that trees and other plants acclimate to elevated CO2 concentrations over time, thus reducing the duration of the potential fertilization effect. In sum, there is considerable uncertainty about the potential of elevated C02 concentrations to increase net ecosystem productivity, carbon storage, and carbon sink strength of forests.

Potential changes in forest composition

Long-term projections of regional net carbon balances depend upon assumptions about the future vegetation composition of currently forested areas (Canadell et al. 2008; Kashian et al. 2006). However, as described in Chapter 5 there is considerable uncertainty regarding the effects of climate change on the composition of forest vegetation. These uncertainties in future forest composition and structure contributes to the uncertainty in long-term projections of forest carbon stocks and flux, and regional net carbon balances (Smithwick et al. 2008; Rhemtulla et al. 2009).

Biomass utilization including energy production

Utilization of woody biomass for energy production and as a substitute for more greenhouse gas intensive materials (e.g., steel and cement) has the potential to provide substantial global carbon benefits (Nabuurs et al. 2007). However, the capacity to realize these potential carbon benefits is uncertain due to current technological limitations, social and political issues, and reliability of feedstock supplies. At regional and local scales, limited and declining capacity in the wood products industry adds further uncertainty to projections of the size of the carbon pool in harvested wood products, and the use of woody biomass to displace fossil fuels.

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Potential Mitigation Options

The recent IPCC report identifies four general categories of options to reduce emissions by sources and/or increase carbon sequestration by sinks by forests:

- Maintaining or increasing forest area;
- Maintaining or increasing site-level carbon density
- Maintaining or increasing landscape-level carbon density; and
- Increasing off-site carbon stocks in wood products and enhancing product and fuel substitution (Nabuurs et al. 2007).

Land Exchange. Occasionally, the Kootenai and Idaho Panhandle National Forests have the opportunity to exchange lands with willing landowners. Where land exchanges result in a net increase in forest productivity or net forested acres within the National Forest System, they may maintain or increase the area of productive forests.

Prompt Regeneration of Disturbed Areas. Rapid tree planting in areas severely disturbed by wildfire can accelerate carbon accumulation, and thus increase stand- and landscape-level carbon density over time. An evaluation of management options to modify the net carbon balance of Canadian forests found that the potential for increasing the forest carbon sink strength was largest with reducing regeneration delays after natural disturbances (Chen et al. 2000). On the Kootenai and Idaho Panhandle National Forests, natural regeneration is often, but not always, successful over time. The interior of high severity burn patches are most prone to long-delayed tree regeneration. In these areas, rapid post-fire tree planting may accelerate forest development and carbon accumulation. However, such treatments are costly and may be financially infeasible (Chen et al. 2000).

Extended Rotations. Several commentators have suggested that increasing timber harvest rotation length can produce global carbon benefits by increasing forest carbon storage (Birdsey et al. 2007a; Nabuurs et al. 2007; Ingerson 2007; Leighty et al. 2006; Birdsey et al. 2000). In concept, increasing rotation ages can result in increased stand- and landscape-scale carbon storage by holding more carbon in forests and avoiding emissions from harvesting. However, there are several factors which suggest that achieving carbon benefits from extended rotations may be problematic.

Extended harvest rotations focused on specific ownerships, forests, and regions will reduce annual timber harvest levels and wood products production in the affected area. It is likely that such local and regional reductions will be offset by market-driven harvest increases by other timberland owners and in other regions. For example, more than 85 percent of the reductions in timber harvest levels on western federal forests in the late 1980s and 1990s were replaced by increased harvest by other timberland owners and regions, including international imports (Wear and Murray 2004; Murray et al. 2004). As a result of this "leakage," it is likely there would be little or no net effect on national or global terrestrial carbon balance, and no net effect on atmospheric concentrations of CO2, as a result of increasing rotation lengths on the Kootenai and Idaho Panhandle National Forests. In addition, increased lumber prices resulting from timber sale reductions (Wear and Murray 2004) could lead to increased utilization of more energy-intensive materials (e.g., steel and cement), and net increases in greenhouse gas emissions from fossil fuel combustion.

Extending rotation ages also increases exposure of landscape-scale carbon stocks to high severity disturbances such as wildfires (see Chapter 10; Kurz et al. 2008a) and may even increase the probability of bark beetle outbreaks (see Chapter 9; Kurz et al. 2008b). In fire-prone areas such as the Kootenai and Idaho Panhandle National Forests, this increases the probability that the theoretical carbon storage benefits of extended rotations will be substantially reduced. Thus, the carbon storage benefits may not persist or be sustainable for extended periods. Recent analysis indicates that the risk of carbon loss due to wildfire is higher on the Idaho Panhandle and Kootenai National Forests than most other forested areas of the U.S. (Hurteau et al. 2009).

Fire Suppression. Several authors have suggested that continued or increased fire suppression effort can help maintain or increase landscape-level carbon density and storage in the forest of the US (Birdsey et al. 2007a; Nabuurs et al. 2007; Birdsey et al. 2000). However, fire management strategies to increase forest carbon storage must consider both the amount of carbon stored and the stability of that storage as climate and fire regimes change (Schimel 2004; Schimel and Braswell 2005).

Aggressive fire suppression can limit the number and size of large fires, and therefore may increase forest carbon storage and sink strength, at least for the short-term. However, as discussed in Chapter 10, it is unlikely that these carbon storage gains can be sustained over time. Since 1986, the number of large forest fires in the U.S. Northern Rockies increased more than tenfold

(1100 percent) and the area burned by large fires increased more than threefold (350 percent) compared to the period 1970 to 1985 (Westerling et al. 2008). Numerous simulations of the effects of projected climate change on wildfire in western North America all indicate an increasing probability of increased annual area burned and increased frequency of high severity fires (Westerling and Bryant 2008; Nitschke and Innes 2008; Bachelet et al. 2007; McKenzie et al. 2004; Brown et al. 2004). If observed trends continue or if the projected changes in fire regimes are even partially realized, aggressive fire suppression is likely to lead in the long run to most acres burning in fewer, more extreme and unmanageable events with greater losses of forest carbon stocks (Hurteau et al. 2008). Thus, it is likely that, at best, the carbon benefits of aggressive fire suppression are temporary, not permanent, and may even result in greater greenhouse gas emissions from fires and loss of forest carbon stocks than would occur with less aggressive fire suppression (Kirschbaum 2006; Breshears and Allen 2002).

Utilization of Forest Biomass for Energy Production. According to the IPCC, "When used to displace fossil fuels, woodfuels can provide sustained carbon benefits, and constitute a large mitigation option" (Nabuurs et al. 2007 pg. 551). A recent study estimates that U.S. forests are capable of sustainably producing 368 million dry tons of wood per year, with 41 million dry tons from currently unused logging residues and 60 million dry tons from hazardous fuel treatments (Perlack et al. 2005). If applied to bioenergy production, this wood residue could offset a substantial percentage of U.S. CO2 emissions from fossil fuels (Richter et al. 2009).

In addition to ongoing energy production from milling byproducts at area wood processing facilities, several opportunities exist to utilize wood residues from timber harvest, hazardous fuel reduction projects, and other silvicultural treatments on the Kootenai and Idaho Panhandle National Forests. These opportunities include Avista Corporation's Bioenergy Plant in Kettle Falls, Washington, several area pellet plants, and area schools and other facilities with high-efficiency wood heating systems. The Fuels for Schools facilities at Kellogg, Idaho, and Troy, Eureka, and Thompson Falls, Montana are estimated to offset more than 1000 metric tons of fossil CO2 emissions per year (David Atkins, US Forest Service, pers. comm.). There is potential for a substantial increase in wood energy production in northern Idaho and northwestern Montana that could replace CO2 emissions from fossil fuels while also reducing CO2 emissions from pile burning and other forest residue treatments.

Summary of Mitigation Options

At the global scale, prevention of large-scale conversion of forests to other land uses (deforestation), primarily in the tropics, provides the greatest opportunity to mitigate the trend of increasing atmospheric concentrations of CO2 (Nabuurs et al. 2007). In the U.S., the largest and most effective mitigation opportunity has already been taken - the creation of State and Federal public forests that share the common objective of "keeping forests as forests" in perpetuity.

Within the context of public forests, individual land management actions are unlikely to have significant long-term effects on the atmospheric concentrations of CO2 and other greenhouse gases. Without a substantial reduction in fossil fuel emissions, the impacts of projected climate change on disturbance regimes and species composition will likely overwhelm the short-term effects of land management actions. From this perspective, the primary forest management action to mitigate increasing atmospheric CO2 concentrations is the sustainable use of woody biomass to generate energy and biofuels, and displace more fossil-fuel intensive construction materials (Nabuurs et al. 2007). As the IPCC concluded; “In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit” (Nabuurs et al. 2007, page 543).

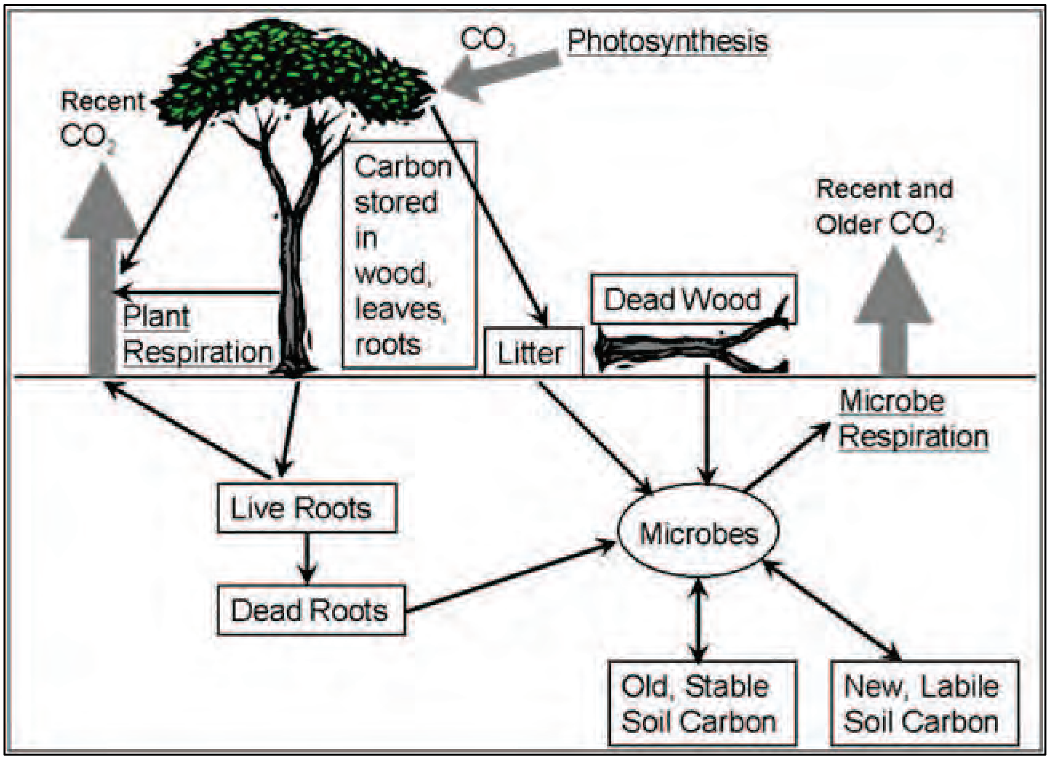

Figure 24. Flows of carbon from the air to the forest and back. Carbon is stored mostly in live and dead wood as forests grow (adapted from Ryan and Law. 2005. Biogeochemistry. 73:3-27)

Table 3. Estimated carbon stocks (Mt) on forested areas of the Kootenai and Idaho Panhandle National Forests

	IPNF	KNF	Total
Total Aboveground Carbon	124.2 (± 4.2)	121.6 (± 3.3)	245.8
Total Belowground Carbon	52.8 (± 0.9)	49.5 (± 0.6)	102.3
Total Forest Carbon	177.0 (± 4.9)	171.1 (± 3.9)	348.1

Notes: Units are million metric tons (Mt) (1 Mt equals 1,102,311 US tons). The values in parentheses are standard error of the mean. The values are derived from data collected in the 1990’s on 351 Forest Inventory and Analysis plots and stored in the Forest Inventory and Analysis database (USDA Forest Service 2006). Calculations are from the Carbon On-Line Estimator [1]. Total above ground carbon is all carbon above mineral soil. It includes bole and crown of live trees, bole and crown of aboveground standing dead trees, coarse woody debris (dead, downed wood more than 7.5 centimeters in diameter), understory vegetation (boles and crowns of trees less than 2.5 centimeters diameter at breast height, shrubs and bushes), and forest floor (fine woody debris less than 7.5 centimeters diameter). Total belowground carbon is all carbon in soil and roots.

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[1] http://ncasi.uml.edu/COLE/

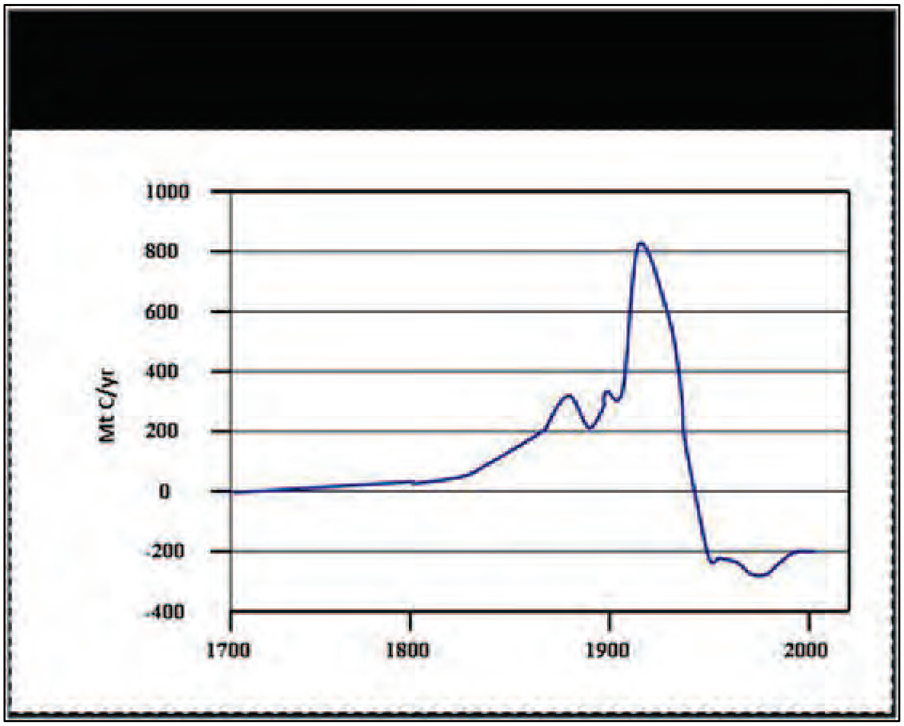


Figure 25. Estimated annual net flux of carbon from land use change in conterminous U.S. terrestrial ecosystems 1700-2000

Blue line is from Birdsey et al. 2006, and represents emissions from drain on sawtimber in the 19th and early 20th century, and subsequent regrowth in the 20th century. Green line is from Houghton et al. 2000b, and depicts annual net flux resulting from estimated land use change, fire and fire management. Positive values indicate a net emission of carbon from the land to the atmosphere. Negative values indicate a net withdrawal, or sink, of carbon from the atmosphere to terrestrial ecosystems.

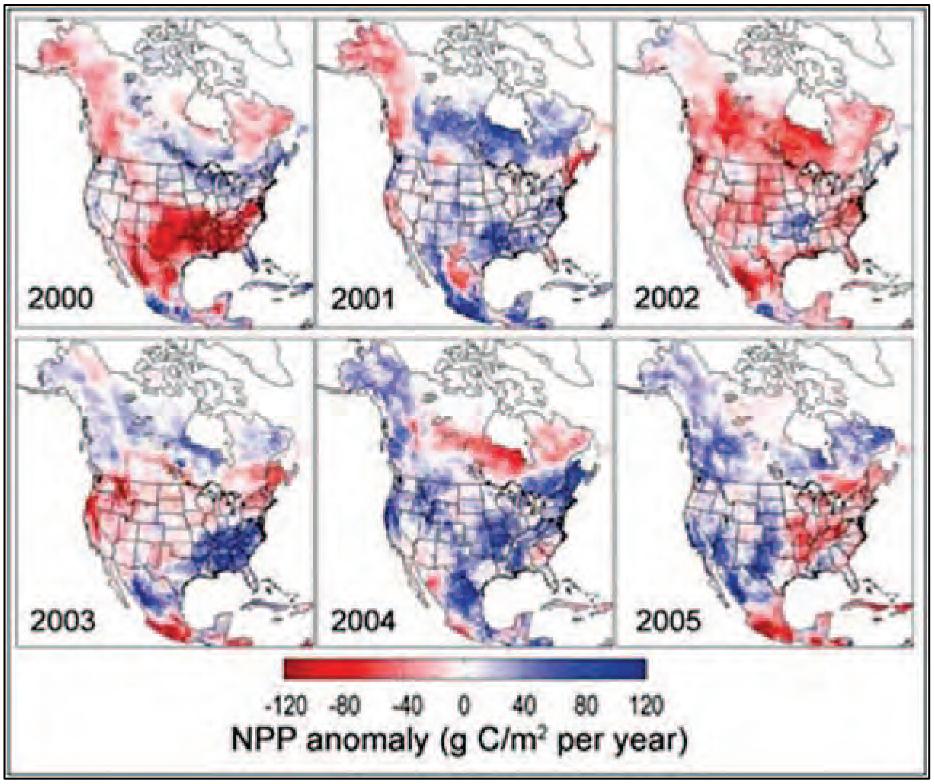


Figure 26. Spatial and temporal variability in net primary productivity (NPP) of North American terrestrial ecosystems 2000-2005

Values are the deviation from 6-year average annual NPP estimated by the MOD17 1-km resolution data product from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the National Aeronautics and Space Administration (NASA) Terra and Aqua satellites. Blue indicates regions where that year's NPP, the net carbon fixed by vegetation from the atmosphere, was greater than average; red indicates where annual NPP was less than the average. See Running et al. (2004) for further information on the MODIS NPP product. Figure courtesy of Dr. Steven W. Running, University of Montana. Source: King et al. 2007a.

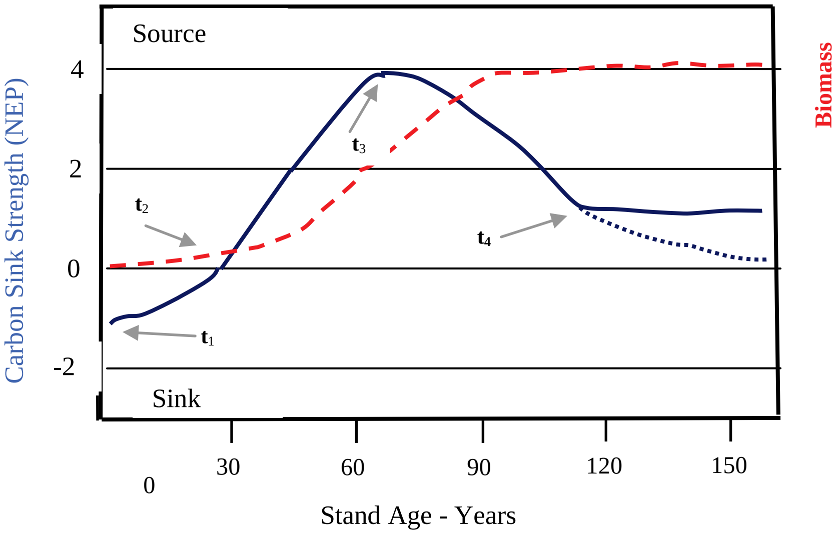
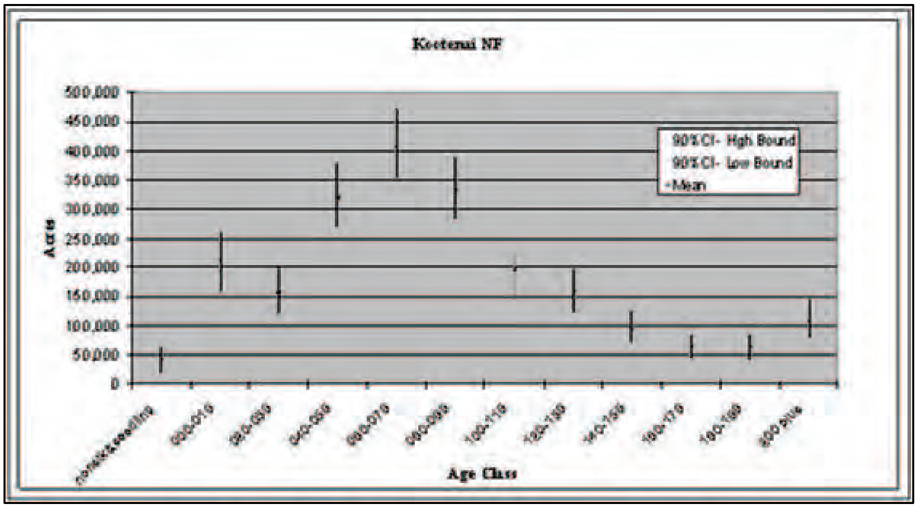


Figure 27. General depiction of carbon sink strength (net ecosystem productivity) and biomass (carbon stocks) accumulation over time of a hypothetical forest stand

t1: initial state after stand replacing disturbance; t2: transition from carbon source to carbon sink; t3: maximum net carbon uptake; t4: slow down of carbon sink, potentially becoming neutral or a carbon source (Kashian et al. 2006; Pregitzer and Euskirchen 2004; Luyysaert et al. 2008). The curves presented may shift to the left or right, and the amplitudes may vary, depending on forest type, site productivity, disturbance regimes, climate and other factors (Smith et al. 2006). Source: Canadell et al. 2007.



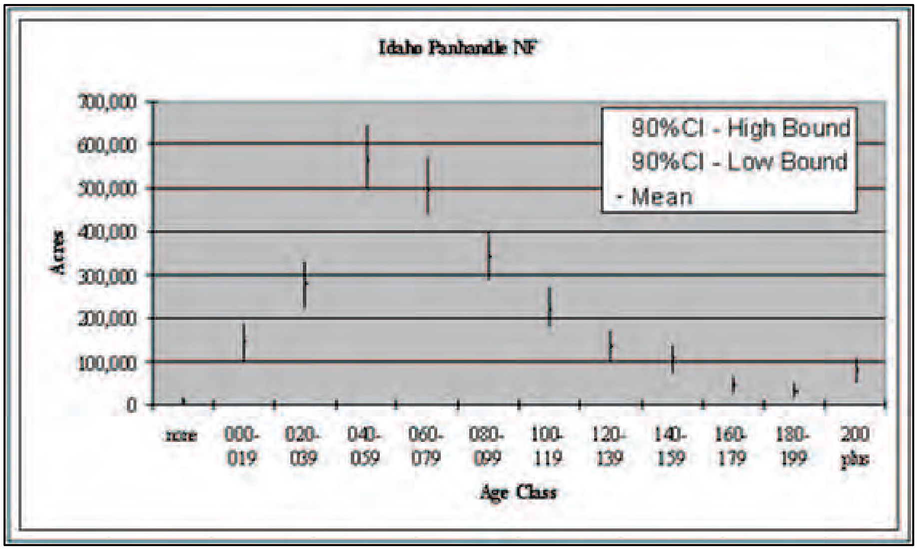


Figure 28. Current age class distribution of the Kootenai and Idaho Panhandle National Forests

Age classes of individual field survey units were calculated as the basal-area weighted average age at diameter at breast height. Calculated values represent conditions at the time of inventory: 1993-1995 for the Kootenai National Forest, and 2000-2002 for the Idaho Panhandle National Forests. The estimated mean and confidence intervals are based on 344 forested FIA field locations (2312 subplots) from the Kootenai National Forest and 393 forested FIA field unit locations (1572 subplots) from the Idaho Panhandle National Forests.

Chapter 8. Noxious Weeds/Invasive Species

Introduction

Global climate change is expected to further expand the risk of plant invasion as a consequence of increased extent and severity of disturbances, such as wildland fire, and enhanced competitiveness due to elevated CO2 (Dukes & Mooney, 1999; Weltzin et al., 2003; Thuiller et al., 2007). Biological conservation and ecosystem restoration face increasing challenges in light of climate change as native species become less viable under future climate conditions (Harris et al. 2006; Millar et al., 2007).

On a regional and local scale basis, predicting which invasive species will be expanding into the Northern Region, let alone the Kootenai National Forest and Idaho Panhandle National Forests planning zone (KIPZ) is a challenge. It appears that most invasive species are still expanding their presence into yet uninfested environments (DiTomaso 2000). As a result, without extensive controlled experiments it is difficult to distinguish whether range expansion of invasive species is the result of climate change or invasive species simply moving into suitable habitat independent of climatic trends.

There are relatively few scientific publications regarding the effects of climate change on invasive plants species in the Northern Rockies compared to some other potential climate change impacts. Recently Bradley et al. (2009) used climate projections from ten atmospheric-ocean general circulation models to evaluate potential effects on five invasive plant species considered problematic invaders in the Western U. S.: Yellow starthistle, tamarisk, cheatgrass, spotted knapweed, and leafy spurge. These species have been established in the western U.S. since the 1800's. Therefore, it seems plausible to assume that currently invaded ranges approximate equilibrium conditions with current climate. They were therefore appropriate for bioclimatic modeling. Potential climate change effects on these species provide an indication of what the future may hold for the northern Idaho and northwestern Montana.

Observed responses to climate change

In recent years Western Montana forests have observed an increased occurrence of cheatgrass monoculture stands following wildfire disturbances and prescribed herbicide treatments of other noxious weeds, such as spotted knapweed. Locations along the Selway River have experienced cheatgrass invasions and spotted knapweed monocultures. 20th century increases in atmospheric concentrations of CO2 may have contributed to the expanding occurrence of some invasive plant species. Although from other portions of the western U.S., recent research has found that experimentally elevated levels of CO2 resulted in increased productivity of cheatgrass, and might increase this species' long-term success and dominance (Smith et al. 2000; Ziska et al. 2005).

Another noxious weed, yellow starthistle, has in past years been found established in a tree plantation in Flathead County, Montana, in the Como Lake area of Ravali County and in eastern Montana. These incidents are actual cases where the exotic invasive was growing as an adult plant and had reproductive capacity.

Projected responses to climate change

In the Northern Region, climate change may increase the risk of invasion by non-native plants. Climate change may also decrease the risk of invasive plant competitiveness if conditions become climatically unsuitable (Bradley et al. 2009). Recent analysis with bioclimatic models suggests the potential expansion of yellow starthistle, tamarisk, and cheatgrass in the Northern Rockies. The same modeling analysis suggests that spotted knapweed and leafy spurge will likely maintain their current distribution of climatically suitable habitat in northern Idaho and western Montana (Bradley et al., 2009).

Tamarisk is a noxious weed that currently is occupying riparian areas in the Southwest U.S. However, it is locally occurring in Eastern Montana along the Yellowstone River. It appears to be poorly constrained by climatic conditions, and according to the modeling effort, northern Idaho and northwestern Montana may become climatically suitable (Bradley et al. 2009), although it currently is confined to riparian areas, suggesting that actual invasion risk is limited.

Key sources of uncertainty

- Ecosystem susceptibility to invasion by nonnative plant species is poorly understood (Chambers et al. 2007).
- Habitat suitability of many western invasive plant species is constrained by precipitation. Climate model projections of future changes in annual and seasonal precipitation are highly variable. Thus, for many invasive plant species changes in climatically suitable habitat is highly uncertain.
- Regional and local-scale predictions associated with invasive species do not exist for most invasive species.

Potential Adaptation Opportunities

- Noxious Weeds risk assessment currently exists for most of the Northern Region (excluding the Dakotas). It identifies risk of vegetation dominance types to selected invasive/noxious weeds. As bioclimatic envelope models for native vegetation/communities are adjusted to accommodate climate change, this effort may also provide utility in predicting altered noxious weeds invasion risk.
- As predictions of noxious weeds expansion and retreat in the Northern Region become more concrete, we may find new potential for restoration opportunities. Without timely human intervention, the window of restoration opportunity presented by climate change may quickly close.
- What may be required in restoration areas is the application of 'transformative restoration' (Bradley and Wilcove 2009), involving the introduction of species native to the larger ecoregion that may not have been present originally but which can maintain ecosystem function (Harris et al., 2006).

Chapter 9. Climate Related Trends in Forest Insects & Disease

Introduction

Native forest insects and pathogens are a natural part of forest ecosystems and serve a critical function within resilient ecosystems. At endemic levels, bark beetles typically infest individual or small groups of trees weakened by drought, injury, diseases and fire (Burdon et al. 2006; Furniss and Carolin 1977). However, large-scale outbreaks of bark beetle populations and native and non-native pathogens can have significant impacts on tree growth, forest composition, and cause extensive tree mortality. In some situations, insect and disease outbreaks may result in conversion of forests to herbaceous vegetation if tree regeneration does not occur (Ryan et al. 2008; Holsten et al. 1995). These direct impacts of some forest insects and pathogens may produce undesirable and costly changes in forest composition, wildlife habitat, timber supply, wildfire hazard, watershed processes, and carbon storage (Dale et al. 2001; Ryan et al. 2008).

Two primary factors influence the potential for large-scale insect outbreaks and damaging pathogens. First, the condition of forest trees and stands determine their susceptibility to insects and pathogens. Tree age, size, species distribution, stand density, and moisture-stress are the most common determinants of susceptibility to insect outbreaks and pathogens. Second, weather and climate variability directly influence the population dynamics of forest insects and the susceptibility of host trees. It has been suggested that climate change is likely to increase bark beetle population eruptions and associated levels of tree mortality (Ayres and Lombardero 2000; Logan et al. 2003; Carroll et al. 2004), although evidence directly attributing the current outbreak to a changing climate has not been documented.

Recent bark beetle epidemics extending from the southwestern U.S. to central British Columbia have focused local public attention and raised questions about the current and future role of climate change in large-scale insect outbreaks, and forest sustainability generally.

Observed Trends in Forest Insects & Diseases

The two most common aggressive forest insects in the Northern Rockies are the mountain pine beetle (MPB) (*Dendroctonus ponderosae*) and Douglas-fir beetle (DFB) (*Dendroctonus pseudotsugae*). The most common and damaging pathogens are annosus (*Heterobasidion annosum*) and armillaria (*Armillaria solidipes*) root diseases, and the non-native fungus white pine blister rust (*Cronartium ribicola*). The following subsections address observed trends for each of these insects and pathogens.

Mountain Pine Beetle

Mountain pine beetle and lodgepole pine have coexisted for millennia (Brunelle et al. 2008). MPB is very responsive to habitat and climate conditions, especially host condition (Amman 1978), temperature (Bentz et al. 1991), and drought (Thomson and Shrimpton 1984). Outbreaks tend to occur during warm and dry conditions and can cease following extreme winter cold (Logan et al. 1998). Outbreaks also require an abundance of suitable habitat for the insect to attack and reproduce. Characteristics of suitable MPB habitat in lodgepole pine include tree diameter (larger trees more susceptible), stand age (older trees more susceptible), stand density (densely stocked stands more susceptible), and species composition (stands with higher proportions of lodgepole pine more susceptible) (Amman and Anhold 1989; McGregor et al.

1981; Shore and Safranyik 1992). Amman (1978) states that 25 to 50 percent of a lodgepole pine stand that is 4 inches diameter at breast height (dbh) and larger will be killed over a 6 to 10 year period during an outbreak. Cole and Amman (1980) indicate higher levels of 85 percent or more of larger diameter trees and smaller proportions of small diameter trees.

Stand and tree susceptibility to MPB in whitebark pine have not been modeled as well as in lodgepole pine. However, observations and research (Perkins and Roberts 2003) indicate that MPB activity is greater in densely stocked stands with larger-diameter trees. Throughout the Northern Rockies, including the Kootenai and Idaho Panhandle regions, whitebark pine is a major component at high elevations. Many of these stands have changed during recent years as larger, older whitebark pines have been killed. Stands of mature whitebark pine are becoming increasingly difficult to locate in the Northern Rockies (Gibson et al. 2008; Kegley et al. 2001, 2004).

Ponderosa pine is a susceptible host to both MPB and western pine beetle (WPB) (*Dendroctonus brevicomis*), although the two insects usually do not occupy the same tree. These bark beetles can cause significant effects in younger, even-aged stands, as well as causing mortality of single trees and small groups of large, older ponderosa pine. These insects are very responsive to trees under stress, whether from drought, dense stocking, lightning, or other causes (Furniss and Carolin 1977). Populations of WPB are normally at low levels, but will increase quickly when drought conditions occur. The occurrence of MPB in ponderosa pine is usually associated with outbreaks occurring in nearby lodgepole pine stands, although expanses of younger, even-aged stands are known to experience high levels of MPB activity (Sartwell and Stevens 1975; Schmid et al. 2007).

Over the course of the 20th century, MPB has periodically caused wide-spread tree mortality in the Northern Rockies. Outbreaks in Idaho and Montana during the 1920-1930s (Evenden 1934; Evenden 1944) and from the late 1970s to early 1980s killed lodgepole pine to an extent comparable to the most recent outbreak (Cole and Amman 1980; McGregor and Cole 1985) (Figures 29 and 30).

Over the last decade, MPB activity has increased in high elevation whitebark pine across much of western US and Canada (Gibson et al. 2008). The epicenter of this activity is in Wyoming and Montana where the bulk of whitebark pine occurs. Populations of MPB in high-elevation whitebark pine stands are currently at higher levels than previously recorded (Gibson et al. 2008). Observations on the Idaho Panhandle and Kootenai National Forests indicate that about 9,000 acres of whitebark pine have been affected each of the past 9 years on average. Currently, it appears the rate of mortality is declining due to the loss of suitable bark beetle habitat (unpublished aerial survey data, FHP).

Throughout western North America, several bark beetle outbreaks are occurring simultaneously in numerous ecosystems across western North America from northern Mexico to central British Columbia and Alaska. Collectively, the recent bark beetle-caused tree mortality is the largest and most severe in recorded history (Bentz 2008; Bentz et al. 2009).

Many susceptible stands of lodgepole pine, ponderosa pine, and whitebark pine remain in the Northern Rockies (Table 4). If climatic conditions continue to stress these stands and provide conditions favorable to MPB. MPB populations will continue and resulting tree mortality is expected to continue until few susceptible host trees remain in many stands (Gibson 2008).

Douglas-fir Beetle

Douglas-fir beetle has a strong preference for stands of Douglas-fir with larger diameter trees, low vigor or growth rate, high tree density, and a high proportion of Douglas-fir in the stand (Negron 1998; Shore et al. 1999). DFB is a less aggressive bark beetle than MPB. However, when populations build it can be a significant mortality-causing agent. Populations increase in damaged, weakened, and downed Douglas-fir following drought, fire, defoliation and windthrow events (Schmitz and Gibson 1996). Generally, populations subside after three to four years. The Idaho Panhandle National Forests underwent a large DFB outbreak in the late 1990's after a major windstorm event in 1996 (Kegley and McConnell 2001). Throughout the Northern Rockies, DFB populations appear to be declining after a population expansion from 1998 to 2006 (Gibson 2008) (Figures 29 & 30).

Root Disease

The two most significant native pathogens in the Northern Rockies and the Kootenai and Idaho Panhandle region are armillaria root disease and annosus root disease. Armillaria root disease kills conifers of all species when they are young, but is especially damaging to Douglas-fir, subalpine fir, and grand fir because these species remain susceptible throughout their lives (Kile et al. 1991). In addition, they often affect canopy closure and create small openings. The effects of these root pathogens are long-lasting as they persist on a site affecting multiple generations of trees. Armillaria and other root diseases influence forest species composition, structure, successional trajectories, and accelerate change to climax species or maintain stands in early seral stages (Byler and Hagle 2000).

At least 3.3 million acres in the Northern Rockies have moderate to severe root disease, with up to 60 percent due to armillaria root disease (USDA Forest Service 2007). On about 3 percent of forest lands in Idaho and Montana shrub fields have replaced forest cover as a result of severe root disease. Incidence and severity of root disease have not been estimated across the Kootenai and Idaho Panhandle region specifically, but a study of Ecosection M333d (Bailey 1994) which includes the southern Idaho Panhandle National Forests and southern Kootenai National Forest, found evidence of root disease on 94 percent of the area sampled (Byler and Hagle 2000). Root disease has on average reduced forest canopy cover by 20 to 30 percent in infected stands.

White pine blister rust

White pine blister rust (WPBR) is an exotic fungus introduced to North America early in the 20th century. It has now spread throughout much of the western U.S. affecting all five-needled pines and causing significant tree mortality (USDA Forest Service 2009). In the Northern Rockies, including the Kootenai and Idaho Panhandle regions, WPBR has severely affected western white pine and whitebark pine. WPBR, in addition to mountain pine beetle and past harvesting, has reduced western white pine to less than five percent of its early 20th century population size in the interior Pacific Northwest (Harvey et al. 2008). Stands formerly dominated by western white pine have shifted toward later seral or climax tree species that are more susceptible to root disease and bark beetles (Byler and Hagle 2000).

In northern Idaho and northwestern Montana, WPBR has killed a quarter to half of all whitebark pine trees (Keane et al. 1994; Kendall et al. 1996; Stuart-Smith 1998; Kendall and Keane 2001). Since the late 1990s, increasing mountain pine beetle-caused mortality in high elevation whitebark pine has exacerbated the decline of this keystone species (Gibson et al. 2008).

Projected Trends in Forest Insects & Diseases

Bark Beetles

Projecting future trends in bark beetle population dynamics is complex with numerous, often interacting, contributing factors. The two primary drivers of bark beetle population eruptions are (1) the distribution and susceptibility of host trees (Fettig et al. 2007) and (2) the effects of temperature and other climatic factors on the survival and development of bark beetle populations (Raffa et al. 2008).Future population trends for mountain pine beetle (MPB), Douglas-fir beetle (DFB), and other bark beetles will be determined primarily by the distribution of susceptible host trees and climatic conditions conducive to rapid population growth (Bentz et al. 2009).

Bark beetle outbreaks require large expanses of susceptible-aged and homogenous forest. Past research has established relationships between stand characteristics and susceptibility to MPB and DFB attack (Fettig et al. 2007). We used MPB and DFB stand hazard rating models to estimate the amount and distribution of susceptible host trees and potential tree mortality for the period 2005 to 2020 on the Idaho Panhandle and Kootenai National Forests (Table 5.5.1). The primary inputs to these models are tree age classes and stand density characteristics derived from forest inventory data. Stands are rated as high, moderate, or low susceptibility to mortality. Based on these susceptibility levels, the models also estimate the amount of each tree species that might be killed over the 15 year period in each susceptibility class.

The model results indicate that a substantial percentage of lodgepole and Douglas-fir stands on the Kootenai and Idaho Panhandle National Forests are highly or moderately susceptible to bark beetles. Approximately 15 to 20 percent of the lodgepole pine stands are moderately or highly susceptible to MPB attack. MPB attacks are likely to kill 80 percent of the lodgepole pine in highly susceptible stands, and 50 percent in moderately susceptible stands (Cole and McGregor 1983).

Twenty five to 30 percent of the Douglas-fir stands are at least moderately susceptible to DFB attack. DFB are likely to kill 60 percent of the basal area in highly susceptible stands, 45 percent in moderately susceptible stands, and 35 percent in stands rated low susceptibility (Negron 1998). These estimated losses are likely worst-case scenarios. To achieve these levels, a triggering event (wildfire, defoliation, windthrow) will be necessary for the population to increase sufficiently to cause this level of mortality. Such a trigger is likely, however, if warmer and drier conditions continue to occur, causing reduced tree vigor due to limited moisture availability through the growing season.

Approximately three to five percent of the ponderosa pine stands are moderately or highly susceptible to MPB and western pine beetle. The amount of mortality was estimated to be 50 percent in the high class, 16 percent in the moderate class, and 8 percent in the low class. These estimates are based on work of McCambridge et al. (1982) and Schmid et al. (2007). Table 4 provides the hazard rating and bark beetle caused mortality estimates on the Idaho Panhandle and Kootenai National Forests. These hazard ratings are based upon current stand characteristics such as tree diameter distribution, age, stand density, and species composition. They do not include climatic factors such as moisture stress that can strongly influence the ability of trees to defend themselves from bark beetle colonization (Bentz et al. 2009).

Climate variability and long-term trends will also influence the potential for large-scale outbreaks of MPB and DFB. Climate influences bark beetle populations in multiple ways, including over-winter survival, reproductive rate and success, dispersal ability, and timing of egg and larval life stages, timing of adult emergence, and time required to complete a life cycle.

Recently, entomologists have developed models of potential effects of climate change on population dynamics of the mountain pine beetle. These models simulate the effects of climate projections on the probability of MPB over-winter survival (cold tolerance) and probability of adaptive seasonality. Adaptive seasonality combines several temperature dependent life history characteristics to describe MPB life cycle timing that results in univoltism (complete life cycle within one year) and adult emergence during an appropriate window of time to facilitate mass attack on host trees (Logan and Bentz 1999; Bentz et al. 2009). A more detailed discussion of the effect of climate change on western U.S. bark beetles has been recently produced (http://www.fs.fed.us/wwetac/projects/PDFs/RTA_Bark_Beetle.pdf).

Cold tolerance models project that the probability of over-winter survival of MPB will increase over most of the western U.S. throughout the 21st century, particularly at higher elevations (Bentz et al. 2009). A substantial increase in cold temperature survival probability, relative to the 1961-1990 periods, is projected for northwestern Montana during the period 2001-2030 (Figures 31 & 32). Cold tolerance models project that at the end of the 21st century, most areas in the western U.S. currently containing pine forests will have a moderate to high probability of cold temperature survival for MPB. Exceptions are the high elevations along the Continental Divide in Montana and portions of the Greater Yellowstone area.

Adaptive seasonality models project a decrease in MPB outbreak potential in lower elevation forests and an increase potential for higher elevation forests, including portions of northeast Washington and northern Idaho, for the period 2001-2030 compared to 1961-1990 (Bentz et al. 2009). By the last quarter of the 21st century, the majority of western U.S. forests, including essentially all of the U.S. Northern Rockies except a small portion of the Greater Yellowstone area, currently occupied by pines are projected to have very low probability of MPB adaptive seasonality (Bentz et al. 2009). The differences in results from the cold tolerance and adaptive seasonality models highlight how different aspects of MPB life history respond differently to changes in temperature.

When the models described above are combined with a model of lodgepole pine stand susceptibility by county, results suggest a general decrease in probability of MPB population success (Bentz et al. 2009).

Although spruce beetle has not been a significant source of tree mortality in the U.S. Northern Rockies in recent decades, a recent assessment of the effects of climate change on spruce beetle population dynamics suggests that over the next 70 years there is an increasing probability of spruce beetle univoltism (one-year life cycle), and thus exponential population growth. Areas with the largest increase in probability of spruce beetle outbreak include high elevation areas in the U.S. Northern Rockies (Bentz et al. 2009).

The MPB model simulations reported above have several important limitations that preclude placing high confidence in the results as realistic predictions of future outbreaks. The models simulate the effects of a single GCM/emissions scenario projection, while numerous equally plausible climate simulations exist. The models were parameterized using MPB population data from a single region that may not reflect the temperature responses of MPB in other areas. In addition, the adaptive seasonality model assumes that a univoltine life cycle is necessary for high probability of an outbreak, even though recent research suggests that MPB can be successful in areas that are not strictly univoltine (Bentz et al. 2009). Despite these limitations, the models clearly reveal how changes in temperature may positively affect one aspect of MPB population growth potential, but negatively affect another. They also reveal how the potential effects of climate change on bark beetle population dynamics vary by geographical location and elevation.

Diseases

Very limited scientific information is available regarding the potential effects of climate variability and change on root diseases and white pine blister rust. In general, the available literature suggests that any climate variation or change related increases in moisture stress of host trees could increase the incidence and spread of root diseases (Shaw and Kile 1991; Wargo and Harrington 1991; U.S. Office of Technology Assessment 1993). Climate change could have positive, negative, or no impact on individual pathogens. However, there is insufficient information available to estimate those effects (Kliejunas et al. 2008).

Key Sources of Uncertainty

For almost all species of bark beetles and pathogens, there is little or no quantitative information on how temperature and other climatic factors affect life history events such as over-winter survival, life stage developmental rates, and timing of adult emergence. Even for those species where some information is available (MPB and spruce beetle), the empirical data is from specific geographic locations and may or may not apply to other locations (Bentz et al. 2009). Recent modeling efforts reveal that such information is critical to estimating effects of climate variability and change on insect population dynamics.

Currently, researchers do not know the relative importance of “adaptive seasonality” and cold tolerance for MPB success. Assumptions in the existing adaptive seasonality model are considered to be too restrictive, and may underestimate population growth potential (Bentz et al. 2009). Thus, model projections of climate-induced declines in adaptive seasonality and population success for MPB should be considered with caution.

Existing projections of bark beetle population response to climate change are based upon observed thermal tolerances and timing of life history stages (phenology). However, bark beetles, other arthropods, and pathogens may face significant climate-related selective pressures. Phenotypic plasticity and genetic adaptation may allow these species with relatively short generation times to respond quite rapidly (Parmesan 2006; Hoffman and Willi 2008). Thus, actual population responses to climate change may differ from modeling results based upon existing thermal tolerances and life history phenology (Bentz et al. 2001; Bentz et al. 2007).

Climate variability and change will continue to affect forest productivity, moisture stress, wildfire regimes, composition, and other factors that influence the susceptibility of host trees to bark beetles, other aggressive insects, and pathogens. A changing climate may also influence fungal associates of bark beetles which may affect the success of bark beetle attacks and population growth (Six and Bentz 2007). Existing model projections of bark beetle population dynamics do not address these potential changes in susceptibility of trees, stands and landscapes. Models describing changes in stand susceptibility through time would provide a more complete evaluation of potential future changes in insect and disease disturbance dynamics under a changing climate (Bentz et al. 2009).

Changes in climate may increase the ecosystem effects of insect and pathogen species that previously have had relatively minor roles in the dynamics of Northern Rockies ecosystems. In addition, some species that currently do not occur in the Northern Rockies may expand their ranges into the region. Changes in the relative abundance and diversity of insect and pathogen species could have surprising effects on the disturbance and succession dynamics on Northern Rockies forests.

Potential Adaptation Opportunities

Increasing the diversity of tree species within stands and across landscapes can reduce the susceptibility of forests to aggressive insects and pathogens (Bentz et al. 2009). Reducing the density of trees can decrease multiple stresses on trees, increase tree vigor and ability to repel insect colonization, and reduce the ability of bark beetles to mass attack susceptible trees by altering forest microclimate (Fettig et al. 2007). These collective benefits of thinning, prescribed fire, and moderate intensity wildland fire increase the ability of trees to survive natural disturbances including insect outbreaks and root diseases. High hazard stands and landscapes with a relatively high proportion of high hazard stands may be priorities for such treatments. The effectiveness of such management actions is maximized when treatments occur at landscape scales; small, isolated stand treatments do not appreciably reduce forest susceptibility to bark beetle outbreaks (Jenkins et al. 2008).

Increasing the diversity of stand ages, size classes, and tree species in currently homogenous landscapes can reduce extent and continuity of highly susceptible stands, and thus the severity of bark beetle-caused tree mortality during outbreaks (Fettig et al. 2007; Bentz et al. 2009). Timber harvest, prescribed fire, and wildland fires managed for resource benefits are the most commonly available tools for increasing landscape heterogeneity.

Whitebark pine is probably the species most vulnerable to changes in forest insect and pathogens resulting from climate variation and change. Reducing the density of trees in whitebark pine stands may reduce their susceptibility to MPB. Removing blister rust infected trees as part of this effort may promote selection for resistance to blister rust (Gibson et al. 2008). Lack of access to high elevation stands often precludes the use of mechanical thinning. Thus, extensive use of prescribed fire and wildland fire managed for resource benefits offers the best hope for reducing whitebark pine susceptibility to MPB and restoring sustainable whitebark pine stands (Keane 2000; Keane 2001; Keane and Arno 2001; Tomback 2001).

Expanding current programs to develop genotypes of western white pine and whitebark pine resistant to white pine blister rust, along with an extensive planting program, may improve the persistence of these tree species (Hoff et al. 2001; Harvey et al. 2008). As these genotypes are selected, consideration of their adaptability to a changing climate needs to be considered and incorporated.

Post-disturbance stand and landscape management to increase tree species diversity stand density, and landscape diversity may promote the long-term resiliency of forests to insect and disease outbreaks or attacks (Joyce et al. 2008; Jenkins et al. 2008).

A program designed to detect and rapidly respond to unexpected or invasive pathogens and insect populations may allow land managers to take early action and prevent larger scale or irreversible effects that may threaten the sustainability of existing forest ecosystems (Millar et al. 2007).

Table 4. Estimated Bark Beetle hazard and estimated loss 2005-2020[1]

National Forest	Relative Hazard Rating				Estimated Loss 2005-2020			
	High	Moderate	Low	None	High	Moderate	Low	Total
	Mean	Mean	Mean	Mean				
Mountain Pine Beetle Hazard in Lodgepole Pine								
Kootenai	5.6%	13.2%	5.8%	75.4%	4.5%	6.6%	18.9%	29.9%
Idaho Panhandle	4.6%	12.9%	3.3%	79.2%	2.7%	6.5%	19.8%	29.9%
Mountain Pine Beetle/Western Pine Beetle Hazard in Ponderosa Pine								
Kootenai	0.8%	2.9%	1.8%	94.6%	0.4%	0.5%	0.1%	1.0%
Idaho Panhandle	0.1%	2.9%	1.5%	95.5%	0.1%	0.5%	0.1%	0.6%
Douglas-fir Beetle Hazard in Douglas-fir								
Kootenai	5.1%	19.6%	21.0%	54.3%	3.1%	8.8%	7.4%	19.2%
Idaho Panhandle	5.4%	25.2%	20.0%	49.4%	3.2%	11.3%	7.0%	21.6%

1 This information was derived by using FIA data and the MPB hazard rating model embedded in the Forest Vegetation Simulator model.

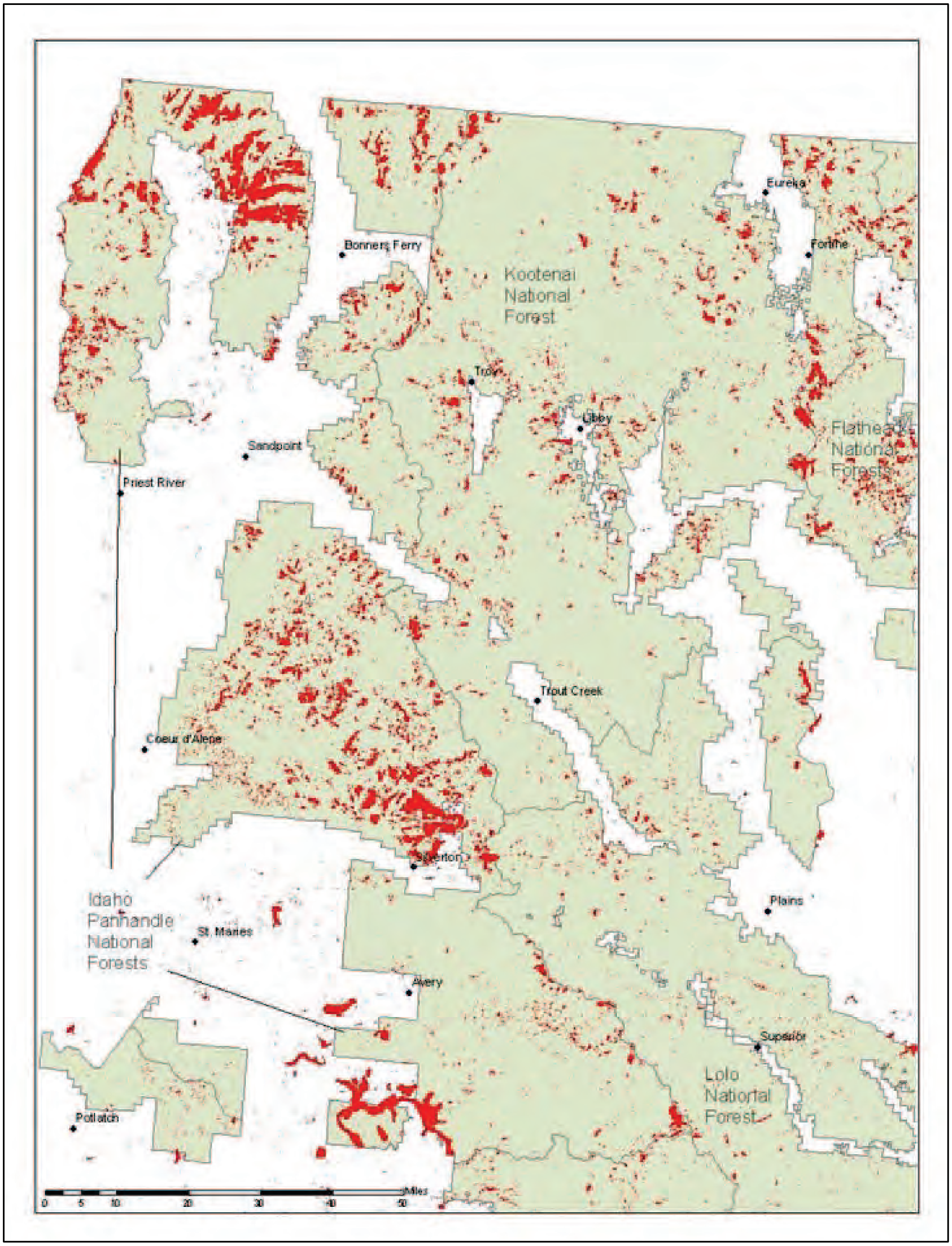


Figure 29. Areas with Detectable Mountain Pine Beetle Mortality, Kootenai and Idaho Panhandle National Forests 2000-2008. The data displayed are a composite of aerial detection survey results

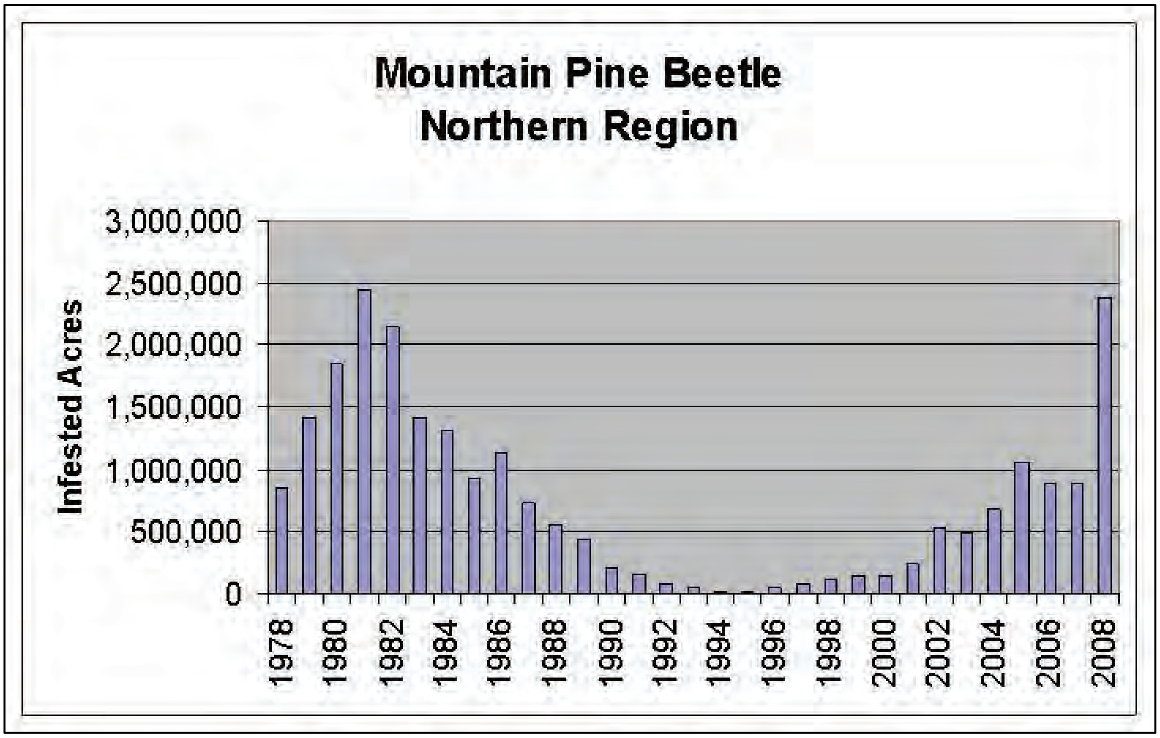


Figure 30. Acres of U.S. Forest Service's Northern Region infested with mountain pine beetle 1978-2008

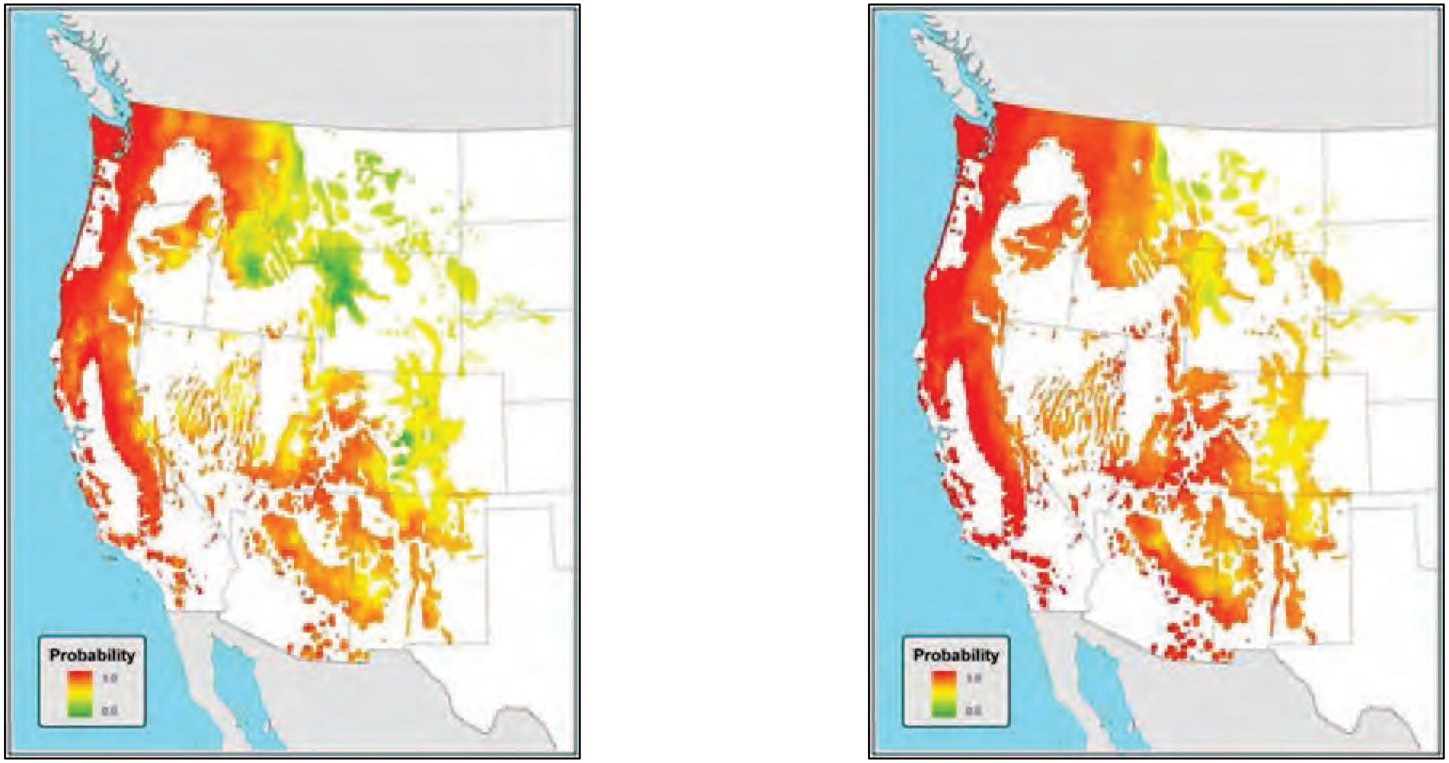


Figure 31. Probability of mountain pine beetle cold temperature survival in pine forests of western U.S. in A) climate normals period 1961-1990 and B) 2071-2100. High probability of survival relates to high probability of mountain pine beetle population success. Source: Dr. Barbara Bentz, USFS Rocky Mountain Research Station (Bentz et al. 2009)

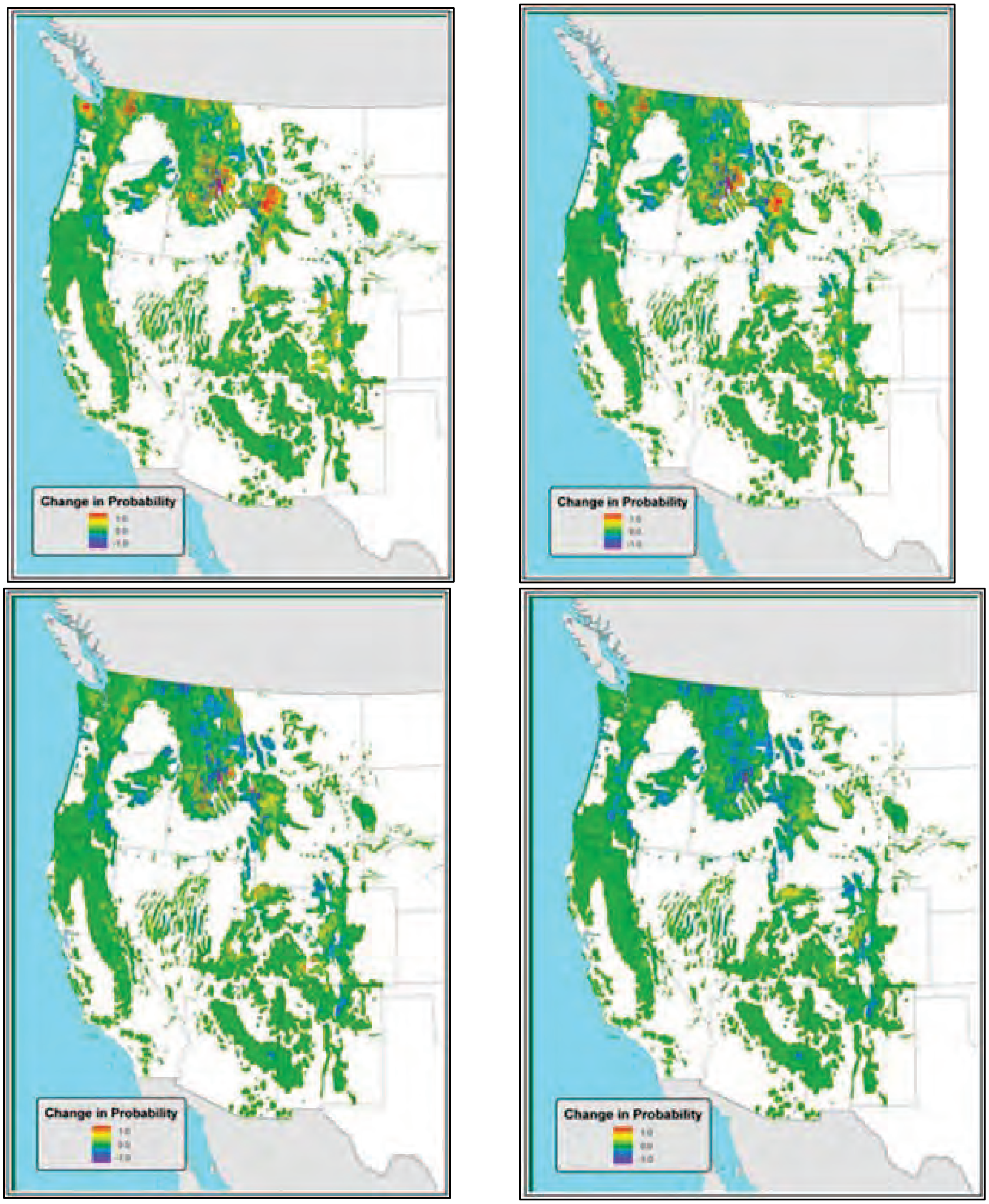


Figure 32. Change in probability of mountain pine beetle adaptive seasonality in pine forests of western U.S. between

A) climate normals period 2001-2030 and 1961-1990, B) 2011-2040 and 1961-1990, C) 2041 – 2070 and 1961-1990 and D) 2071 – 2100 and 1961-1990. High adaptive seasonality suggests increased mountain pine beetle population success. Note the change in probability scale ranges from -1.0 to +1.0. In some areas, adaptive seasonality is disrupted with increasing temperature. Source: Dr. Barbara Bentz, USFS Rocky Mountain Research Station (Bentz et al. 2009).

Chapter 10. Climate Related Trends in Wildland Fire

Introduction

Fire has been a fundamental part of the Northern Rockies forests for many thousands of years. Long-term variations in temperature and precipitation patterns have resulted in continuously changing fire regimes (Whitlock et al. 2008). Variability in climate and fire regimes over the Holocene strongly influenced forest composition and structure (Whitlock et al. 2003; Hallett and Hills, 2006; Mack et al. 1983). Future changes in climate could have major effects on the timing, frequency, intensity, severity, and average annual extent of wildland fires. Moreover, climate-induced changes in fire regimes, depending on the magnitude of change and interactions with other ecosystem and social stressors, could have substantial impacts on the ecosystems, economies, and communities of the Northern Rockies (McKenzie et al. 2009).

Observed Trends in Wildfires

Fire records for the Kootenai and Idaho Panhandle National Forests show that there is substantial year-to-year and decade-to-decade variability in acres burned by wildfires over the last 100 years (Figure 33). Episodes of large wildfires occurred in the early 20th century, followed by an extended period from 1937 to 1988 with relatively few acres burned. A trend of increasing acres burned is evident from the mid-1980s to the present. Similar patterns of inter-annual and inter-decadal variability in acres burned are found for the entire Pacific Northwest and much of the western United States.

Over the last 20 years in the western United States there has been a large increase in the frequency of very large wildfires and total acres burned. An analysis of fire records for forested Federal lands in the western U.S. from 1970 to 2003 found that there has been a fourfold increase in the number of large fires and a sixfold increase in area of forest burned since 1986 compared to the period 1970 to 1985 (Westerling et al. 2006). The greatest increases were found in the Northern Rockies where since 1986 the number of large forest fires increased more than tenfold (1100 percent) and the area burned by large fires increased more than threefold (350 percent) compared to the period 1970 to 1985 (Westerling 2008).

Westerling et al. (2006) attributed these recent trends to an increasing frequency of warm spring and summer temperatures, reduced winter precipitation and earlier snowmelt, leading to longer fire seasons and increased drought stress on forest vegetation. Throughout the west, years with earlier snowmelt had five times the number of large fires as years with late snowmelt. In the Northern Rockies, 66 percent of large fires since 1970 occur in early snowmelt years, while only 9 percent occur in late snowmelt years (Westerling 2008).

Other recent studies place the trends of the last 20 years in a longer-term context, and examine the influence of broad climate patterns, including the inter-annual and inter-decadal patterns of the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), on large fire occurrence and acres burned. Results of this research may improve our understanding of more recent trends and help inform evaluations of the impacts of potential future climate changes on fire regimes.

Episodes of numerous large fires have occurred in the past in the Pacific Northwest and Northern Rockies (Pyne 1982; Whitlock et al. 2003; Morgan et al. 2008; Heyerdahl et al. 2008; Whitlock et al. 2008). Analyzing a compilation of 20th century annual fire perimeter maps for forested areas of the Northern Rockies (Idaho and western Montana), Morgan et al. (2008) found eleven “regional-fire years”[1] that accounted for 74 percent of the total fire extent from 1900 to 2003. These high fire years all occurred during the period 1900 to 1934 or after 1988; none occurred between 1935 and 1987 (Figure 34). During both the early- and late-20th century periods, regional-fire years were associated with warm spring temperatures, followed by warm, dry summers (Figure 34).

20th century regional-fire years are associated with the positive phase of the PDO (Morgan et al. 2008; Collins et al. 2006; Littell 2006; Gedalof et al. 2004) (Figure 34). During the 20th century 67 percent of the forested area burned in the Northern Rockies was in cold forests (dominated by lodgepole pine, subalpine fir, and Engelmann spruce) and dry forests (ponderosa pine and Douglas-fir). The distribution of total fire extent among vegetation types was not disproportionate to their relative occurrence (Morgan et al. 2008). These results generally confirm the conclusion of Westerling et al. (2006) that warm springs contributed to regionally synchronous fires in the late 20th century, and demonstrate that the same is true in the early 20th century. The inter-decadal variation in fire extent during the 20th century, including the mid-century gap in regional-fire years, appears to result from complex interactions of climate variation, climate change, fire suppression, land use, and vegetation.

Additional studies have used data from fire-scarred trees to examine the occurrence of regional-fire years in the Northern Rockies and inland Northwest prior to the 20th century, (Hessl et al. 2004; Heyerdahl et al. 2008a; Heyerdahl et al. 2008b). Since 1650, there have been at least 29 years with large fires and large total area burned in the Northern Rockies (Heyerdahl et al. 2008b). Throughout this multi-century period, regional fire years were ones of warm springs followed by warm-dry summers. Although PDO is a strong driver of regional fire years in 20th century, a correlation of PDO with regional fire years is not evident in prior centuries. ENSO does not appear to be a significant driver of either modern or historical fires (but see Heyerdahl 2008a). There is insufficient evidence at present to conclude that the increase in the frequency of large fires and total area burned in the Northern Rockies since the mid-1980s is outside the range of variation experienced earlier in the Holocene (Whitlock et al. 2008).

Projected Trends in Wildfires

GCM simulations for the Pacific Northwest consistently project increases in average annual and seasonal temperatures (Mote et al. 2008; Appendix 2). Most, but not all, models project a decrease in summer (June, July, August) precipitation (Mote et al. 2008). Given the observed correlation of large fire years with warm springs and dry summers over the last several centuries, it seems reasonable to infer that the projected changes in spring and summer climate for the Pacific Northwest will likely increase the frequency of large fire years. However, there are many factors in addition to seasonal temperature and precipitation that influence the potential for large fires including fuel arrangement and continuity, topography, daily and hourly weather, fire management policies and tactics, and the timing and amount of ignitions.

There have been several published studies evaluating the effects of projected climate changes on wildland fire in the western United States and Canada. Various types of models have been used

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[1] Morgan et al (2008) defined “regional-fire years” as those exceeding the 90th percentile in annual fire extent from 1900 to 2003. In other words, “regional-fire years” are those where the total area burned in the Northern Rockies exceeded 252,823 acres. Regional-fire years were: 1910, 2000, 1919, 1994, 2003, 1988, 1926, 1929, 1992, 1934, and 1931, in order of decreasing fire extent.

including statistical models, mechanistic simulation models, and landscape disturbance models (Flanigan et al. 2005a). These modeling studies also vary in the climate projections used to evaluate future wildfire characteristics. Results suggest that in many forested regions of western North America the following effects are possible:

- Longer fire seasons (Brown et al. 2004; Nitschke and Innes 2008);
- Increased number of days with high fire danger (Brown et al. 2004);
- Increased frequency of ignitions (Price and Rind 1994; Bachelet et al. 2007);
- More frequent episodes of extreme fire behavior (Nitschke and Innes 2008);
- Increased fire severity (Flanigan et al. 2000; Nitschke and Innes 2008);
- More frequent large fires (Westerling and Bryant 2008);
- Increased average annual area burned (Bachelet et al. 2001; McKenzie et al. 2004; Flanigan et al. 2005b; Bachelet et al. 2007; Lenihan et al. 2008); and
- Increased risk of property and resource loss (Westerling and Bryant 2008; Nitschke and Innes 2008).

Recently, the Climate Impacts Group at the University of Washington developed statistical models of projected annual area burned, based on two GCMs and two emissions scenarios, for the Pacific Northwest region, including Idaho and western Montana (Littell et al. 2009). The models suggested a doubling or tripling of annual area burned by 2080s. Averaging the results from both GCMs, the models projected that regional area burned would increase from about 0.5 million acres (median annual acres burned from 1916 to 2006) to 0.8 million acres in the 2020s, 1.1 million acres in the 2040s, and 2.0 million acres in the 2080s. In addition, the models projected that the probability of more than 2.0 million acres burning in a given year increases from 5 percent, during the period 1916 to 2006, to 33 percent by the 2080s (Littell et al. 2009).

The IPCC concluded that in North America "disturbances such as wildfire…are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons, and to interact with changes in land use and development affecting the future of wildland ecosystems" (Parry et al. 2007 page 56; Field et al. 2007). Similarly, a recent assessment by the U.S. Climate Change Science Program found that "several lines of evidence suggest that large stand-replacing wildfires are likely to increase in frequency over the next several decades because of climate warming" (Ryan et al. 2008 page 87).

Key Sources of Uncertainty

Lack of locally specific studies - Published analyses of the potential effects of climate change on wildland fire evaluate broad geographic areas such as individual States or ecosystems such as boreal forests of Canada. There is a high degree of uncertainty in extrapolating the results of these studies to other areas and more local scales. While the recent study by Littell et al. (2009) focuses on the Pacific Northwest region, we are aware of no studies modeling the potential effects of projected climate changes on wildfires specifically in the Northern Rockies or the Kootenai and Idaho Panhandle National Forests.

Projected trends in spring and summer precipitation - Seasonal and monthly precipitation projections are perhaps the most significant source of uncertainty in evaluating potential effects of climate change on wildland fires. GCMs are considerably less skillful in simulating precipitation than temperature (CCSP 2008). A recent analysis of twenty GCMs, each simulating two emissions scenarios, revealed mid-21st century summer (June, July, and August) precipitation projections for the Pacific Northwest varied from a 17 percent increase to a 30 percent decrease, with a mean of between -4.6 and -12 percent (Mote et al. 2008; Appendix 2).

Synoptic weather patterns - Most studies of climate change effects on wildland fire are broad in extent and relatively coarse in spatial and temporal resolution compared to many factors that influence large fire growth. For example, large fire growth events are often associated with short-term fluctuations in atmospheric conditions such as persistence of high pressure ridges, periods of high atmospheric instability (i.e., high Haines Index), and wind events associated with passage of cold fronts. These synoptic weather features are not well simulated in GCMs, and are not explicitly considered in most impact analyses which typically focus on projected changes in average temperature and precipitation (Fauria and Johnson 2008).

Climate change effects on ENSO and PDO - The El Niño Southern Oscillation (ENSO) has been shown to influence winter and spring temperature and precipitation in the Pacific Northwest, and the positive phase of the Pacific Decadal Oscillation (PDO) is associated with 20th century large fire years in the inland Northwest and Northern Rockies. However, the effect of climate change on the behavior of the ENSO and the PDO is largely unknown (CCSP 2008; Randall et al. 2007).

Fuel continuity - The spread of wildfires, and potential for large fire growth, can be limited by the discontinuity of fuels across the landscape (Finney 2007). Most studies of climate change effects on wildland fire do not consider the continuity of fuels across landscapes, thus adding uncertainty to projected changes in average fire size and annual area burned. If fires and other stand replacing disturbances occur more frequently, the resulting landscape pattern may limit the size of future fires and total area burned (Collins et al. 2009).

Potential Adaptation Opportunities

Aggressive fire suppression can limit, at least temporarily, the number and size of large fires. As fire weather conditions increase in severity, fire suppression success rates decline. Thus, fire suppression as a climate change resistance strategy is likely to become increasingly expensive and ineffective over time as fuels accumulate and if the frequency of warm springs and dry summers increases. This strategy will likely be effective only under moderate burning conditions, and in the long run may lead to most acres burning in fewer, more extreme and unmanageable events with greater undesirable consequences (Reinhardt et al. 2008).

Where appropriate, prescribed fire, mechanical thinning, and wildland fire management can restore fire dependent ecosystems so that they are less vulnerable to changes in disturbance under changing climatic conditions. This will be most effective in forest areas that historically burned in low and mixed severity fire regimes but have experienced extended periods without fire and now are at high risk of burning in stand replacement fires. To be effective, fuel treatments need to be of sufficient scale and strategically arranged to achieve desired effect on future fire behavior.

Where consistent with other resource management objectives and when risks to private property are low, management of wildland fires can develop landscape fuel patterns that limit future large fire growth and annual area burned (Collins et al. 2009).

Particularly in dry forest types, use of mechanical thinning, prescribed fire, and wildland fire under moderate burning conditions can reduce the density of trees and reduce the risk of severe fire effects on resources and ecosystem services including water quality, fish and wildlife habitat including old growth, and carbon storage.

In areas adjacent to homes and other high value assets, fuel reduction treatments may increase likelihood that fires burn in low severity surface fires rather than crown fires. In addition, strategically located fuel breaks may reduce the chances of wildfires spreading into populated and other high value areas. This may also increase the likelihood that houses and other high value assets can be more easily protected and forest stands may survive with minimal impact. However, under extreme fire weather conditions fuel treatments may have little impact on fire behavior.

Efforts by private property owners to construct homes and other buildings with fire resistant materials and eliminate flammable vegetation immediately adjacent to structures can substantially reduce the risk of property loss to fire even during extreme fire weather events (Cohen 2000).

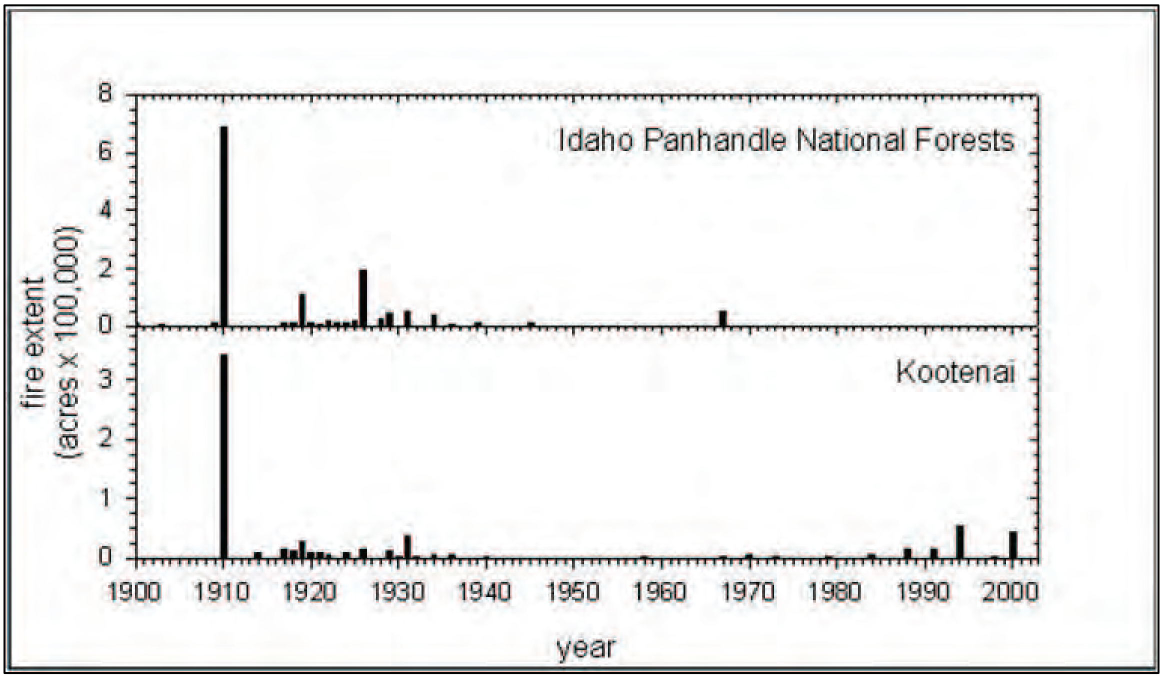

Figure 33. Annual acres burned on Kootenai and Idaho Panhandle National Forests from 1900 to 2006. Data are based on composite annual fire perimeter maps (Morgan et al. 2008). Source: Dr. Emily Heyerdahl, U.S. Forest Service, Rocky Mountain Research Station

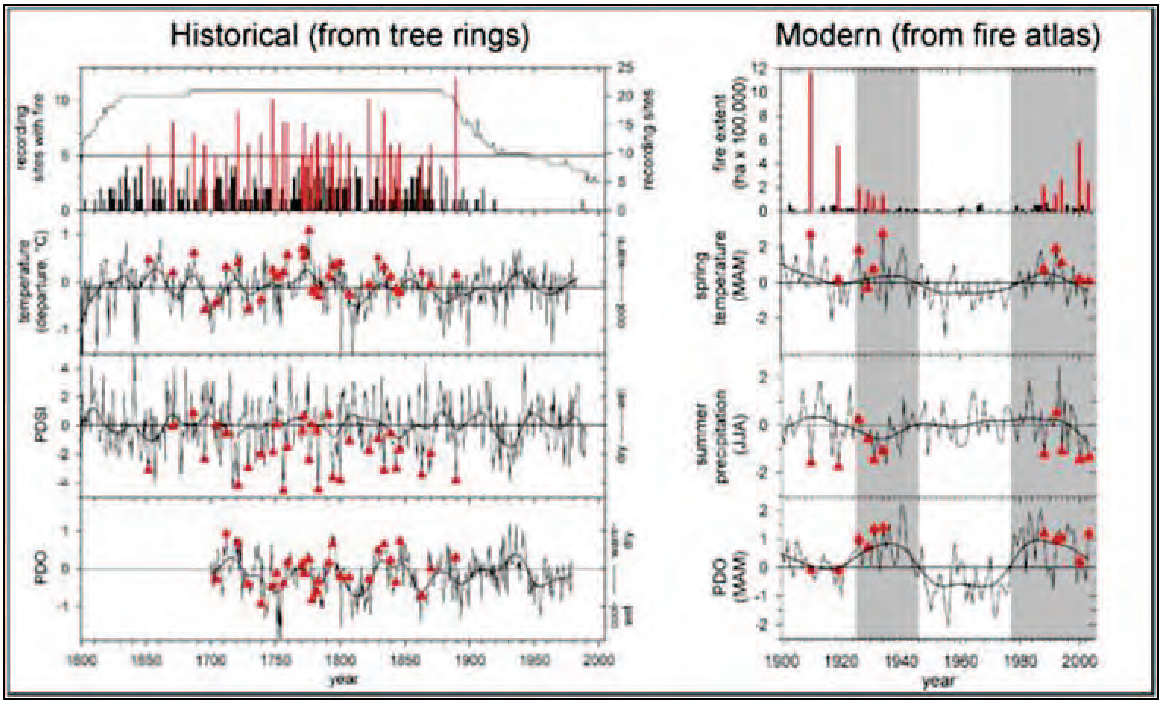

Figure 34. Regional fire years in forested areas of the Northern Rockies (Idaho and western Montana)

Regional fire years are indicated by red (bars in top plots and triangles in lower plots). Historical (1650 to 1900) and modern (1900 to 2003) regional fire years were ones when springs were warm and summers were dry. The Pacific Decadal Oscillation (PDO) is associated with large fire years in the 20th century but not in the historical period (bottom plot). This figure is a composite of data presented in Heyerdahl et al. 2008b and Morgan et al. 2008. Source: Dr. Emily Heyerdahl, U.S. Forest Service, Rocky Mountain Research Station.

Chapter 11. Terrestrial Wildlife

Introduction

National forests provide key habitat for diverse wildlife taxa. In the western United States, habitat diversity is high, though the spatial extent of some habitat types may be relatively small, and habitat patches may be separated by considerable distances or inhospitable matrix lands (Bilby et al. 2007; Joyce et al. 2008). These terrestrial habitats are already being demonstrably affected by climate change (Janetos et al. 2008; Karl et al. 2009). In turn, wildlife populations inhabiting these ecosystems are being influenced, either directly or indirectly, by changing environmental conditions (Root and Schneider 2002; Inkley et al. 2004; Parmesan 2006). As a driver of biotic systems, climate affects individual fitness; population dynamics; species abundance and distribution; and ecosystem composition, structure, and function (Parmesan et al. 2000; Parmesan 2006; Janetos et al. 2008). Climate change is, however, not the only driver of terrestrial wildlife populations; exogeneous stressors such as land use change, management practices, pollution, and human demography also affect wildlife, as do natural disturbances such as insect outbreaks and wildfire. Furthermore, climate and non-climate stressors can synergistically influence terrestrial wildlife (Noss 2001; Root and Schneider 2002; Thomas et al. 2004; MEA 2005; Malcolm et al. 2006; Parmesan 2006; Janetos et al. 2008; Karl et al. 2009).

In response to climate change, terrestrial wildlife have three basic options (Rice and Emery 2003; Parmesan 2006). Species can respond in place, through genetic, physiological, or behavioral adaptations (e.g., shifts in morphology or foraging strategy). Alternatively, wildlife can move to a new location. Finally, species unable to successfully reproduce and survive face local extirpation or extinction.

Observed responses to climate change

Several comprehensive reviews and meta-analyses (Root et al. 2003; Parmesan and Yohe 2003; Parmesan 2006; Janetos et al. 2008) have concluded that the majority of terrestrial biota included in analyses showed changes consistent with expected population responses to a warming climate.

<u>Distributional shifts</u> in latitude and elevation were commonly recorded (poleward or upward), suggesting that climate change has already begun to impose lasting effects with critical implications at multiple spatial scales. This pattern has been recorded in the past; during Pleistocene glaciations, species expanded their range to new locations (Parmesan et al. 2000; Root and Schneider 2002; Martinez-Meyer et al. 2004; Guralnick 2007; Brown 2008). The rapid rate of present warming (IPCC 2007), however, exacerbates the challenge of maintaining and restoring already reduced and fragmented populations (Root and Schneider 2002; Janetos et al. 2008; Karl et al. 2009).

<u>Advancing phenology</u> is well-documented for many migratory birds and butterflies (Inouye et al. 2000; Root et al. 2003; Price and Root 2005; Parmesan 2006; Janetos et al. 2008). For migratory birds, the timing of spring arrival to breeding grounds is correlated with the presence of seasonally-available food resources as well as reproductive success and survival. Earlier spring emergence of pollinators and hibernators is also being documented (e.g., Inouye et al. 2000).

<u>Disease</u> emergence and spread is a concern, though considerable uncertainty regarding the impacts of climate change on parasite and pathogen dynamics remains (Harvell et al. 2009; Lafferty 2009). West Nile virus has dramatically influenced local populations of sage grouse, and

evidence suggests that sage grouse have minimal resistance (Naugle et al. 2004; Walker et al. 2007).

Extirpation and extinction has been linked to warming climatic trends for a few taxa. Climate change has been linked to the extinction of several butterfly species (McLaughlin et al. 2002; Franco et al. 2006), and to the local extirpations of pikas in the Great Basin (Beever et al. 2003).

Projected responses to climate change

Climate change is expected to significantly restructure existing plant and wildlife communities, though responses will be species-specific and highly variable (Parmesan 2006; Janetos et al. 2008). Climate change will alter the selection pressures on a wide range of traits, and the relative rates of environmental change and evolutionary adaptation will vary among populations (Bradshaw and Holzapfel 2006). Evidence from past warming indicated that most species responded ecologically by moving to new locations, but dispersal rates and directions differed, resulting in novel species assemblages (Root and Schneider 2002; Brown 2008), thus influencing interspecific interactions such as competition, herbivory, and predation (Joyce et al. 2008). Past warming was gradual, however, compared to the current, rapid climatic trends, which may outpace evolutionary change (Bradshaw and Holzapfel 2006; e.g., Barnosky and Kraatz 2007).

Although wildlife responses are expected to be complex, several patterns are projected. Highly mobile wildlife species with large geographic ranges and wide physiological tolerances will respond more favorably to a changing climate. Wildlife are expected to shift their ranges poleward and upward along elevational gradients (Inkley et al. 2004; Parmesan 2006), but range shifts may be hampered by habitat fragmentation, roads, and urbanization (Brown 2008). Thus, widespread, generalist, invasive species will benefit from rapidly changing environmental conditions (Dukes and Mooney 1999; Simberloff 2000; Chornesky et al. 2005; Joyce et al. 2008). In a warmer climate, invasive species are expected to become a larger problem in areas that are currently cooler (Joyce et al. 2008). In contrast, rare, narrowly distributed, and endemic species, or those animals with limited dispersal ability, are projected to decline (e.g., McDonald and Brown 1992).

For animals directly affected by one or more climatic variables, projected population responses will depend on the direction of environmental change, life history characteristics, and non-climate stressors influencing dispersal (e.g., fragmentation). For instance, cold-limited species will likely expand their ranges, if suitable habitat exists. Among cold-limited wildlife, species with faster generation times (e.g., insects) will adapt more rapidly to changing conditions, which may also result in the range shift or expansion of arthropod-borne infectious diseases (Daszak et al. 2000; Harvell et al. 2002; see also Harvell et al. 2009; Lafferty 2009). In contrast, longer-lived, cold- or snow-dependent mammals such as wolverines (Magoun and Copeland 1998; Copeland et al. 2007), lynx (Gonzalez et al. 2007), pikas and snowshoe hares (Beever et al. 2003; GAO 2007) will be dramatically affected by a warming climate.

Wildlife populations will also be indirectly affected by the effects of climatic trends. Anticipated vegetative changes will affect wildlife at multiple spatial scales, though rates of vegetation change will vary with vegetation dispersal speed (Root and Schneider 2002; Janetos et al. 2008). Several community types and their associated wildlife populations are likely to greatly decrease in area, including alpine, subalpine spruce-fir, aspen, and sagebrush (Bilby et al. 2007); evidence from sagebrush bird declines supports this contention (Knick et al. 2003). Mammals inhabiting western public lands expected to experience noticeable effects of climate change include grizzly bears, bighorn sheep, pikas, mountain goats, and wolverines (GAO 2007). In addition, movement patterns of deer, bighorn sheep, and elk may be affected temporally, as snowpack patterns shift (Janetos et al. 2008). Finally, the projected 60-90 percent loss of suitable bird habitat may decrease Neotropical migratory bird species richness by 30-57 percent (Price and Root 2005).

Key sources of uncertainty

Generating reliable predictions of the effect of climate change on terrestrial wildlife is hindered by many factors:

- Variability in physical climate systems (IPCC 2007, Karl et al. 2009);
- Uncertainty in vegetative community shifts (Dale et al. 2001, Root et al. 2003, Bilby et al. 2007, Brown et al. 2008, Janetos et al. 2008, Joyce et al. 2008);
- Interactions between climate and non-climate stressors, and between biotic and abiotic ecosystem components (Root et al. 2003, Parmesan 2006, Bilby et al. 2007, Brown 2008, Janetos et al. 2008, Joyce et al. 2008, Karl et al. 2009);
- Variation in life history strategies, physiological tolerance, and dispersal abilities (Root et al. 2003, Parmesan 2006, Bilby et al. 2007, Janetos et al. 2008);
- Missing information on species-level responses (Root et al.2003, Parmesan 2006, Bilby et al. 2007, Janetos et al. 2008);
- Species interactions (e.g., competition, predation) (Root et al. 2003, Parmesan 2006, Bilby et al. 2007, Suttle et al. 2007, Janetos et al. 2008);
- Influence of invasive and exotic species (Root et al. 2003, Parmesan 2006, Bilby et al. 2007, Janetos et al. 2008);
- Non-analog communities resulting from differential responses to changing environmental conditions (Root et al. 2003, Parmesan 2006, Bilby et al. 2007, Janetos et al. 2008, Karl et al. 2009);
- Inadequate monitoring systems to document changes (GAO2007); and,
- Model constraints on scale and accuracy.

Potential Adaptation Opportunities

Management plans could incorporate several adaptation options into their decisions (Root and Schneider 2002, Inkley et al. 2004, Bilby et al. 2007, Janetos et al. 2008, Joyce et al. 2008):

Forestall ecosystem change

- Adopt landscape management practices to enable species movements through larger management unit sizes, broader habitat corridors (north-south), and increased habitat continuity;
- Prevent and control invasives; and
- Use prescribed and wildfire to maintain ecosystems.

Manage for ecosystem change

- Assist transitions, population adjustments, range shifts, other natural adaptations (e.g., assisted migration: Inkley et al. 2004, Hoegh-Guldberg et al. 2008);
- Employ monitoring and adaptive management to explore directions of change and natural response at local scales;

- Create or enlarge reserves, oriented north-south along elevational gradients, in northern parts of ranges;
- Consider multi-scale wildlife habitat needs when selecting reserves: habitat fragmentation and changes of habitat will influence the ability of such reserves to support particular biota in the future;
- Increase reserve redundancy and buffers;
- Maintain healthy, connected, genetically diverse populations;
- Determine the prevalence of adaptive genes within populations (i.e., introduce disease-resistant individuals into a population rather than translocating the population to accommodate the expanding or shifting range of a disease);
- Manage for asynchrony, diverse conditions;
- Promote connected landscapes to enable dispersal and migration, recolonization, and genetic exchange;
- Evaluate/reduce fragmentation, plan cumulative landscape treatments to encourage defined corridors as well as widespread habitat availability;
- Realign disrupted conditions to range of current or anticipated future environments (rather than HRV conditions); and
- Adjust harvest and yield models.

Options to forestall and manage for ecosystem changes

- Manage for resilience by reducing other stressors, while at the same maintaining natural disturbance processes;
- Anticipate and plan for surprise and threshold effects;
- Monitor populations to detect changes;
- Species interactions and competition under changing climate are complex and unexpected (Millar and Woolfenden 1999, Harris et al. 2006, Willis and Birks 2006, Suttle et al. 2007);
- Experiment with refugia; and
- Environments that appear more buffered against climate and short-term disturbances could be considered as sites for long-term retention of species.

Chapter 12. Special Areas

Introduction

The 2008 planning rule, and associated directives, includes the designation of "Special Areas" as one of the six primary forest plan components (USDA Forest Service 2008). Special areas are often protected from other management uses, and this report uses the terms "special" and "protected" synonymously. Examples of administrative designations that help to meet the planning objectives for special areas on National Forest System lands include Research Natural Areas and Special Interest Areas. Congressionally designated special areas, such as Wilderness Areas and Wild and Scenic Rivers, also contribute critical lands to the national network of protected sites in the United States. While this report emphasizes administratively designated areas, many of the principles and concerns relate to all protected areas.

Protected areas are one of the primary conservation tools used for contributing to ecosystem and species sustainability, and their identification and establishment has long been used to achieve such goals (Hannah et al. 2007; Rodrigues et al. 2004). Rare and unique species, habitats and plant communities are commonly the targets for such protection, as well as sites with representative common habitats. The USDA Forest Service Research Natural Area (RNA) network is an example of such a protected area system, which seeks to protect examples of all of the important habitats on National Forest System lands (Evenden et al. 2001). Special Interest Areas (SIAs) are also commonly designated to protect areas with unique natural features, and are often used to promote conservation education. National Forest plans allocate acreage to each of these types of protected areas, and the plans also contain desired conditions, objectives, guidelines and similar guidance for their management and stewardship.

There are many implications of climate change for protected areas, given that they have fixed political boundaries but species and ecosystems do not (Lovejoy 2006). As species disperse to follow their required environmental and climatic conditions, many could migrate from the protected areas in which they are currently found (Peters and Darling 1985), assuming that unfragmented habitat surrounding the protected sites is available for such emigration (Lovejoy 2006). While this may lead to questioning the continued validity of designating protected areas, there are strong arguments for adding more areas to the national and global network despite the potential effects of climate change (Hannah et al. 2007; Welch 2005). Such areas will be the bases from which future biogeographical patterns will emanate (Lovejoy 2006), and strategies for integrating climate change in protected area selection and design have been proposed (Hannah et al. 2002).

Nationwide, the Forest Service has established 482 RNAs, protecting over 570,000 acres. In the Northern Region, 107 RNAs have been established, protecting over 147,000 acres. There are currently 28 established RNAs on the Kootenai and Idaho Panhandle National Forests (KIPZ), and five proposed for establishment. There are 44 established Special Interest Areas within KIPZ, and 64 new potential SIAs are identified in the Forest plan revisions. These special areas protect a range of vegetation types and species that are likely to be differentially affected by climate change. The vegetation types represented in the established and proposed RNAs in KIPZ are summarized in Table 5.

Observed trends and responses to climate change

Changes in species distribution patterns due to changing climate regimes have been documented in a wide range of ecosystems worldwide. Influences on the distribution and abundance at range margins, both in latitude and elevation, have been observed (Lenoir et al. 2008). Shifts of species ranges poleward, and upward along elevation gradients, are expected (Parmesan 2006). A significant upward shift in species optimum elevation has been observed in west Europe; the shift is larger for species restricted to mountain habitats (Lenoir et al. 2008).

A recent study of tree mortality rates in the western United States, including northern Idaho, indicated that mortality increased in many areas, while recruitment rates increased to a lesser extent; these demographic changes can lead to substantial changes in forest structure, composition, and function. These changes are consistent with exogenous causes, with regional warming and drought stress being likely drivers (van Mantgem et al. 2009). The tree genera that were observed to have increases in mortality include Tsuga and Abies, two of the prominent genera that occur in RNAs in KIPZ (Table 5).

Similar climatically influenced changes to species distribution patterns and forest dynamics may be occurring in the protected areas within the KIPZ planning zone.

Projected responses to climate change

The climate changes that are projected to occur as a result of increased greenhouse gas emissions will drive physical and biological changes on the Earth's surface, and biome changes are certain to take place. New assemblages of species and an increasing dominance of pioneer species should be expected (Welch 2005), including within protected areas.

Changing climatic trends (e.g., increased temperatures, altered precipitation patterns, earlier snowmelt) and events (e.g., longer summer droughts) can be expected to have an impact on the vegetation types that are currently represented in the protected areas on the KIPZ planning zone. This region generally includes habitat types that are relatively warmer and moister than elsewhere in the Northern Region, so any climatic shifts that lead to drier conditions could have a significant effect on the plant communities in this zone. While more detailed analysis is needed to assess the role of changing climatic conditions, increased mortality of certain tree species in northern Idaho has already been observed (van Mantgem et al. 2009). Of particular concern will be the potential effects that may occur in specialized habitats (e.g., peatlands and other wetland types) and sites that are refugia for certain vegetation types (e.g., cool air drainages that support Thuja plicata [western red cedar] stands). For example, wetlands could potentially be directly affected by changes in runoff patterns, and altered temperature regimes may affect landscape-scale patterns of microsites and refugia.

Modeling of plant-climate relationships in the western United States also suggests the possibility of major changes in tree species distributions. In addition, the extent of montane forest in northern Idaho and northwest Montana is predicted to decline (Rehfeldt et al. 2006; see article and website for details). Such changes may dramatically affect the tree species composition in protected areas within KIPZ, and could hypothetically lead to the loss of species in some cases. Table 5 displays the vegetation types within proposed and established RNAs in the zone, and some species (e.g., Picea engelmannii) may decline in the region where these RNAs are located by 2090 (Rehfeldt et al. 2006).

Key sources of uncertainty

- Dispersal abilities of species under a rapidly changing climate, (Araujo et al. 2004). Even if protected habitats are available for species to migrate to, local extirpation or extinction may result if present habitat becomes unsuitable faster than new areas can be colonized (Peters and Darling 1985).
- Chance of increased fire in habitat types that historically have not been prone to large or severe fires.
- Inherent uncertainty in modeling the future ranges of species based on climate projections (Cole et al. 2008).
- Potential disaggregation of plant communities that are currently represented in protected areas (Peters and Darling 1985).
- Potential effects of temperature-driven drought stress and mortality in trees if annual precipitation declines and temperatures increase in the northern Rockies (as observed in the genera Abies and Pinus in the Sierra Nevada [van Mantgem and Stephenson 2007]).

Potential Adaptation Opportunities

As climate change continues to exert its influence on species and ecosystems, the importance of establishing and managing protected areas for long-term conservation will actually increase rather than decrease, for a number of reasons. Protected areas provide examples of the least disturbed natural habitats, and therefore the best hope for natural responses to changing climate (e.g., species' range shifts; Hannah and Salm 2005). Ecosystems with undiminished biodiversity may store more carbon and retain pools of carbon longer (Brown 2008), and conservation of forests is a critical tool in mitigating climate change (Ricketts et al. 2010). In addition, protected areas can be viewed not just as reserves for particular species or habitats, but as arenas for changing species diversity (Halpin 1997). As such, the following adaptation opportunities for special areas may be considered:

- Identification and establishment of new protected areas, and expansion of existing protected areas where needed. Protection of key ecosystem features, including structural characteristics, species, and areas that represent important "keystones" of overall ecosystems, is one of the seven adaptation approaches recommended by the U.S. Climate Change Science Program (SAP 4.4, 2008).
- In identifying future areas to add to the RNA / SIA and other protected area networks, selection of sites containing a greater diversity of topography and soils and including greater range of elevation will be more likely to continue to provide habitat for species of concern (Peters and Darling 1985; Peters 1992). Also, additions to the protected area network in KIPZ should be focused on the vegetation types and habitats that are not currently represented. A regional status assessment for RNAs indicated several such needed protection targets on both Forests in KIPZ (Table 6; Chadde et al. 1996). Use of downscaled climate projections may also provide a means for identifying key sites for future protection. All of these approaches could be used in the forest planning process to identify priority sites for conservation.
- Reduction of stresses from non-climate sources (e.g., invasive species, habitat fragmentation or alteration) will be important to maintaining as nearly as possible the integrity of protected areas (Hannah and Salm 2005).
- Monitoring of ecological conditions in protected areas (Parrish et al. 2003), to assess 1.) The status of the species and habitats protected therein, and 2.) The effects of climate change on species and communities over time. The potential utility of the RNA network on National

Forest System lands for detecting and monitoring the effects of climate change is extremely high. Of particular concern within KIPZ will be the current and future status of habitat refugia (e.g., western red cedar stands).

- Identify protected areas that warrant continual management intervention to maintain a historic or existing plant community (via the opportunities described below) and those that should remain "hands-off" (with no intervention), and clearly define the goals for each in the context of climate change. In the former case, significant investments may be needed to maintain a desired community in the face of climate change. In the latter case, the areas could serve as reference sites for understanding the effects of climate change, as discussed above with respect to monitoring.
- Stewardship management ("intervention") in established protected areas should remain an option. Such treatments would simultaneously provide research opportunities for understanding the effectiveness of management for mitigating the influences of climate change. Cole et al. (2008) suggest the following potential actions for mitigation and conservation in protected areas:
  - Restore disturbance regimes, such as fire or flooding, where they favor native species and maintain important ecological processes.
  - Restore extirpated species.
  - Prevent and mitigate threats, such as non-native invasive species.
  - Sustain "slow" variables, e.g., soil characteristics and regional species pools, to maintain ecosystem capacity to recover.
  - Conserve dominant and uncommon species; species or plant communities that are currently rare may become more important as conditions change.
  - Create conditions resistant and resilient to climate change and other stressors.
  - Consider assisted migration of species (although this is very controversial).
  - Weigh the possibility that passive degradation will occur if active management is not pursued.
- Focus management efforts in protected areas on local-scale corridors along natural environmental gradients (such as elevation, soils, or precipitation) and keystone habitats (such as riparian areas or peatlands) that provide critical resources (Olson et al. 2009).
- A review of adaptation approaches for agencies managing protected areas is provided by Scott and Lemieux (2005), and summarizes needed approaches for system planning and policy; management (including active, adaptive ecosystem management); research and monitoring; and capacity building and awareness. These approaches are continuously evolving, and additional opportunities should be evaluated in the future as they are developed.

Table 5. Summary of vegetation types and aquatic targets found in established and proposed RNAs in the KIPZ planning zone, (Chadde et al. 1996)

VEGETATION TYPES AND AQUATIC TARGETS	NATIONAL FOREST
Abies grandis/Clintonia uniflora	IPNF
Abies lasiocarpa/Clintonia uniflora	IPNF
Abies lasiocarpa/Luzula hitchcockii	IPNF
Abies lasiocarpa/Menziesia ferruginea	IPNF
Abies lasiocarpa/Xerophyllum tenax	IPNF

VEGETATION TYPES AND AQUATIC TARGETS	NATIONAL FOREST
Picea/Clintonia uniflora	KNF
Populus trichocarpa	IPNF, KNF
Pseudotsuga menziesii/Calamagrostis rubescens	KNF
Pseudotsuga menziesii/Physocarpus malvaceus	IPNF
Pseudotsuga menziesii/Vaccinium cespitosum	KNF
Thuja plicata/Athyrium filix-femina	IPNF
Thuja plicata/Clintonia uniflora	IPNF, KNF
Thuja plicata/Oplopanax horridum	IPNF, KNF
Tsuga heterophylla/Clintonia uniflora	IPNF, KNF
Tsuga mertensiana/Luzula hitchcockii	KNF
Tsuga mertensiana/Menziesia ferruginea	IPNF, KNF
Festuca viridula	IPNF
Aquatic features (streams, ponds, wetlands, fens, etc.)	IPNF, KNF

Table 6. Vegetation types recommended for addition to the RNA network in the KIPZ planning zone (Chadde et al. 1996)

VEGETATION TARGETS	NATIONAL FOREST
Betula glandulosa	IPNF
Eleocharis pauciflora	IPNF
Pseudotsuga menziesii/Festuca scabrella	KNF
Scirpus acutus	IPNF, KNF
Thuja plicata/Athyrium filix-femina	KNF
Thuja plicata/Equisetum	IPNF
Thuja plicata/Gymnocarpium dryopteris	KNF
Thuja plicata/Lysichiton americanum (tentative)	KNF
Tsuga heterophylla/Gymnocarpium dryopteris	KNF
Tsuga heterophylla/Xerophyllum tenax	IPNF
Tsuga mertensiana/Clintonia uniflora	IPNF

Chapter 13. Climate Related Social and Economic Trends

Continuing climate change has the potential to affect the counties and communities influenced by KIPZ management. Uncertainty regarding changes to climate amplifies the traditional uncertainty regarding future economic conditions. The social and economic values generated by the Forests may be impacted by climate induced changes to ecological systems. Impacts to ecological systems result in changes to recreation, forest products, restoration activities, lifestyles, and population. There are several categories of potential effects that merit discussion. In general there may be changes to the NFS lands that dominate the land base of KIPZ counties, which could lead to changes in the forest products industry, lifestyles, recreational use, and residential occupancy.

Some of the anticipated climatic changes may alter forest productivity and the geographic vegetation distribution due to changes in water availability (Milly et al 2005; Stewart et al 2004; Mote 2003), fire frequency (Westerling et al 2006) and the current relationship of native and non-native insects and diseases with forests (Williams et al. 2000). This could affect the health, succession trajectory, distribution, and mortality rates of local trees and have cascading effects on ecosystem services, as well as flows of economic goods and service from NFS lands. In general, Ryan et al (2007) found that forest productivity in the Interior West is expected to decrease in future decades. However, the projected volume of commercial forest products is not expected to stray significantly from levels projected in KIPZ Plans.

Under the influence of climate change, there may be future biomass energy markets that can take advantage of byproducts from forest management, supplementing government revenues from harvesting and concurrently attempting to address greenhouse gas emissions (Miles 2004). Future global and national concern about greenhouse emissions may exert pressure (via cap and trade markets or other mechanisms) to simultaneously reduce hazardous fuels surrounding communities and wildfire emissions in general by substituting renewable energy sources (brush, seedlings, saplings, small diameter material) from selected national forest system lands for fossil fuels (Miles 2004). At present however, beyond the limited market areas that several hog fuel boilers and a single chip- using firm in Montana, markets for small diameter material, tops, and branches are not viable. In addition, Libby, one of the largest towns in the KIPZ economic impact area has topography that traps particulate emissions, constraining future wood burning compatibility with healthy ambient air quality.

Since these lands currently provide some of the source materials for forest products harvesting and manufacturing, any of the changes described above could lead to some impacts on the local economies in the KIPZ planning zone. Included in these changes may be changes in the type, location, and seasonality of product harvest. Increased temperatures could continue to lead to drier forest conditions with increased risk of large fires (Westerling et al 2006). This may change fire season restrictions and safety-related closures. This may also simply shift the harvest season earlier in the calendar year as warmer spring temperatures and drier conditions (Cayan et al 2001) may mean roads are passable earlier most years. Winter logging over frozen ground or snow, designed to protect sensitive soils may not be a reliable design option in the future. In fact, rain on snow events that currently affect mostly low elevation areas may become more common at higher elevations (McCabe et al 2007). If this happens then road maintenance and logging operations may need to adapt with different best management practice designs to prevent negative water quality impacts.

The lifestyles of most residents in the KIPZ are tied in some way to national forests. Scenic enjoyment and recreational use are a common theme in the lives of most KIPZ residents. Residents value lifestyles associated with low density recreation and high quality outdoor experiences. Future climates may have substantial impacts on the foundation of these experiences. For example, trout fisheries that provide the majority of fishing attraction and economic activity rely on cold water for their survival. If lack of snow leads to insufficient flows and low oxygen levels exceed scientifically identified thresholds these opportunities may diminish (ISAB 2007). If wildlife habitat makes rapid transitions the big game populations may change hunting opportunities positively or negatively (Seasons End 2009). Similarly, although the impacts would vary based on how future temperatures unfold within the forecasted range, several ski areas operating under special use permits from the Forest Service may see shorter seasons and less use (Mote et al 2005). On the other hand, summer use seasons, such as hiking and backpacking, may be extended leading to greater visitation with warmer temperatures (Loomis and Richardson 2006), less snowpack and earlier snowmelt. Other forest product gathering such as firewood or mushroom collection could be enhanced under warmer wetter scenarios with increased tree mortality. Depending on each resident's suite of outdoor activities the future climate has the potential to improve or diminish quality of life. Regardless of these changes, one thing is likely, there will be continuing trends of increased population and increased visitation in the KIPZ if 1) sea levels rise and portions of the country insulated from sea level rise experience additional population growth (the current distribution of the US population, has roughly half of the nation's population living within 50 miles of a coastline (US Census 2000), and/or 2)increasing temperatures force people to move from other mountainous western US areas (e.g., Arizona and New Mexico) to cooler, more northern mountainous climates (e.g., Montana and northern Idaho). Either of these situations implies that many people would likely relocate to the Northern Rocky Mountains, including the KIPZ.

Another area of substantial concern is climatic driven changes to fire regimes in the KIPZ. Any continuing climatic changes that lead to warmer drier conditions have the potential to elevate wildfire threats to the growing number of wildland urban interface communities (Stein et al 2007). The ecological impacts of wildfires as well as forest pests and diseases are expected to rise, with extended periods of high fire risk and large increases in area burned (IPCC 2007b). Projected increases in area burned annually in the United States range from a 4 to 31 percent increase Bachelet et al 2003) to a doubling or tripling of annual area burned by 2080s (Littell et al. 2009). The frequency of years when this is a concern may increase. This could lead to shorter, more restricted, and less enjoyable summer recreation seasons, and consequent disruptions or losses in jobs and income associated summer recreation. Although the KIPZ has relatively few resort destination areas, some of the large lakes and wilderness areas emphasizing scenery could be negatively affected by more frequent smoke-reduced visibility.

Weather data for recent decades shows that the KIPZ climate has been warming. Clearly, some uncertainty exists about the magnitude of future climate change in the KIPZ. While there are several potential impacts to economic conditions associated mainly with forest products and recreation opportunities, the adaptive management mechanisms of the revised forest plans should help economies adapt and remain resilient to whatever climate change that does occur.

Chapter 14. Contributing Authors

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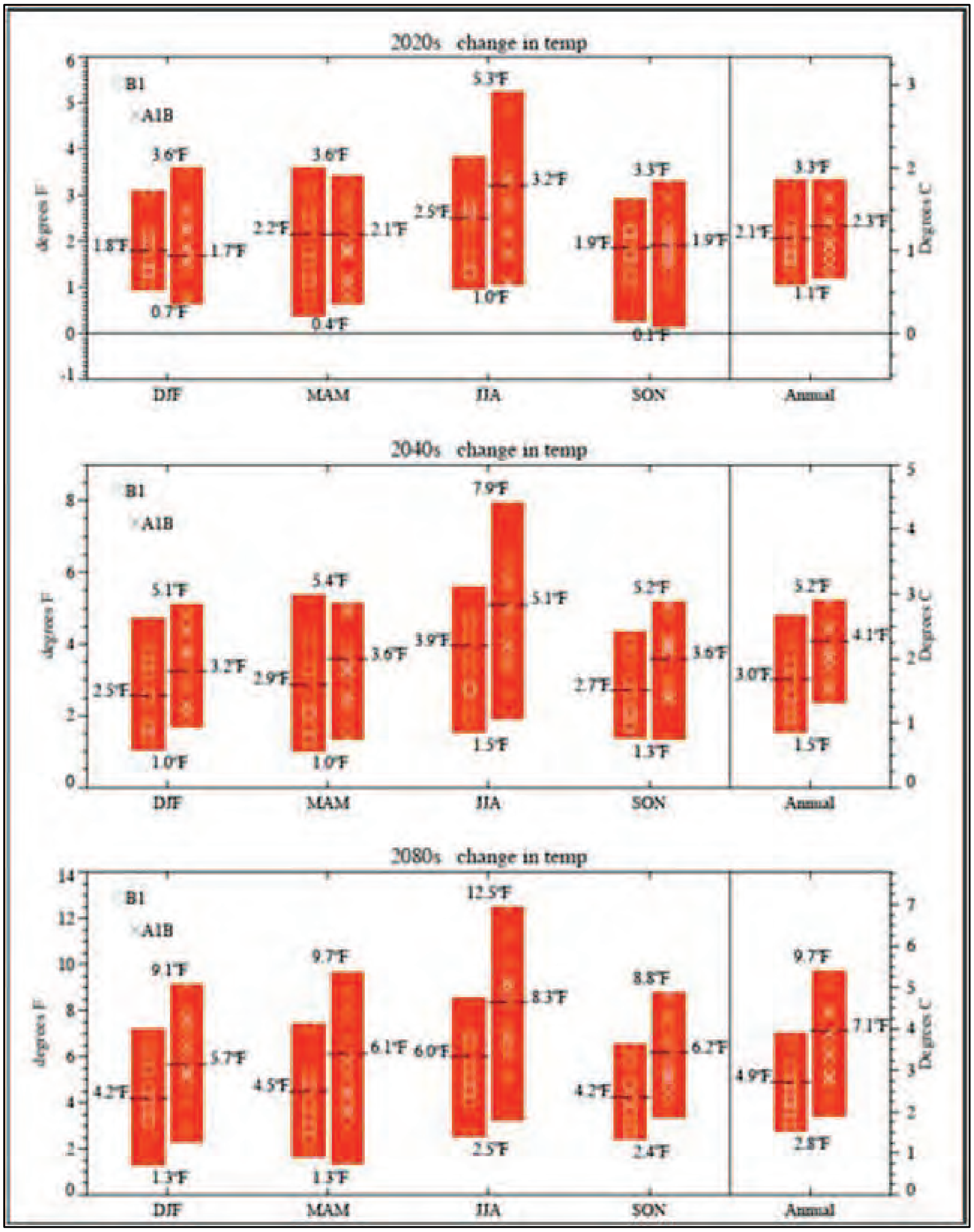
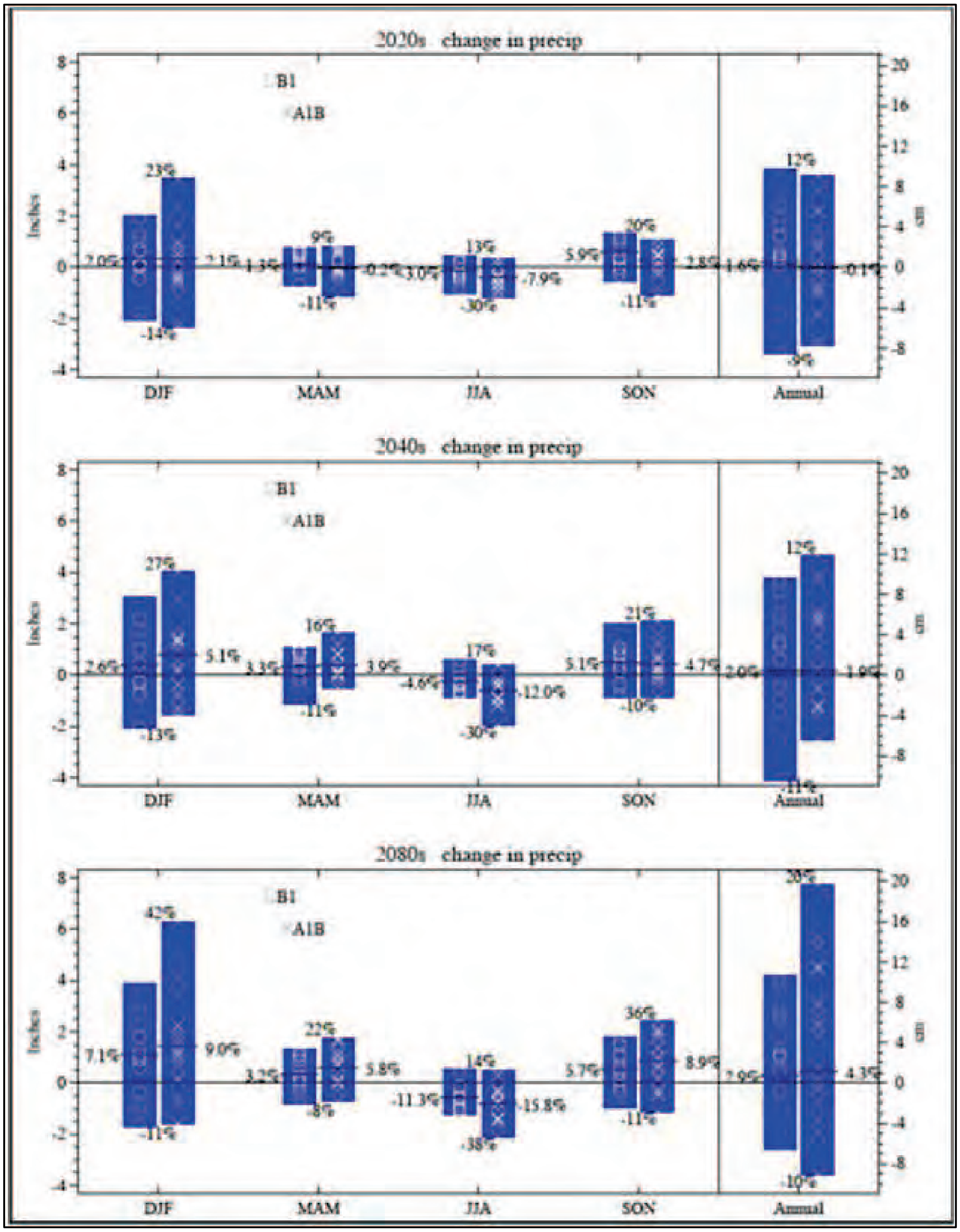
Jim Olivarez	Regional Invasive Species Coordinator
Steve Shelly	Regional Botanist
Bruce Sims	Regional Hydrologist
Catherine Stewart	Regional Fire Ecologist
Dr. Keith Stockmann	Regional Economist
Dr. Arthur Zack	

Appendix 1

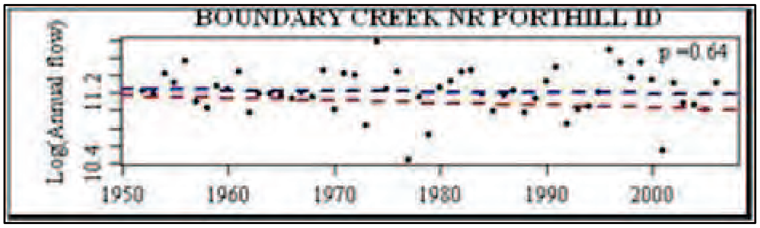


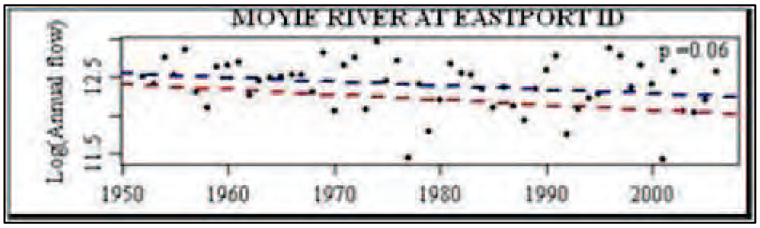
Range of projected changes in temperature for each season (DJF=winter, etc.) and for the annual mean, relative to the 1980s. In each pair of bars, the left one is for SRES scenario B1 and the right is AIB. The REA mean is shown as a horizontal line and the value printed. Circles and x's represent individual model values, and the highest and lowest change for each season and decade is printed. Source: Mote et al. 2008.

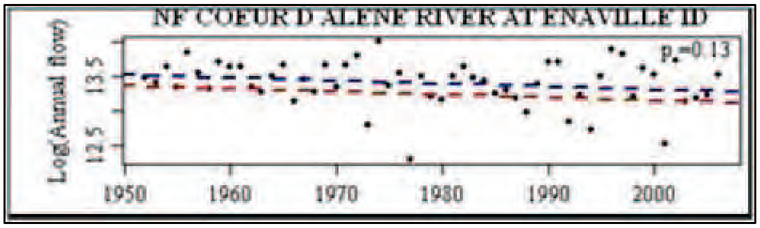


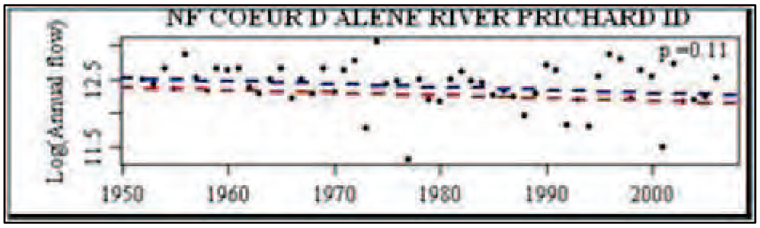
As above, but for precipitation, the height of the bars indicates the actual precipitation but the percentages are calculated with respect to a reference value for that season, so that -11 percent in JJA is much less than -11 percent in DJF. The reference values for the extremes are that model's 20th century mean for that season (or annual mean), and for the REA average the reference is the all-model 20th century value.

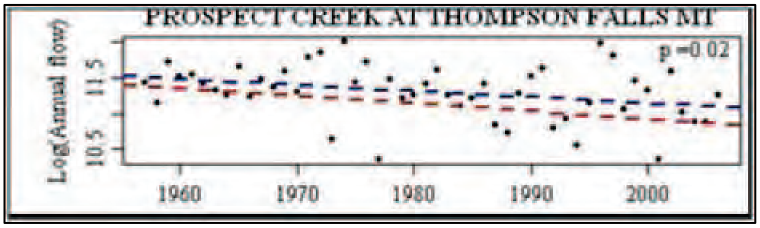
Appendix 2

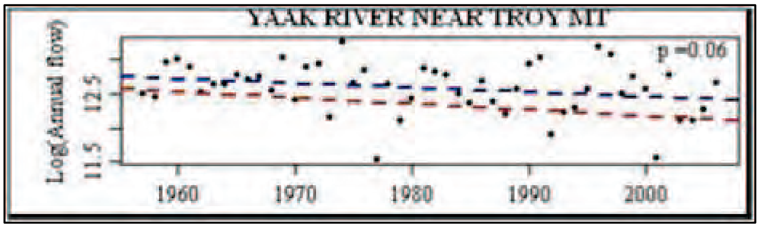

BOUNDARY CREEK NR PORTHILL ID
p =0.64
Log(Annual flow)
11.2
10.4
1950
1960
1970
1980
1990
2000


MOYIE RIVER AT EASTPORT ID
p =0.06
Log(Annual flow)
12.5
11.5
1950
1960
1970
1980
1990
2000

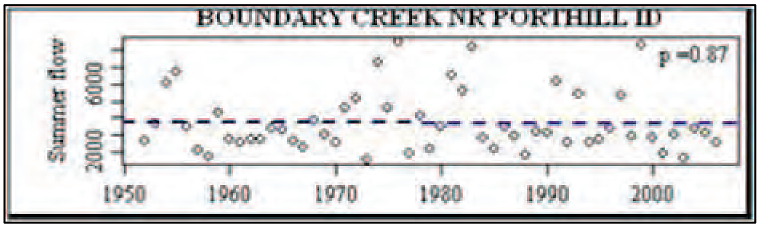

NF COEUR D ALENE RIVER AT ENAVILLE ID
p =0.13
Log(Annual flow)
13.5
12.5
1950
1960
1970
1980
1990
2000

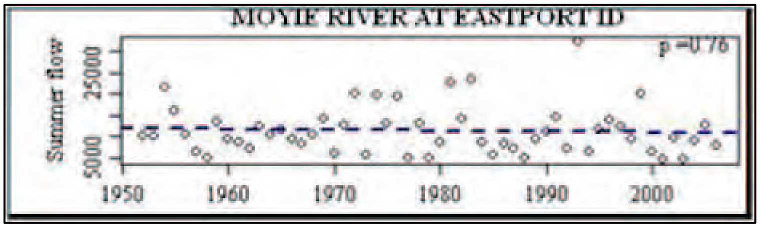

NF COEUR D ALENE RIVER PRICHARD ID
p =0.11
Log(Annual flow)
12.5
11.5
1950
1960
1970
1980
1990
2000

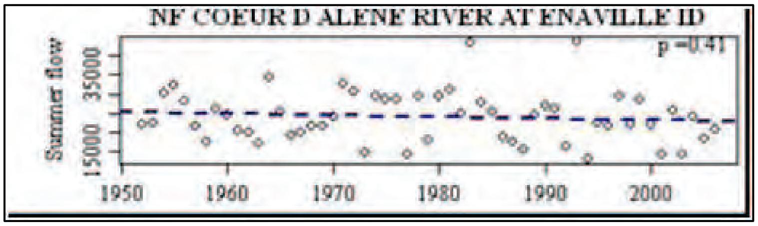

PROSPECT CREEK AT THOMPSON FALLS MT
p =0.02
Log(Annual flow)
11.5
10.5
1960
1970
1980
1990
2000

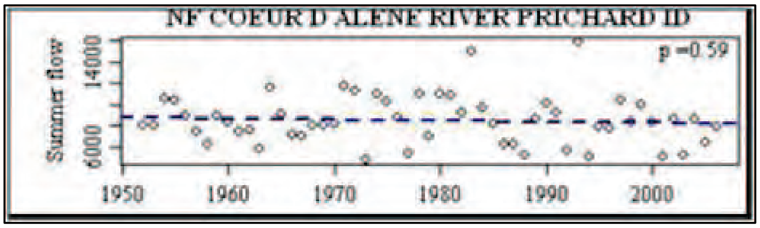

YAAK RIVER NEAR TROY MT
p =0.06
Log(Annual flow)
12.5
11.5
1960
1970
1980
1990
2000

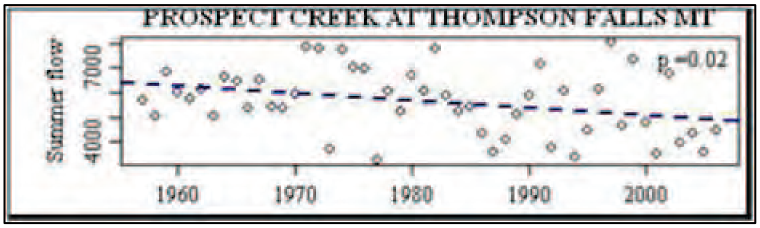
Mean annual flow (log transformed) for six Northern Idaho stream gauges (1951-2006). Blue line denotes trend in mean annual flow. Red line denotes trends in 25th percentile flow years (those years below the 25th percentile of all flow years for that station). P-values (upper right corner) indicate the statistical significance of trends in mean annual flow. Values less than 0.10 are considered statistically significant at the 90 percent confidence level. Three of six gauges show statistically significant declines in flow during this time period.

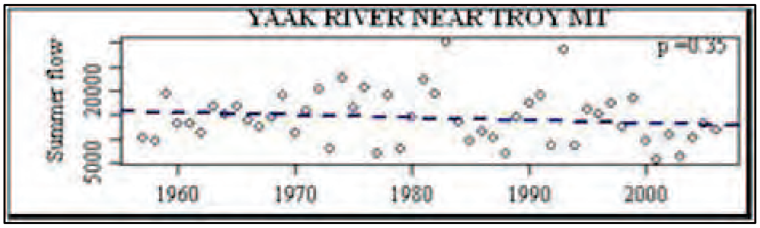












Trends in summertime (July15th-September 15th) flow for 6 Northern Idaho and Western Montana stream gauges (1951-2006). Blue line denotes trend line in mean summertime flow during this time period. P-values (upper right corner) indicate the statistical significance of trends in mean annual flow. Values less than 0.10 are considered statistically significant at the 90 percent confidence level. Only one gauge shows statistically significant trends in summertime flow.

Appendix 5

Comparative summary of the mid-21st century results from statistical species distribution models produced by two modeling groups. This summary is based upon an examination of maps of projected “core habitat” and “range” from the Natural Resource Canada modeling group (NRCan) and maps of projected “likelihood index” values from the U.S. Forest Service Rocky Mountain Research Station (RMRS) modeling groups.

Species	Agreement Score	Modeling Group	Simulation Results
Western Larch	Agree	NRCan	All simulations show a reduction in the distribution of suitable habitat in the U.S. Northern Rockies. The NCAR simulations (both A2 and B2) show the least reduction. The HadCM3 simulations both project the near elimination of suitable habitat in north Idaho and western Montana.
		RMRS	All models show a slight to moderate decline in the “likelihood index” throughout Idaho and Montana. The CGCM3 simulations (both A2 and B1) project the elimination of suitable habitat for a substantial percentage of north Idaho.
Whitebark pine	Agree	NRCan	All simulations project a substantial decrease in suitable habitat. Limited amounts of core habitat remain only in Colorado, the Greater Yellowstone area, and the Uinta Mountains of Utah. The CGCM-b2 and both NCAR simulations project a reduced amount of “core habitat” along the Continental Divide in Montana.
		RMRS	All simulations project widespread and substantial declines. Nearly all simulations project no or very low likelihood of occurrence in the U.S. Rockies, except the highest elevations of the Greater Yellowstone area, Colorado, and the Uintas.
Ponderosa pine	Disagree	NRCan	Most simulations project modest reductions in core range in much of the western U.S. The amount of reduction in Idaho and Montana varies considerably among GCMs. The HadCM3 model projects more than a 50 percent reduction in core habitat in Montana and Idaho, while the CGCM2 and NCAR simulations show only slight reductions.
		RMRS	Projections are vary considerably among models in a spatially complex pattern. Most models project increased likelihood of occurrence in mountainous area of Nevada, Utah, Colorado, and Wyoming, including areas outside the current range. In the Northern Rockies, model results are quite variable. Some models project an increased likelihood of occurrence in central and southern Idaho and southwest Montana. Most models show a substantially reduced likelihood in northern Idaho and western Montana.
Douglas-fir	Disagree	NRCan	All models show moderate to substantial reductions in core habitat in the Northern Rockies. Both HadCM2 projections project the near elimination of habitat in northern Idaho and much of western Montana. Most models project a slight increase in core habitat in the Greater Yellowstone area.
		RMRS	Most models project little change in likelihood of occurrence in U.S. Northern Rockies including northern Idaho and western Montana. The exception is the HadCM3 A2 and B1 simulations, which show moderate reductions in these areas. Most models project increased likelihood in the Greater Yellowstone area.
Lodgepole	Strongly	NRCan	All models project moderate to substantial reductions throughout the U.S. Northern Rockies. Core habitat is available in all models

Species	Agreement Score	Modeling Group	Simulation Results
pine	disagree		only in portions of the Greater Yellowstone area
		RMRS	All models project moderate to substantial reductions in likelihood of occurrence in the U.S. Northern Rockies, with the least reduction in high elevation areas.
Western Red Cedar	Strongly disagree	NRCan	All models show moderate reductions in occurrence of core habitat in the Pacific Northwest and Northern Rockies. Models consistently project substantial reductions in northern Idaho and western Montana.
		RMRS	All models project substantial increase in likelihood of occurrence within current range in northern Idaho and western Montana, and an increase in the extent of suitable habitat in Blue Mountains of Oregon, central Idaho and western Montana.
Western hemlock	Strongly disagree	NRCan	All models project a substantial reduction in core habitat in the U.S. Northern Rockies, and its near elimination in Idaho. Most models retain a sliver of core habitat along the Northern Continental Divide in Montana, and the emergence of core habitat in northern portions of the Greater Yellowstone area.
		RMRS	All models show an increased area of suitable habitat in north Idaho and along the Northern Continental Divide in Montana. Most models suggest the emergence of suitable habitat in southern portion of the central Idaho mountains, the Blue Mountains of Oregon, and northern portions of the Greater Yellowstone area.
Subalpine fir	Agree	NRCan	All models project a substantial reduction in the distribution of climatically suitable ABLA habitat in U.S. Northern Rockies. The HadCM3-A2 and B1 simulations project near total elimination of suitable habitat in Idaho and Montana.
		RMRS	All models simulate substantial reductions in climatically suitable ABLA habitat, although not quite to the extent as the NRCan models. All RMRS models project that mid-century ABLA habitat is limited to highest elevation areas of U.S. Northern Rockies.
Engelmann spruce	Disagree	NRCan	All models project a moderate to substantial increase in distribution of climatically suitable PIEN habitat in western U.S., including Northern Rockies. The exception is northern Idaho, where most models project a decrease in suitable habitat.
		RMRS	All models project a moderate decrease in distribution of climatically suitable PIEN habitat in U.S. Northern Rockies. RMRS models agree with NRCan model projections of substantial decrease of suitable habitat in northern Idaho.

Appendix Science Review Draft Comment-Response Document

Chapter 1 Introduction				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
1	General comment		Adaptation options would be better discussed in the Introduction [rather than Chapter 2].	Subsection of chapter 2 titled "General Adaptation Options" is moved to the end of Chapter 1, Introduction.
1	1	12	And the vulnerability of host trees to insects, yes?	Text changed: "...forest insect population growth and vulnerability of host trees,…"
1	2	18	Not that it matters too much in an agency context, but "institution" and "institutional" have very different meanings in the adaptation literature than the way this is used. As long as you don't branch out later to a discussion of "institutional capacity" and "institutional barriers," this usage is fine. Otherwise, why not say, "other agencies, institutes, and universities is expected....	Text changed: "...by the Forest Service, other agencies and universities…."
1	3	2	This statement seems to gloss over the potential for there to be conflicts between adaptation and mitigation - it will be interesting to see if this is mentioned later.	Interesting point. No changes made
1	3	13	Is this process currently free to operate, and is the loop between science, decision making, outcomes, and revisiting the decision frequently closed?	Text changed: "...can be adjusted through forest plan amendments."

Chapter 2 Observed and Projected Climate Trends				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
2	General comment		I've reviewed Chapter 2 "Observed and projected Climate Trends." It is well-written, well-organized and answers the questions posed in the introduction. I thought it did an excellent job of summarizing and relating climate change information and set the stage for examining impacts to the PNW and Kootenai and Idaho Panhandle National Forests. I particularly liked the fact that there was a good blend of referenced material (e.g., not all from IPCC) and that global and national scales set the context for the local scale.	
2	General comment		I was impressed with the thoroughness of this chapter as well as the fact that recent scientific articles were used in the chapter to augment the IPCC Report from 2007. The authors have done a very good job of consolidating a lot of information into a few pages of dense, but easy-to-read text. The graphs and tables are well-suited to supporting the information in the text.	
2	General comment		I fell the chapter does adequately characterize the major scientific uncertainty associated with climate projections. However, as I mention further in response to question 3, I feel there needs to be a more thorough discussion of the type of precipitation and the impacts of a possible switch from snow-dominated to a rain-dominated hydrology. I refer them to Barnett et al., 2008, Science, and Stewart et al., 2005, Journal of Climate for data to support the need for a discussion of such impacts.	Text changed as suggested with recommended citations.
2	General comment		I felt that this part of the chapter [acknowledgement, disclosure, and description of uncertainty in the scientific information] was very complete, both because uncertainties were included in the predictions and a thorough discussion of possible projection uncertainties was provided. In addition, there was a very good discussion of how the CIG attempted to reduce uncertainty in model results.	

Chapter 2 Observed and Projected Climate Trends				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
2	General comment		In covering the Observed Climate Trends, there were references to time periods that were not clear. Particularly on page 2, paragraph 2: “over the last 100 years,” “from 1976 to present,” and “the last decade” could be interpreted differently by readers, particularly as the report ages. I would be more specific (e.g., from 1976-2007 or during 2000-2008, correcting for the dates)	Chapter 2 has been edited to provide specific start and end dates for reported trends.
2	General comment		Didn't go over lit cited in great detail but noticed that Field et al. 2008 is also cited as NRC 2008	Text Changed: Citation to NRC 2008 is changed to Field et al., 2008
2	General comment		Summary - Great job on this succinct description of climate change science and our current state of knowledge.	
2	1	14	But not van Mantgem et al. 2009?	No change made. The article by van Mantgem et al. (2009) is discussed in the chapter on forest productivity and carbon.
2	1	16	Dave Peterson maintains that there has been no increase in area burned in the PNW.	Text changed: “…an increase in the number of large wildfires in the western U.S. from 1950 to 2007 (Gillet et al. 2004; Westerling et al., 2007; Littell et al. 2009),”
2	1	16	2006?	Text changed: “Westerling et al. 2006”
2	2	22	Citation? Or link to Julius et al. sentence that comes after. But even Julius didn’t actually do this research, correct? This statement needs a primary literature anchor. In SAP 4.4, the citation for these changes (Fig 2.2) is: U.S. Environmental Protection Agency, 2007: Proposed Indicators for the U.S. EPA’s Report on the Environment (External Peer Review). U.S. Environmental Protection Agency.	Text change: citation changed to USEPA 2008 (final ROE)
2	3	1	Citation?	Text change: Deleted sentence “The last decade was the warmest in more than a century of instrumental observations.”
2	3	4	Is that Janetos 2008, or?	Text change: added citation to Karl et al. 2009.
2	3	7	Citation?	Text change: added citation to Gray et al. 2008.

Chapter 2 Observed and Projected Climate Trends				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
2	3	13	On page 3, I would define "heavy precipitation". Also, there is little reference to the type of precipitation (e.g., page 4). It is important to discuss changes from snow to rain (even if we haven't seen large shifts yet, although we may have) as these changes, expected in the relatively near future, could have dramatic impacts on the proposed adaptations.	Text change: "The U.S. has had a statistically significant increase in heavy precipitation (defined generally as the upper 10% of all daily precipitation amounts), primarily during the last three decades of the 20th century and over the eastern portions of the country (Karl and Knight 1998; Groisman et al. 2005; CCSP 2008)." Text change: added "Analyses of weather station records from 1949 to 2005 reveal that the proportion of winter (November-March) precipitation in the form of snow compared to rainfall has decreased nationwide and in the western U.S. where 75 percent of weather stations experienced snowfall reductions (Knowles et al. 2006; Feng and Hu 2007)."
2	3	13	Figure shows regional differences, but no temporal variation. It is important to note that SEASONAL changes can mean much more than ANNUAL changes for vegetation – need to see if this is in a discussion below as a source of uncertainty.	No change in text. Trends in seasonal temperature and precipitation are discussed in the following subsection titled "The Pacific Northwest, northern Idaho, and northwestern Montana."
2	3	18	What's the end-date of this analysis, and what is the citation. The paper that show this is Mote 2003, but that analysis is somewhat dated. That too should be in an uncertainty discussion.	Text change: "During the period 1920 to 2000, annual mean temperatures in the Pacific Northwest warmed about 1.5°F, more than the global average (Mote 2003). " Later sentences in this paragraph include citations to more recent publications from Hamlet and Lettenmaier (2007) and Pederson et al. (2010).
2	3	19	Perhaps consistent would be a better word…..	Text change: "The warming has been generally consistent and widespread throughout the region (Figure 2.4)."
2	3	21	Citation?	Text change: added citations to Hamlet and Lettenmaier 2007 and Pederson et al. 2010.
2	4	5	Figure 2.5 says nothing about decadal variability. You would need a time series graph or some comparison bar charts to say that in a figure.	Text change: Annual precipitation in the Pacific Northwest increased 14% for the period 1930 to 1995, with considerable year-to-year variability (Mote 2003; Halmet and Lettenmaier 2007) (Figure 2.5). However, these trends are not statistically significant and depend on the time frame analyzed.

Chapter 2 Observed and Projected Climate Trends				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
2	5	3	first sentence is awkward. Almost reads as if 'trends' is supposed to be 'terms'. Also, a statement that variability in general (not just more frequent extremes) will increase might be useful in the first paragraph. The last sentence (The number of frost days....) should be reworded so it doesn't imply that there are 4 less days per year x 50 years = 200 fewer frost days per year by 1999.	Text change to first sentence: "The information presented above describes trends in average climatic conditions. " Text change to last sentence: "Averaged over the entire U.S., the number of frost days (daily minimum temperature less than 32˚F) decreased by 0.8 days per year during the period 1948-1999, with decreases of 2.6 days per decade occurring in the Pacific Northwest (Easterling 2002). "
2	6	2	FYI, we have a paper in press at Climatic Change that shows extreme heat days are more frequent and have doubled in the span of summer months during which they can occur for the northern Rockies in Montana.	References to Pederson et al. 2010 have been added to appropriate locations along with additional text related to content of Pederson et al. 2010. Text change: deleted sentence "We are aware of no recently published studies of observed trends in extreme climate events specific to the Pacific Northwest or Northern Rockies."
2	6	2	Two parts of CIG's recent WA assessment look at this obliquely in terms of flooding and runoff: http://cses.washington.edu/db/pdf/wacciach6salmon649.pdf http://cses.washington.edu/db/pdf/wacciach9storminfra652.pdf	References to Pederson et al. 2010 have been added to appropriate locations along with additional text related to content of Pederson et al. 2010. Text change: deleted sentence "We are aware of no recently published studies of observed trends in extreme climate events specific to the Pacific Northwest or Northern Rockies."
2	6	14-15	Should there be a different version of this sentence for climate change, climate variability, and climate? IRI predicts ENSO variation 3-6 months in advance with some success. The error associated with ten years of climate prediction is likely to be smaller than the error associated with tend days of weather prediction, right?	No change to text.
2	6	18	It should be "World Meteorological Association".	Text change: "World Meteorological Association"
2	7	18	Modeling, not models, is a method. The models themselves aren't methods, are they? Models are tools.	Text change: "principal tool"
2	8	2	Could cite SRES here.	Citation added to text and references
2	8	4	line 4, missing "a" between "to" and "set"	Text change: added "a"
2	8	5	You mean PCMDI?	Text change: added citation to Meehl et al. 2007.

Chapter 2 Observed and Projected Climate Trends				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
2	9	20	Of the U.S. – otherwise this suggests a weirdly skewed distribution of global temps.	Text change: “areas of the continent.”
2	11	5-8	first paragraph under "Key Sources of Uncertainties" - make clear that the performance improvement is that we can better reproduce what we've already experienced (20th century observations), therefore we trust the models' future projections more. This is mentioned later but should be here because it is a sensitive point.	Text change: added “including the ability to simulate observed historical climate.”
2	12	7	2nd paragraph, 3rd line - extra "ly" on "moderately"	Text changed to delete “ly”
2	12	7	This is a difficult descriptor – A1B is initially higher than ALL scenarios out to about 2015, then it is less than A2 and A1Fi at about 2020, and eventually less than B2 by the 2090s. It is fair to say it is moderate between 2020 and 2080.	No change
2	12	10-11	Which is not very far off for decisions that have impacts measured in decades to centuries. This statement downplays the difference, and plays into the hands of those who cite Solomon’s paper and say our choices don’t matter. They may or may not, but this treats it a little lightly.	Text change: “However, these differences among model projections are not significant until the second half of the 21st century.”
2	12	18	There should be a better explanation here – I think you mean about climate modeling in the GCM future, but this is imprecise as written. ENSO prediction is currently in terciles (33%, 66%) for months in advance and is not perfect but not too bad either.	Text change: “Although there have been recent advances, the response of some aspects of natural variability, such as the El Niño Southern Oscillation, to increased greenhouse gases remain highly uncertain and therefore add uncertainty to multi-decadal GCMs simulations (Vecchi and Wittenberg 2010). “
2	12	22	last line, extra "by" in sentence	Text corrected
2	13	6	And interation between land surface processes and climate on greenhouse gasses?	No change to text
2	Figures 2.2 and 2.3		These are AVERAGED over the period, no annual anomalies – that would require a time series.	Legends for both figures changed: “Change in annual average….”

Chapter 3 Watershed Hydrology				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
3	General comment		I've reviewed the Watershed Hydrology chapter of your document and found it to be clearly organized, well-written, and consistent with current research findings. It has appropriate caveats and makes clear the limits of our understanding of mountain watershed responses to climate change.	Thanks.
3	General comment		Strong synthesis – probably the best chapter.	
3	General comment		An excellent chapter that captures the relevant information for the national forests and is thorough and well-balanced in its assessment.	
3	General comment		The emphasis on snowpack, snowmelt and runoff timing, and late summer flows makes sense because of the degree to which the Idaho Panhandle and Kootenai National Forests are snow-dominated. One suggestion would be to add a paragraph or two mentioning the indirect ways in which climate change can influence snow accumulation and ablation and late summer flows. For instance, April 1 SWE can be directly influenced by increased temperatures melting the snowpack but also forest canopy interception and sublimation of snow are enhanced by vapor pressure deficit shifts and can influence snow accumulation. Evapotranspiration will increase if trees start growing a month earlier and the growing season is lengthened, resulting in lower summer flows. Both these less direct impacts of climate change to snowpack runoff will be greatly impacted by climate change increases in forest fire frequency and severity. Mentioning these early in the document provides the context of landscape-climate interactions for the reader as they go through the information on snowpack-climate relationships.	No change to text.
3	1	3	extra period before Serreze citation	Text change: period deleted

Chapter 3 Watershed Hydrology				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
3	2	1	first sentence in "Snowpack trends". Perhaps add that April 1 SWE declined despite increases in average annual precipitation to make clear that it isn't due to lack of moisture. Page 4 mentions that temperature increase is the cause (Mote et al. 2006)	No change made to text. Research on the contributions of temperature and precipitation to the observed declines in April 1 SWE vary geographically (Compare e.g., Mote et al. 2006 with Moore et al. 2007). This suggests to the authors it would be appropriate to avoid geographically broad generalizations about the relative influence of temperature and precipitation on observed trends in April 1 SWE.
3	2	2	Define. What is and is not a snow dominated watershed? At what fraction (50.001%? 60%) of annual precipitation = snow is a watershed "snow dominated"?	Text change: "…snow-dominated watersheds, where more than 50 percent of the annual precipitation is snow."
3	3	3	But not Stewart et al. 2005?	No change to text. Stweart et al. 2005 and other studies are cited subsequently in the paragraph for more specific findings.
3	3	10	I think you need to substitute "decreasing trends" with earlier trends"	Text change: "…trends of earlier spring snowmelt were greatest at low and mid-elevation sites…"
3	3	11	I count four studies. This value of 8000 ft is conserved across all three/four regions? Seems that elevation is a meaningless comparison between the PNW and the Sierra given the different climatic and hydrologic regimes – the point is physical with respect to the interaction of temperature and precipitation, not elevation per se, which is a surrogate for those.	Text change: delted parenthetical "(over 8000 feet)". Reworded sentence to: "All three of these studies found that trends of earlier spring snowmelt were greatest at low and mid-elevation sites while generally high-elevation sites where temperatures generally remain sufficiently cold longer into the spring to limit snowmelt show little change." Lettenmaier et al. 2008 is a general synthesis and not a study presenting results of unique analysis. Thus, there are only three "studies" cited.
3	3	21	Remove "declining"	Text change: deleted "declining".
3	4	5	Also see these: Mote, P.W., A.F. Hamlet, and E.P. Salathé. 2008. Has spring snowpack declined in the Washington Cascades? Hydrology and Earth System Sciences 12: 193-206. Casola, J.H., L. Cuo, B. Livneh, D.P. Lettenmaier, M. Stoelinga, P.W. Mote, and J.M. Wallace. 2009. Assessing the impacts of global warming on snowpack in the Washington Cascades. Journal of	Citations added to the text and literature cited.

Chapter 3 Watershed Hydrology				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
			Climate doi: 10.1175/2008JCLI2612.1	
3	5	1	Misspelled Data	Corrected spelling
3	5	5	Interesting. Didn't chapter 2 find an increase of 44% precipitation in summer for the IPNF/KNF area? That should be going somewhere…..runoff should be increasing, storage should be increasing, or AET should be increasing. Maybe that's the reason that summer flows aren't declining as much as might be expected.	No change to text.
3	5	9-21	This is very cautious language for something that has a reasonably good literature behind it. Wouldn't 50-60 years of data suggest something useful given that there are obvious and published ENSO and PDO influences in the data and trends that are superimposed on top of that that the best available science concludes is likely warming related (e.g., below)? This sub-regional analysis either needs to be stated more explicitly with a documentation of the claimed uncertainty given all the analyses cited above	No change to text. The following paragraph summarizes additional information from detection and attribution studies that attempt to quantify the relative influence of natural variability and atmospheric concentrations of GHGs on snowpack and runoff timing.
3	7	2	In the near term – that's not necessarily true many decades out, at least not true enough to use the word "prevent" which is strong.	Text change: deleted sentence "At higher elevations, temperatures may remain sufficiently low to prevent much change."
3	8	19	Remove "the for", sentence seems a little awkward.	Text change: Deleted "the for"
3	8	11	Implications of 21st century climate change for the hydrology of Washington State. McGuire Elsner, M., L. Cuo, N. Voisin, J. Deems, A.F. Hamlet, J. Vano, K.E.B. Mickelson, S.Y. Lee, and D.P. Lettenmaier. (In press). Implications of 21st century climate change for the hydrology of Washington State. Chapter 3.1 in The Washington	Discussion summarizing findings of Elsner et al. 2010 are added toward the end of this section on "Projected Trends Related to Climate Change."

Chapter 3 Watershed Hydrology				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
			Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, Washington. http://cses.washington.edu/db/pdf/wacciach3hydrology644.pdf	
3	10	4	All the same model, or different models in each instance? See Elsner et al. 2009 (above) for similar results in an ensemble of 20 models and 2 SRES scenarios. That publication has been peer reviewed.	Text change: added parenthetical description of the GCM used in Rauscher et al. 2008. The original text noted that Payne et al. (2004) and Leung et al. (2004) used the same GCM and emissions scenario (PCM/BAU). A summary of results from Elsner et al. 2010 has been added to the text.
3	10	10-13	http://cses.washington.edu/db/pdf/wacciach3hydrology644.pdf	Text change: deleted the following sentences summarizing studies of California and and the Colorado Basin: “Consequently, their projections are of limited use for local-scale land management applications, and should be applied with awareness of the uncertainty inherent in these projections. More recent studies have used an ensemble of GCMs driven by two or more emissions scenarios (Christensen and Lettenmaier 2007; Maurer et al. 2007). These studies address projected hydrologic changes in California river basins and the Colorado River basin. At present, we are not aware of any studies of projected hydrologic changes in the Pacific Northwest or Northern Rockies based on downscaling of multiple GCMs driven by two or more emissions scenarios. “ Added the flowing text: “A very recent study by Elsner et al. (2010), used an ensemble of 20 GCMs driven by two emissions scenarios (B1 and A1B) to evaluate projected changes in snow water equivalent (SWE), soil moisture, runoff, and streamflow over the State of Washington and the Columbia River Basin. Their analysis concluded that April 1 SWE is projected to decrease by 28 to 30% across the State of Washington by the 2020s, 38 to 46% by the 2040s and 56 to 70% by the 2080s. The largest decreases occur in areas below 3,280 feet elevation, with declines of 38 to 40% by the 2020s to 68 to 80% by the 2080s. In mid-elevation areas (3,280ft-6,559ft), April 1 SWE is projected to decrease 25-27% by the 2020s, 35-43% by the 2040s, and 53-

Chapter 3 Watershed Hydrology				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
				67% by the 2080s. Projected decreases in April 1 SWE are less in higher elevation areas. Elsner et al. (2010) also conclude that under most scenarios annual runoff annual runoff is projected to increase from 2.1 to 6.2% in the State of Washington through the 21st century. Their simulations of changes in monthly streamflow hydrographs project that snow-dominant watersheds are likely to have reduced peak flow in the late spring and early summer and increased cool season flow compared to historical observations. Transient rain-snow watersheds are projected to shift to a streamflow pattern characteristic of rain-dominant watersheds, with significantly increased winter streamflows, and substantially reduced peak flow in the late spring and early summer.
3	10	21	by how much?	Text change: paragraph deleted.
3	11	11	Citation? Invasives can grow pretty fast in a post-fire setting even with drought.	No change in text. Statement is based on professional experience.
3	11	12	Take “s” off “results”	Correction made
3	11	18	Higher relative to what?	Text change: deleted clause “the higher level sources of.” Sentence now reads: “In addition to the uncertainty associated with future greenhouse gas emissions, global climate model simulations, and downscaling methods,… .”
3	11	21	At the very least, the author should close the list of bulleted sources of uncertainty with a statement about the net magnitude of this uncertainty, how it relates to observed variability in the 20th century,	No change made to text.
3	12	1	That’s in addition to the GCM simulation uncertainty in the sentence prior?	Yes. The sentence prior mentions general sources of uncertainty in climate projections. This sentence highlights the specific source of uncertainty regarding GCM simulations of precipitation.
3	12	4-5	Again, this is a critique of the models, which was already dealt with above. The question here is supposed to be about additional uncertainty that is intrinsically hydrologic – this uncertainty you are describing is about the direct influence of topography on temperature and precipitation even though you say it is on hydrology. Most GCMs and RCMs don’t	Hydrologic models used to evaluate projected climate change effects are often driven by climate projections derived from GCMs and RCMs. Therefore, it is important for consumers of this information to understand how uncertainties in climate projections may influence estimates of hydrologic effects.

Chapter 3 Watershed Hydrology				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
			project hydrology – that's for hydrologic models to do. Clarification is required.	
3	12	4-5	Water sheds at what scale? HUC 6? The Columbia is a watershed, so is the Amazon, but then so is Boundary Creek. Be specific with respect to scale.	See response to next comment below.
3	12	4-5	To what end? Maybe better way to state how this influences uncertainty is to say something like, "The resolution of most climate models is too coarse to account for local topographic influences on the hydrologic processes of small to medium sized watersheds. This increases the uncertainty associated with applying global model projections to local decisions."	Text change: Sentence rewritten to: "The resolution of most climate models is too coarse to account for local topographic influences on the hydrologic processes of small to medium sized watersheds (e.g., 6th and 5th hydrologic unit codes). This increases the uncertainty associated with applying global model projections to local decisions. "
3	12	15-16	Not entirely, though they are uncertain. Collins et al. 2005, Climate Dynamics, 24, 89-104.	Text change: The effects of climate change on major patterns of inter-annual and inter-decadal variability (e.g., ENSO and PDO) are uncertain.
3	13	1-4	By whose estimation? It seems there are a number of publications out there that claim to have done just this?	Text change to add citations to Lettenmaier et al. 2008 (see especially pages 146-150). Lettenmaier et al. at page 150 states; "Essentially no aspect of the current hydrologic observing system was designed specifically for purposes of detecting climate change or its effects on water resources.… As a result, many of the data are fragmented, poorly integrated, and in many cases unable to meet the predictive challenges of a rapidly changing climate." See also Elsner et al. page 15.
3	13	1-4	So what's a decision maker to do? The list of a half dozen or so bulleted sources of uncertainty brings up several issues of note and could rationally be used to infer that some stop gap research needs are obvious. However, the subtext or implication of these as it stands is that the projections have little value. Why would a manager consider the adaptation options below (which are good) if the projections are so	Text change: added new last paragraph to section titled Key Sources of Uncertainty: "Although there are uncertainties associated with projections of potential hydrologic impacts of climate change particularly at finer spatial scales, this does not imply that the potential impacts are unknown or that recent studies are not useful to decision making. The numerous studies reviewed are generally consistent in their projections of some fundamental hydrologic changes. From these studies it appears

Chapter 3 Watershed Hydrology				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
			uncertain as to be useless? Also, FOUR of the sources are intrinsically climatic, and point to sources of potential error in hydrologic estimation that come from CLIMATE. The other two are intrinsically hydrologic, and appear to point out flaws in hydrologic modeling. The real question, as it was stated prior to the bullets, however, is, “What are the sources of uncertainty?” Wouldn’t it be better to clearly state the impacts of each source of uncertainty on hydrologic parameters so that the magnitude of the uncertainty can be constrained? Perhaps a table illustrating these values would be useful. As it stands, this series of sources of uncertainty appears to be suggesting that hydrologic projections are foolish because there is so much uncertainty. In reality, (1) ensembles of models tell us several things about the nature of the climate system that are quite likely and things that are not so likely, (2) the effects of PDO and ENSO are statistically describable, (3) the influence of topography is quantifiable within a first approximation, (4) regional climate models are evolving and already provide useful understanding about things like snow albedo feedback as stated earlier, (5) networks of observations exist and become parts of analyses published in peer reviewed literature, so THAT is the best available science. It would appear from this approach that until there is perfect information, the uncertainty is too high to make a decision. Doesn’t the literature point another direction, namely that the way forward is clear scientifically and that the decision context depends on the cost, exposure, and risk involved?	likely that projected changes in climate in the Northern Rockies and Pacific Northwest will result in reduced mountain snowpack, earlier spring peak runoff, reduced summer and fall streamflows, and higher winter streamflows. The potential hydrologic effects of climate change add substantial risks to numerous environmental assets, particularly when combined with other stressors on watershed processes (e.g., wildfire impacts, changes in land use, and increasing consumptive demands). Adaptation actions can reduce these risks.
3	13 14	17-22 1-17	Should this be bulleted and indented for clarity?	Text change: bulleted and indented for clarity.

Chapter 3 Watershed Hydrology				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
3	13	21-22	The reasons for introducing beaver should be self-evident but might be amplified just a little. Explain in terms of impacts.	Text change: “Reintroduce beaver to appropriate watersheds and adopt management policies that ensure population persistence once established to help compensate for earlier spring snow melt runoff.”
3	14	13-14	What about reduced canopy coverage and increase in solar load to snowpack? There’s a tradeoff at stand densities too low to shade snow, right?	Text change: added sentence: “Recognize that reducing stand density may reduce shading, increase solar radiation, and contribute to accelerated snow melt.”
3	18	9-14	Missing titles for Payne et al. 2004 and Pierce et al. 2008	References corrected to add titles.

Chapter 4 Climate Change Related Trends in Aquatic Ecosystems				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
4	General Comment		Scientific uncertainties are expressed in association with those climate related impacts to aquatic ecosystems that the authors address (although there are additional impacts that should be discussed – comments below).	See response below
4	General Comment		The closing statement in the section on sources of uncertainty (page 11, that “the only outcome that can be predicted with virtual certainty is major surprises.”) goes too far in my opinion. I think there are a series of habitat trends that a warming climate will cause in aquatic systems and about which we can be fairly confident (shifts in habitat & resource availability). In many instances, these will have predictable biological consequences (shifts in species distributions and phenologies), although it is true that surprises will sometimes result from the interactions amongst multiple factors.	Text change: phrase deleted.

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Chapter	**Page**	**Line**	**Comment**	**Author Response**
4	General Comment		The chapter on Aquatic Ecosystems covers only a portion of the relatively rich scientific knowledge base that exists regarding how aquatic systems are, or will be, affected by climate change. Moreover, portions of the discussion are sometimes at odds with the general consensus that exists in some areas of the literature, and interpretations specific to the Kootenai/Panhandle NFs are often lacking, even where they may sometimes be made.	Chapter has been substantially revised to address this and following comments. Revised text strives to tie more directly to published scientific literature, and tie interpretations to northern Idaho and northwestern Montana where the authors felt it is reasonable and not entirely speculative, to do so.
4	General Comment		This chapter is not ready for prime time yet. The text seems poorly linked together, is not well integrated with other chapters, and needs a careful once-over for stylistic issues, particularly the topic sentences and clarity. Moreover, it doesn't have what I'd call scientific veracity. The only figures used to support these arguments are lifted from a somewhat dated paper that already forms the basis of some arguments in other chapters.	Chapter has been substantially revised to better reference other Chapters and minimize redundancy with other Chapters. In revising the Chapter, the authors strived to tie the text more directly to, and cite published scientific literature. Figures in previous version of the Chapter have been deleted, and replaced with tow new figures taken from recent literature.
4	General Comment		Much of the research Gordie Reeves is/has been involved in pertains to this paper and its arguments, but not a lot of it is cited here.	Publications of Dr. Reeves are cited in the paper where the authors believed they are relevant.
4	General Comment		In general, the support for arguments here needs to be increased and tightened up so that it is scientifically written and defensible.	See response above.
4	Section II. Observed Trends		This section begins with a brief review of past land management effects on aquatic ecosystems in the Kootenai/Panhandle NFs, but offers little with regards to climate related impacts on aquatic systems—either within the Kootenai/Panhandle or in other areas.	In revising the Chapter, the authors attempted to relate observed trends to climate where there is evidence to support such connections. Relatively little peer-reviewed data or analysis is available specific to northern Idaho and northwestern Montana.
4	Section II. Observed Trends		If either the Kootenai or Panhandle NFs had long-term stream temperature records, those would provide valuable insights as well. In other areas of the PNW, long-term temperature increases at least partially attributable to climatic trends are documented in studies by Bartholow 2005, Morrison et al. 2002, and Petersen	The revised chapter cites published stream temperature trends, including the articles suggested by the reviewer and a recent article by Kauscher et al. 2010. Instead of repeating Chapter 3 summaries and citations to publications on observed hydrologic trends, the revised chapter briefly summarizes those findings and

Chapter 4 Climate Change Related Trends in Aquatic Ecosystems				
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			and Kitchell 2001. Changes in regional hydrologic attributes (timing, magnitude, and frequency of runoff events) related to climate and relevant to aquatic organisms are documented in Stewart et al. 2005; Regonda et al. 2005, Pagano and Garen 2005, Hamlet and Lettenmaier 2007, Rood et al. 2008, Casola et al. 2005 among others. Perhaps here it would be appropriate to cross-reference the preceding chapter on hydrology to avoid significant redundancies.	refers the reader to Chapter 3.
4	Section II. Observed Trends		Case histories that document the effects of long-term climate trends on fish or amphibian populations are relatively limited. Most studies addressing this topic focus on how reproduction/growth/movement of organisms are affected by short-term, interannual fluctuations in thermal or flow regimes (many examples in bibliography). Studies by Hari 2006, Juanes et al. 2004, and Rand et al. 2006 are some of the few examples addressing fish population responses to longer term trends. The authors cite the study by McMenamin 2008 that links amphibian declines to climate later in the chapter, and it might also be discussed in this section.	Revised chapter includes references to most of the publications suggested by the reviewer.
4	Section III. Projected Trends		I was confused by the fact that this section began with subsections on air temperature and precipitation. These topics were covered more appropriately in the second chapter of this document that discussed climate change in general. In this chapter, it seems the challenge is to interpret these broad parameters in a way that is most meaningful to aquatic systems. Climate manifests in these systems most directly and rapidly through thermal and hydrologic regimes, with secondary effects potentially being felt through wildfires, possible vegetative conversions in riparian areas, and altered sediment, nutrient, wood regimes. The authors might consider some reorganization of subsections to capture these distinctions, which I attempt to discuss in more detail below.	Chapter has been revised to substantially reduce redundancy with other Chapters and address the iimpacts to aquatic ecosystems as suggested by this comment.

Chapter 4 Climate Change Related Trends in Aquatic Ecosystems				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
4	Section III. Projected Trends		Better integration between this and previous chapters would increase the efficacy of the whole – much of this argument exists in prior chapters.	See responses above.
4	Section III. Projected Trends		Most aquatic organisms are ectothermic and incapable of independently regulating their metabolic rates, so thermal regimes are often dominant factor shaping species distributions, patterns of abundance, and life history characteristics. However, there is not a 1:1 relationship between air and stream temperature because a variety of physical processes affect the transfer of heat energy from the atmosphere to the stream and these processes vary both spatially and temporally. Additionally, the largest portion of streamheat budgets (50% - 75%) is typically due to the amount of solar radiation that reaches the stream, so riparian vegetation type and the occurrence of wildfire may have strong local influences on stream temperatures that are independent of air temperature. The result is that streams in close spatial proximity, especially those in complex mountainous terrains, often have very different thermal regimes, despite exposure to similar air temperatures. So although it is true that stream temperatures are likely to increase in the future, these increases may only generally track air temperature increases, and will in some locales be more strongly affected by the secondary effects of climate change manifest through wildfires or conversion of riparian vegetation types. Also, long-term streamflow reductions like those described in Chapter 3, on hydrology, have the potential to make streams more responsive to heating from air temperature increases or radiation gains.	Text changed to incorporate this comment.
4	Section III. Projected Trends		The main question, therefore, is what will change the most across the Kootenai/Panhandle NFs in the future? If large fires do not occur, then stream temperature increases will generally correlate with air temperature increases and trends in stream flow. If wildfires do occur,	Chapter revised to address this comment.

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			or conversion of riparian vegetation occurs (away from trees to shrubs/grasses) in association with climate change trends, then stream temperature increases could be greatly accelerated and spatially heterogeneous. This future uncertainty is considerable and needs to be addressed. Good recent reviews on stream temperatures are provided by Webb et al. 2008 and Caissie 2006 and the bibliography also lists several case studies that document the effects of fire on stream temperatures in addition to the case histories related to long term climate trends referenced above in the previous section on “Observed trends.”	
4	Section III. Projected Trends		Many trends in stream hydrology relative to climate are now apparent across the western US and likely to continue for the foreseeable future. With few exceptions, however, the biological implications of many such trends are not entirely clear. The trends with the clearest biological ramifications are likely to be decreases in summer flows, increases in winter flood frequency, and flow variability/persistence. Here again, the authors may want to coordinate this discussion with the previous chapter to avoid some redundancies or conflicting statements.	Text revised to address this comment.
4	Section III. Projected Trends		Declines in summer flow are generally predicted in association with most warming scenarios due to earlier snowmelt runoff, a greater proportion of winter precipitation falling as rain rather than being stored in snowpack, and/or increased summer evapotranspiration by vegetation. Another general prediction, as stated in chapter 2, is for more precipitation to occur in winter and less in summer, but for the annual amount of precipitation to stay relatively constant or increase slightly. Although flow records from the 6 local gaging stations referenced in chapter 3 support the predicted summer flow reductions (most are not yet statistically significant, but are close to becoming so in future years),	Text revised to incorporate this comment.

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			concurrent trends in precipitation timing and amount deviate from the general expectations—with summer/spring precipitation increasing during the 20th century and remaining relatively constant in the fall/winter (Table 2.1, Chapter 3). Flow reductions, therefore, are presumably the result of increased evapotranspiration from higher temperatures/afforestation over the last century, in combination with earlier snowmelt runoff over-riding the effects of increased summer precipitation. If summer flow reductions continue, they will reduce the volume of habitat for aquatic biota within individual reaches, reduce terrestrial interactions (and potential recruitment of food items; Baxter et al. 2005), and the throughput of food items due to lower drift rates associated with decreased flow velocities (Harvey and White 2006). If summer flow reductions continue to proceed, the upper extent of perennial flow in some streams will start to become intermittent more regularly, which could constrain the lineal extent of the network and further reduce terrestrial/aquatic interactions (Clair and Ehrman 1996). These same reductions may also start to preclude upstream access to traditional spawning areas by fall spawning fish at some point.	
4	Section III. Projected Trends		The second hydrologic trend with obvious biological relevance on the Kootenai/Panhandle NFs is a change in the probability of extreme floods. Across the western US during the 20th century, these risks have both increased and decreased in association with climatic trends. In those portions of north Idaho and NW Montana that are occupied by the Kootenai/Panhandle NFs, however, the risks of both 20- and 100-year floods have increased substantially (Figs 5 and 6 in Hamlet and Lettenmaier 2007), and is in stark contrast to adjacent areas. The chapter's authors might consider examining changes in flood risks (magnitude, frequency, and	Text revised to add information on changes in flood risk and associated impacts on aquatic ecosystems. Figure depicting Hamlet and Lettenmaier (2007) estimates of 20th century changes in flood risk has been added.

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			timing) at the 6 flow gages used to provide local trend assessments.	
4	Section III. Projected Trends		Changes in flood risks are generally expected to be greatest in watersheds with midwinter air temperatures near or slightly below freezing, which characterizes much of land area within the Kootenai/Panhandle NF (see Figs 1 and 5 in Hamlet and Lettenmaier 2007). Areas near the freezing threshold have winter precipitation/streamflow regimes that are a mix of rain and snow (transitional hydrologies), and are especially sensitive to rain-on-snow events and any additional warming. A report prepared by Casola et al. (2005) discusses these sensitivities, has excellent maps highlighting areas in the PNW that are sensitive to change (Fig 9), and provides examples of stream hydrograph shifts that may occur in the future. If mid-winter flood events do become more common, fall spawning fish species like bull trout, brook trout, and brown trout may be especially sensitive to these changes because bed scour could easily destroy eggs incubating in the gravel and eliminate yearly recruitment. A recent paper by Tonina et al. (2008) models similar scenarios associated with timber harvest for two north Idaho watersheds.	Chapter revised to add discussion of changes in flood risk, including citations to articles suggested by the reviewer.
4	Section III. Projected Trends		Altered stream hydrologies may also affect the way that sediment and wood are transported through stream networks. If this altered transport capacity is accompanied by increases in wildfire activity (as appears to be occurring across much of the western US; Westerling et al. 2006), supplies of sediment and wood delivered to the stream network could increase, which has several implications for aquatic organisms. Because most fire related sediment is delivered to and through	Chapter revised to add subsection on how altered stream hydrology and upland disturbance processes may affect aquatic ecosystems as suggested by the reviewer.

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			channels in episodic, postfire pulses,populations isolated in small, steep headwater tributaries may become more susceptible to catastrophic debris flows that could cause local extirpations. Larger, mainstem channels or lower gradient areas on smaller streams could start to aggrade as they adjust to the influxes of additional materials. Depending on the frequency and intensity of larger flood events relative to sediment supplies, channel morphologies could widen to handle flashier runoffs and higher peak flows. Habitat diversity and structural complexity may also increase over time due to the additional inputs of sediment and wood. Several good references treat this subject area in greater detail and I would direct the authors to the section on “Fire and aquatic ecosystems” in the bibliography for a list of pertinent references. Many of the potential changes associated with sediment and wood regimes are linked to the occurrence of future fires, which presents considerable uncertainty regarding the timing and extent of these events. However, large fires were characteristic of north Idaho and NW Montana early in the 20th century (Morgan et al. 2008) and have recently burned across much of central Idaho/western Montana, so it seems more a matter of when, not if, these events will occur again, especially with ongoing warming trends. Perhaps more specifics about future fire potential on the Kootenai/Panhandle can be obtained from the chapter in this assessment on wildfire.	
4	Section III. Projected Trends		One of the lesser studied aspects of climate change impacts to streams is the potential for altered nutrient and water chemistry regimes. Papers by Clair and Ehrman 1996, Schindler et al. 1996, Hauer et al. 1997, Poff 2002, and Vincent 1997 are some of the few that address this topic. These treatments are often superficial, however, and I am not aware of a detailed assessment that fully addresses potential responses to	No change to text because of the limitations in the published literature as noted by the reviewer and the lack of local or regionally specific information on climate-induced changes in nutrient and water chemistry regimes.

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			climate change in Rocky Mountain streams. One could hypothesize that increased solar radiation inputs associated with open riparian areas, warmer stream temperatures, and greater sediment inputs from fires/debris flows will increase nutrient & productivity levels, but similar predictions for other water chemistry parameters relative to climate are more difficult to make.	
4	Section III. Projected Trends		In combination, the changes to aquatic ecosystems described in the sections above may mean dramatic shifts in the spatial and temporal distribution of habitats and resources available to fish and amphibians. Whether such changes are positive or negative, however, will depend on the species and the local setting. Some species will gain habitat while others systematically lose it. Fall spawning fish may be at increased risk from greater winter flooding, while species with distributions that are currently constrained by warm water temperatures will probably lose habitat in the future. Any species that currently exists in small, isolated habitats will be at risk from larger disturbances synchronized across broader areas.	Text ahs been revised to address the reviewer's point.
4	Section III. Projected Trends		The authors address in detail several case studies of aquatic organisms with sensitivity to climate change. One such study by Rieman et al. (2007) focuses on bull trout, a species of particular interest on the Kootenai/Panhandle NFs. The author's current interpretation of this work is overly general and probably too pessimistic. A closer examination of the results specific to the hydrologic units that encompass these forests suggest that maybe 10% – 60% of current thermally suitable natal areas could be lost under warming scenarios plausible by 2050 (Figs 1 and 4 in Rieman et al. 2007). However, this area of north Idaho and NW Montana also have the potential to retain some of the largest areas of quality habitat in the future (Fig 5). The 10000 ha figure cited by the authors was based	Text has been revised to incorporate this comment.

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			largely on relationships developed in drier portions of the bull trout range in southern Idaho, and corresponds to approximately 40 km of contiguous stream habitat. The watershed area needed to provide this length of stream habitat is likely considerably less in the wetter climate of north Idaho/NW Montana.	
4	Section III. Projected Trends		Another case study that might be useful to incorporate is the work by Mote et al. (2003). In this paper, past climate years characteristic of warm, dry and cold, wet conditions associated with PDO/ENSO cycles are used as surrogates to examine effects on snowpack, streamflow, forest and fish growth, etc. that could represent future “average” conditions. A range of management issues and options are discussed that are highly relevant in this context.	No change to text. Interannual and interdecadal climate variability is addressed in Chapters 2 and 3.
4	Section IV. Key Sources of Uncertainty		A key source of future uncertainty is the magnitude and rate of future changes in the climate system. Future warming may be faster than recent trends and the magnitude of increase by 2050 could range anywhere from 1°C – 3°C. Nobody knows for sure, but a gradual warming of 1°C by mid-century would translate to relatively moderate forest changes that proactive management efforts could adequately address. If changes are at the upper end of possible warming scenarios, however, effective management will be hugely challenging.	Text modified to address this comment.
4	Section IV. Key Sources of Uncertainty		As the authors assert, understanding how future climate changes will interact with local landscapes and management practices will also be challenging, but I don’t view the picture quite as bleakly as the authors, who take the position at the bottom of page 11 that nothing will be predictable in the future except surprises. Yes, the future is unknowable with certitude, but it is also very likely that streams and aquatic ecosystems will become warmer, more variable, and prone to larger, synchronized disturbances from floods, fires, debris	Text has been modified to address this comment.

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			flows, and droughts. Appropriate monitoring designs that focus on key biophysical attributes could minimize future surprises by determining rates of change in aquatic ecosystems that are used to assess future risks. If management actions can be used proactively to provide systems with resilience in key areas, then even "surprises" from future disturbances wouldn't necessarily have deleterious effects on valued resources.	
4	Section V. Potential adaptation options		The authors address many potential adaptation options, but may also want to consider including: 1. Assisted migrations are an option for species/populations in isolated, fragmented habitats that will not be able to track shifts in suitable habitat distribution further north or towards higher elevations. 2. Maintaining biodiversity, at both genetic and phenotypic levels, provides species/populations with maximum adaptive capacity. There may be elements of existing populations that are not favored by recent environmental conditions, but which could prosper in association with future environments. 3. Maintain or restore instream flows. Larger water volumes are less susceptible to heating and provide greater habitat volume for aquatic species. 4. Control or eradicate non-native species. A lack of non-native competitors allows native species access to a greater range of habitats and resources that can provide resilience to future environmental change. 5. Desynchronize landscapes. Restoring patchiness or heterogeneity to forests and streams will make them less susceptible to large disturbances synchronized across broad areas that would simultaneously affect many populations. 6. Use downscaling tools to identify and map important biophysical attributes and their sensitivity to future change. Address future uncertainty by developing management contingency plans that encompass a range	The text has been modified to incorporate the reviewer's suggested adaptation options.

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			of future scenarios—from low to moderate to high warming.	
4	1	7	Is ecology a thing that gets things stirred up? As a field of study, I suspect it is, but is the work choice a good one?	Text changed to : “Climate change is altering hydrologic processes and amplifying the risk… .”
4	1	16	Winter? As opposed to snow?	Text changed to: “…more precipitation as rain and less snow, … .
4	1	16	More, right? Or is it less? And when? Summer? Be specific.	Text change: deleted two sentences on hydrosystem operations.
4	1	17	So they won’t be adversely affected?	Text change: deleted two sentences on hydrosystem operations.
4	1	18	Impacts on?	Text change: deleted two sentences on hydrosystem operations.
4	1	18	Like hydropower and naviagable rivers, or like irrigation?	Text change: deleted two sentences on hydrosystem operations.
4	1	19-20	Changes? In which direction and of what kind? Make this broader for a wider range of potential readers.	Text change: deleted two sentences on hydrosystem operations.
4	1	23	Caps or not?	Caps are used only when referencing a specific, named national forest.
4	1	24	Citation, or opinion?	Sentence changed to: “Water quality, water quantity and aquatic biodiversity are important ecosystem services provided by the national forests.”
4	2	1-4	We the USFS, the authors? More precision would be useful, though I like the positive assessment.	Sentence changed to: “While some uncertainty exists regarding the extent, location, or timing of climate change impacts, land managers can anticipate aquatic ecosystem changes and respond with flexible and adaptive management strategies.”
4	2	9	Isn’t cold relative? What is cold? Certainly less than 20C, but is it less than 10C, or is there no agreement?	No change to text.
4	2	13	Their → life cycles	Text changed to: “cycles.”

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4	2	13-18	Again, more specificity. Are there any citations that can be brought to bear on this? Particularly the upstream effects of milling logs – what's the mechanism for this?	Add citations to Lee et al. 1997 and Rieman et al. 2003.
4	2	19	In what ways? Ecological integrity is a slippery, nebulous thing.	No change. The impacts on aquatic systems are described in preceding sentences.
4	2	20	How?	No change. The impacts on aquatic systems are described in preceding sentences.
4	3	6	For?	Text changed by replacing "to" with "for."
4	3	6-8	This reads a little obtusely – it could be edited for clarity.	Sentence changed to: "Of particular concern for native salmonids is the fragmentation of aquatic habitat that impedes or prevents recolonization of an area disturbance, such as flood or fire, cause a local population to be extirpated. "
4	3	14-21	This is already treated in earlier chapters – if length is an issue, this could be edited for consistency so that the text is better integrated.	Text change: paragraph deleted.
4	3	24	Citation? What data?	Added citation to Lee et al. 1997.
4	4	5-6	It is thought by….?	Text changed to: "This shift in the relative abundance of fish species may be the result of… ."
4	4	8-9	Because browns are not affected by whirling disease parasites?	Added citation to Vincent 2002.
4	4	17	Winter precipitation	Text changed to clarify.
4	5	14	Not necessarily – annual precipitation is different than precipitation extremes. This needs to be tightened up a lot to be accurate and precise.	Text deleted.
4	5	15-16	Need to better document what the actual impacts are up front.	Text revised in response to this comment.
4	5	21	Very informal…	Sentence deleted.
4	5	20-24	Also informal…language needs tightening up. NRDC and MTU aren't necessarily peer reviewed, are they? This should be clarified.	Text and citations deleted, and replaced with citations to peer-reviewed publications.

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4	6	14-15	What is the role of riparian vegetation changes in these watersheds? In the coastal PNW, that's an important part of the story. Has it been studied in the IPNF and KNF?	No change to text in response to this comment.
4	9	3	How are those different?	Text changed to eliminate redundancy.
4	9	19-20	Two years do not a line make – this is not really supportable, particularly since 1993 was one of the wettest summers in recent decades. Alarming, yes, but is that an opinion or fact?	Sentence deleted.
4	10	13	Westerling says nothing about the severity of fire that is backed up with data. That says something about the severity of the fire season, which means nothing in the fire world. Climate change increases the number of fires over a given size in that paper – that's it.	Sentence deleted.
4	10	18-19	Unless the loss of snowpack duration and the evaporation in spring and early summer due to all that extra solar radiation causes a decreased flow.	Sentence deleted.
4	12	12-14	Joyce et al. 2008?	Sentence deleted.

Chapter 5 Climate Related Trends in Forest Composition				
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5	General comment		General comment. A good thoughtful look, properly skeptical re models. Statements concerning changes in forest community that have occurred need better citation FS 2003 doesn't do it. The wet period of the mid 20th century probably had more effect on forest conditions than you give it credit for. But even if you give it more weight, in your analyses forest composition had been radically altered during a	Section on observed changes modified substantially to limit statements to those supported by primary literature, which is cited more frequently in the modified version. Added language to clarify role of "natural" climate variability, including the Pacific Decadal Oscillation. Thinning and other adaptation options are mentioned on the Adaptation Options section of this chapter, which also includes cautionary statements regarding assisted migration.

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			period of relatively stable climate. Many of these changes make the forests less durable in the face of change and so, one of the better approaches is to create more durable forests for the current situation knowing that these will also be generically more durable in the future. Luckily increased durability is generally compatible with maintenance of species distributions as much of what has occurred has been the increasing dominance of a few species. Thinning to improve individual stem health with the goal of maintaining the most durable members (generally large) of the entire species assemblage represents both good forest management for the present and for whatever may show up. In general, these types of “no-regrets” policies should be favored given the large degree of uncertainty in the future. More speculative approaches such as assisted migration, given our current inabilities to model fine-grained climate can be expected to fail more often than not, and will be expensive to implement.	
5	General comment		Good review of sources of scientific information for this topic. Good lists of uncertainties and adaptation options. Although it may be implicit in the discussion, it should be stated up front that uncertainty about species composition in a warmer climate is very high despite the availability of modeling results.	Thanks.
5	2	2	Be more specific – this could be any number of factors. Temeprature? Precipitation? Change in snow? Season of change, mechanism?	Text change: “The authors attributed these observed increases in average annual temperature and precipitation. “
5	2	7	Compared to what? Please give ranges of climates inferred by authors, alternatively describe plant community.	This paragraph is replaced with new paragraph including citations to primary literature.
5	2	8	Title of Chatters and Leavell implies it’s only 1500 years?	Citation deleted.
5	2	8	Not in citations list	Citation deleted.

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5	2	9	What is the evidence of this?	Sentence deleted.
5	2	10-12	How are these inferred? This needs to be better supported.	Sentence deleted.
5	2	21-22	Citation??	Sentence deleted and replaced with new paragraph citing primary literature.
5	2	21-22	These and other statements concerning observed changes in forest composition are very specific and extremely important. They need to be carefully referenced: that is, how were the current and historical data derived, what is the precise time period that provided the historical data, and what are the associated uncertainties associated with current and historical estimates. For example, FIA based composition metrics be linked to specific survey periods and would have easily calculated errors.	Paragraph has been revised with citations to primary literature. Referenced studies are based upon simulation modeling and empirical estimates derived from comparing aerial photography from early to mid 20th century with later aerial photography. These studies include calculation of statistical significance, but not error estimates. FIA data are not yet sufficient to calculate trend over time, since there has only been one sample completed to date.
5	2-3	22-1	Show citation or data or at least some evidence WITH METHODS and SOURCE, otherwise these don't belong here and are unsupportable.	Citations added to Hessburg et al. 1999; Hessburg et al. 2000, and Hahn et al. 1997.
5	3	3	Drama? Most important, most widespread, etc. would be better. Give acres of effect.	The word "drama" is deleted, and replaced with "most well-known."
5	3	4	Re white pine blister rust, 90% of western white pine has been killed, but it is more like 30% for whitebark pine (see discussion in Chapter 9).	Sentence deleted.
5	3	8-9	Correct use – graphs are incorrect.	Graphs corrected.
5	3	10-11	This statement needs to be cited or softened, e. g. "likely due to..."	Sentence deleted.
5	3	10-11	What are the observations that support this? Where is the data?	Sentence deleted
5	3	12	Again, how do we know that it is the decline in larch, and not some other factor or related factors, that lead to this incease?	Sentence deleted.

Chapter 5 Climate Related Trends in Forest Composition				
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5	3	12-15	I know what you mean, but the intent and what's written here aren't perfectly parallel, and this is an important point. Those large PIPO are still there in some cases, and in other cases they were logged and sometimes replaced by other forest types. Where they still exist, they have an understory of more shade tolerant species. The sentence sounds as if all the pine are gone, which glosses over a secondary, but important point.	Sentence revised to be more general and include citations to Hessburg et al. 1999, and Hessburg et al. 2000.
5	3	17-20	There is at least one grammar problem with this sentence.	Sentence revised.
5	3	17-21	These statements should be either cited to primary sources and/or should have explanatory text: e. g. based on an analysis of ??? patch sizes have decreased. This is true for all statements in this paragraph.	Citations to primary sources added.
5	4	4	This keeps getting cited as though it proves the points you are making. I don't doubt that much of this is true, but you need to do one of two things: (1) either SHOW the DATA THAT LEAD TO THESE CONCLUSIONS or say upfront that it is PROFESSIONAL JUDGEMENT. The way it is presented confuses it with research, and it is NOT RESEARCH unless the data are presented, to say nothing of peer review. The reason this is important is that management decisions can be made for many reasons, including professional judgement, but they should be made on the best available science when that science is available, and if it is not, that needs to be stated. The last sentence of this paragraph implies that there are already stands in which DATA suggest TRENDS toward these IMPACTS. In fact, I suspect that what you mean is that this document has statements about conditions that are consistent with broadly known principles of forest growth, resilience,	Reference deleted and paragraph revised. Citations to primary literature are added. In addition, figure added based on primary literature (Hessburg et al. 2000)

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			disturbance etc. So, you need to cite those general studies or reviews when they exist OR you need to show local data that confirm these statements.	
5	4	7	I don't think Morgan et al 2008 concludes that climate variability altered forest composition. Instead, it concludes that climate influences fire in the 20th century, and the impacts are time- and vegetation dependent.	No change.
5	4	7-9	Given that many trees are 150 years old or older, probably not anthropogenic climate change, right? Changes in establishment, mortality, and disturbance would be first evident.	Climate "change" modified to use the term "variability."
5	4	12	Citation.	Added citation to Malanson et al. 2007.
5	4	6-13	For much of the west (not sure about this area), the period from about 1940-1990 was unusually wet. This wetness would lead to many of the observed changes even without anthropogenic influences: fire would decrease, drought intolerant species such as alpine fir would increase etc.	Paragraph modified to emphasize "natural climate variability" and include mention of PDO as one potential manifestation of climate variablilty.
5	4	19	Suggest also citing Cushman et al. 2007 in this discussion of models. Cushman, S.A., D. McKenzie, D.L. Peterson, J.S. Littell, and K.S. McKelvey. 2007. Research agenda for integrated landscape modeling. USDA Forest Service RMRS General Technical Report RMRS-GTR-194.	Added citation to Cushman et al. 2007.
5	5	1-2	Cushman et al. 2007?	No change to text. The authors chose not to include the citation to Cushman et al. (2007) here because that publication does not discuss bioclimatic envelop or statistical species distribution models, which are a common class of models summarized in the text following.
5	6	2-3	Kind of redundant – only thing missing is global.	No change to text.
5	6	3-6	And ACCURATE observations of species presence,	Text change: added clause ", and accurate observations of

Chapter 5 Climate Related Trends in Forest Composition				
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			absence, and age.	species presence, absence, and age. "
5	6	7	Usually just the climate, but see Iverson et al.	Text change: "Statistical species distribution models typically project the future distribution of climatically suitable habitat for an individual species, not the actual occurrence or range of a species."
5	6	14-15	e.g., biomes?	No change to text. Bachelet et al. and Lenihan et al. use the terms "vegetation classes" and "plant functional types." Their hierarchical vegetation classification includes some higher level classes that might equate to general conceptions of "biomes", but the articles cited report results at a finer level of resolution.
5	6	19	How to reconcile this with Morgan et al. 2008 that at the scales of MC1, fire suppression success appears not to have been as big a factor as climatic synchronization of fire?	We don't. Lenihan et al. (2008) use assumptions to model fire suppression. Specifically, "…to roughly estimate the effect of fire suppression in MC1 simulations, there is a provision within the module to dynamically limit annual area burned in each grid cell to 12.5% of the unconstrained value." Pg. 17.
5	6	20-21	Only with CO2 induced water use efficiency TURNED ON. If you limit this effect, that statement is not nearly conclusive.	Text change: added clause ", especially if vegetation growth response to elevated CO2 is assumed to be high."
5	7	2-4	Wouldn't it be better to use peer reviewed versions of MC1 from Neilson et al? I thought they had done the whole West? If not, need to say WHY this is the best available science	Text change: deleted paragraph referring to unpublished information. Also deleted Appendix 5.A. display of maps from unpublished high spatial resolution MC1 simulations.
5	7	8	It would be useful to provide a panel in the appendix that shows a change map too so that the reader can focus quickly on this point. For example, show the top three to five transition types that occur, and map where the CHANGE occurred.	Text change: deleted Appendix 5.A. displaying unpublished high spatial resolution MC1 simulations.
5	7	14-19	For when? 2100 relative to 1970-1999? Give time frame and benchmark.	Text change: "over current climate (1980-1997). "
5	7	23	Define at first use for non-technical audience.	Text change: replaced "PVTs" with "potential vegetation types (PVTs).

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5	9	10	There are many more than 9 species listed in online file.	Text change: "The RMRS projected the distribution of "climate profiles" for numerous tree species in the western U.S.… ."
5	9	9-12	Wait a minute. My copy of Rehfeldt 2006 says they used the IS92a scenario and only CGCM2 (not 3) and HADCM3. GFDL isn't in there. The updated online version of these data needs to be cited as online: http://forest.moscowfsl.wsu.edu/climate/futureClimate.html	The website is cited in footnote 1.
5	9	16-18	Yes, emission scenarios diverge later	No change to text.
5	9	16-17	In terms of climate or in terms of species projections?	Text change: "simulation of future tree species distributions."
5	9-10		Although the appropriate caveats have been stated for bioclimatic envelope modeling, the statements about reduced habitat for western larch, whitebark pine, and lodgepole pine – and other species as well – are unsupported with logic based on biological science. Competition is not mentioned as a factor, and that will critical in determining future species composition. If habitat declines for all of these species, which species will occupy the landscape?	Text change: added "inter-specific competition" to the list of relevant factors in the sub-section titled "Summary of Projected Trends in Species Composition." There is apparent disagreement among forest ecosystem scientists about the support and logic for the results of bioclimatic envelop models. The text notes that "Each type of model has strengths and limitations" and cites several articles that provide more details about these strengths and limitations. All the studies cited are from peer-reviewed literature.
5	10	3	This analysis is for Washington State only.	Text change: "(see also Littell et al. 2009 for similar analysis specific to the State of Washington)."
5	10	3-5	Could it be that the relationships between climate and western red cedar distribution are stronger in CA than in the northern U.S. Rockies? Isn't it possible that there are multiple determining climatic factors, with the relative importance varying spatially? It's no surprise these analyses disagree somewhat. Peterson and Peterson (2001) has direct evidence of why this might be.	No change to text.
5	10	5	5b?	Citation and appendix deleted.

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5	10	15	going further, you could even say they are estimates of climatically suitable ranges.	Text change: modified sentence to read: “Thus, they should be viewed as estimates of potential changes in climatically suitable habitat, rather than quantitative predictions of the future distribution of tree species and forest types (Janetos et al. 2008).
5	10	18-21	Polite. Truth is that they are all over the place, and, for your purposes offer no guidance. They do indicate that things will change, but you knew that without the models.	No change to text.
5	10	20	That’s how Littell et al. 2009 used the information for WA – potential climatic stress indicator.	No change to text.
5	11	14	Field trials would underscore this even more – real data from real experiments is confirmation.	Agree
5	11	16-22	Yes this is a very important point. The GCMs for example are projecting average changes across 30-50 yr intervals. Nothing reacts to means.	Agree
5	11	20-22	Climate variability also influences disturbance, as you state earlier (Morgan et al. 2008), and it can logically be inferred from that that a small number of years with large area affected by disturbance can have a disproportionately large effect on vegetation.	Text change: added: “In addition, climate variability also strongly influences disturbance processes and mortality rates of trees. “
5	12	1	How is this different from complexity? Please explain.	Text change: deleted paragraph on complexity since it is redundant with the sum of the other sources of uncertainty described.
5	12	13	B?	Citation and appendix deleted.
5	12	18	Citation?	Text change: added citations to Körner et al. 2007 and Hyvönen et al. 2007
5	14	1-6	A bit too hopeful, based on current knowledge. Planting success requires climatic knowledge at the level of the site. We really don’t have this now. Expect high levels of failure not only in having the seedlings make it in the wrong climate but also in guessing where the right climate will be.	Agree. The paragraph includes the sentence: “In some cases, this option may be difficult to implement since the first objective is to ensure that the seedlings survive existing conditions to become established. “ Text change: added sentence: In addition, given multiple sources of uncertainty, there is considerable risk in projecting specific climatic conditions at

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				particular planting sites.
5	14	8	Adaptive or adaptation?	Text change: “adaptation” substituted for “adaptive.”
5	14	22	One of the most important ways to maintain species is to control stem density. In terms of reducing additional stressors, at the plant level thinned forests will be much less stressed and therefore less susceptible to the insects and pathogens (or fire for that matter) that will be the agents that actually kill the mature trees. This is one of the real opportunities for active management.	

Chapter 6 Rare Plants				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
6	General Comment		A well written document. The adaptation approach is well thought through, however it is generally passive (not necessarily a bad thing). In considering active management associated with rare plants, there are probably additional things that can be done for those that are associated with water. For bog plants, as things dry out conifers will spread toward the centers of the bogs, increasing transpiration. Conifer removal where conifers are threatening wet meadows etc. could be useful in some cases. Even more important, stream beds that have down cut can be restored such that they interact with their flood plains, greatly increasing the width and quantity of riparian areas. Encouragement of beavers in some locations can also produce extended wet areas. In total, there are probably a lot of things that can be done to help riparian areas (and hence riparian rare plants) when compared to alpine areas.	Added a section on wetland and riparian rare plants in the “Potential Adaptation Opportunities” section (page 8). [Note: there are no true bogs in Region 1. All peatlands in the Region are fens – since they are influenced by both precipitation and groundwater.]
6	2	8	“impacts… are discussed”	Corrected text.

Chapter 6 Rare Plants				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
6	3	21	"… cannot…"	Corrected text.
6	3	21	predictions or projections?	No change to text. The cited article states "predictions."
6	4	8	The implication in your statement is that species in the obligate mutualism would have differential responses, uncoupling the mutualism. Right?	Right. Modified text to clarify statement.
6	5	11	Define first use of acronym (KIPZ).	Text changed: "Kootenai-Idaho Panhandle Planning Zone (KIPZ)"
6	5	12	"Locally or universally rare" plants?	Text changed: "numerous plant species that are rare locally or rangewide"
6	6	21	Is it important that that variation is frequently poorly understood / quantified?	No change to text. While it is true that life history strategies, physiological tolerances, and dispersal abilities are not well known for many species, it is well-established that these vary widely among species – thus justifying the statement that generalization is difficult. See cited references.
6	9	3	Whitebark pine as a keystone species: "That's debatable. The keystone concept was initially related to complete ecosystem reorganization, and I have some trouble with whitebark as a keystone. For grizzly bears and Clark's nutcrackers and some ground squirrels, it's an important species. However, it is not always a keystone species with respect to forest function and subalpine forests in general. I don't dispute that it is important, but I think there could be a backlash associated with this characterization, which is not entirely supportable scientifically. It is a human construct invented to try to keep things simple, but it makes them simpler on the surface than they really are.	Text changed, to remove whitebark pine as a cited example of a keystone species in this case (although many whitebark pine researchers would view it differently). It definitely has an obligate mutualism with Clark's nutcracker, however, so the text was changed to cite it as an example of a taxon with a co-evolved relationship with another species (page 8).

Chapter 7 Climate Related Trends in Forest Productivity and Carbon				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
7	General Comment		First, this is a nicely written and scholarly review of the topic. All of the important points are covered, and all of the important scientific literature is included. I especially liked	Thanks.

Chapter 7 Climate Related Trends in Forest Productivity and Carbon				
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			the estimates of the carbon stocks and fluxes for the local forests.	
7	General Comment		Excellent review of concepts and science, which are well connected to inferences about carbon. One point that should be made clearer is that while individual actions at small spatial and temporal scales generally result in large carbon impacts, aggregation across large spatial and temporal scales generally result in low variability and minimal change. A paragraph that discusses connections between mitigation and adaptation (e.g., thinning increases resilience and provides biomass) would be useful towards the end.	The Introduction has been rewritten to provide a brief overview of scale issues, as suggested.
7	General Comment		Forest carbon is not complicated, but it is complex. It is especially difficult for most people to understand the different scales of space and time that it gets evaluated at. So, I'd suggest a bit of an overview explaining the cyclical nature of forest carbon, the importance of spatial scale, and the importance of knowing where you are in the cycle to evaluate what is happening and where you are going. I imaging Jim Morrison wrote this chapter, and if so, he has access to the Issues in Ecology material we are working on now. Something like a short version of what we developed for the 'Biology of Forest and Carbon' would be a helpful introduction and improve understanding.	The Introduction has been modified as suggested, including addition of a new figure summarizing basic forest carbon flows.
7			I've noticed that my lay friends that read my scientific papers really have difficulty with the journal form of references in the text (e.g., Ryan 2009). They find them very disruptive to flow and understanding. Us scientists have trained ourselves to want them and can deal with both references and flow. How about using a numbered footnote reference style1, which would be much less intrusive to readers and flow for this and for other chapters.	We agree that the citation form is cumbersome. However, we have not made the suggested change because it is the standard format used in this type of administrative report, and often insisted upon as evidence of scientific rigor.
7			I'd keep the number of significant digits to 3 or less, not the current 5.	Changes made accordingly.

Chapter 8 Invasive Plant Species				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
8	General Comment		Although I'm not familiar with the literature on climate change effects on invasive/noxious weeds, it appears there is little available information to make informed decisions regarding invasion potential of noxious weeds. The result is high levels of uncertainty as suggested within the report.	No change. We agree that there is a high level of uncertainty about the effects of climate change on invasive plant species at local scales. These effects have received relatively little research attention compared to some other climate change impacts.
8	General Comment		In this chapter the statement is made that climate change predictions have been made for 5 species of invasive plants, but the results of these modeling exercises are not spelled out. A table spelling out the predicted trends for common species in the two NFs would be helpful.	Results of this modeling study (Bradley et al. 2009) are summarized and cited in the Chapter.
8	General Comment		Given the potential rapid adaptability of many invasive species (although climate change specifics appear to be unknown), one recommendation might be to increase early detection programs with the forests.	No change
8	General Comment		I am unfamiliar with the what the KIPZ area is. A definition might be in an earlier chapter I did not read. Please define in the Chapter.	Text changed to : "…let alone the Kootenai National Forest and Idaho Panhandle National Forests planning zone (KIPZ) is a challenge. "
8	General Comment		There a potential invertebrate species that could pose problems in addition to noxious weeds. For example, Gypsy moth is an exotic, tree-defoliating insect that is frequently introduced into the western United States. In spite of an abundance of potential host species (e.g., aspen) these introductions have yet to result in established populations. Climatic suitability for gypsy moth in the western United States, however, will dramatically increase during the remainder of the 21st century under reasonable climate change scenarios (Logan et al. 2007).	No change to text. Forest insects are addressed in the Chapter on Forest Insects and Diseases.
8	1	3	This chapter suffers from a lack of careful connection of the published science to the local changes anticipated under climate change?	Chapter has been modified to add some references. However, to date there has been very little scientific research on the effects of climate change on invasive plant species in the northern Rockies.

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8	1	7	Is this a disturbance that takes out a whole ecosystem, an ongoing process, a changing process related to climate change, or? More precision would be helpful.	Text changed to: “Global climate change is expected to further expand the risk of plant invasion as ar consequence of increased extent and severity of disturbances, such as wildland fire, and enhanced competitiveness due to elevated CO2 (Dukes & Mooney, 1999; Weltzin et al., 2003; Thuiller et al., 2007). “
8	1	13	Define citation first used	Text changed to : “…let alone the Kootenai National Forest and Idaho Panhandle National Forests planning zone (KIPZ) is a challenge. “
8	1	14	?? Word choice? Expanding?	Text changed by replacing “expressing” with “expanding.”
8	1	15	Who? Multiple authors?	Text changed to : “As a result, without extensive controlled experiments it is difficult to distinguish whether range expansion of invasive species is the result of climate change or invasive species simply moving into suitable habitat independent of climatic trends.“
8	1	16	That’s not necessarily so. An experiment could do this in a reasonably controlled fashion.	Text changed to : “As a result, without extensive controlled experiments it is difficult to distinguish whether range expansion of invasive species is the result of climate change or invasive species simply moving into suitable habitat independent of climatic trends.“
8	1	16	Isn’t climate part of that capability – the species have unique climatic tolerances and requirements, right? How is this separate?	Text changed to : “As a result, without extensive controlled experiments it is difficult to distinguish whether range expansion of invasive species is the result of climate change or invasive species simply moving into suitable habitat independent of climatic trends.“
8	1	17-18	Climate models don’t predict invasive species, but the output of climate models can be used to do that.	Text change : sentence deleted.
8	1	20	Citation?	Text change: added citation to Bradley et al. 2009.
8	2	2	Maybe. It depends on exactly how general you intend to be. Climate change has very different effects on species within the same genus of native conifers (e.g., Pinus), so why would we expect it to be reasonable to infer that responses would be similar across different orders?	Text change: sentence deleted.

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8	2	10	Citation?	This statement is based on personal observation of resource management professionals of the U.S. Forest Service. No citation needed.
8	2	12	Citation?	This statement is based on personal observation of resource management professionals of the U.S. Forest Service. No citation needed.
8	2	14	Isn't invisibility a difficult term? It sounds more like the likelihood that a community can be invaded, when I think you mean the invasive potential of chategrass.	Text changed to: "and might increase this species' long-term success and dominance (Smith et al. 2000; Ziska et al. 2005). "
8	2	14	Et al. is the fomat used in the previous 7 chapters….	Format changed to et al.
8	2	15-16	Such as?	Text change: sentence deleted.
8	2	17	Seasonality, direction, magnitude of changes would be helpful.	Text change: sentence deleted.
8	2	18	Which is not the KIPZ, right? Please make the connection for non-technical readers?	Text change: sentence deleted.
8	2	18	Inconsistent citation format?	Citation format changed.
8	2	21	Citation?	This statement is based on personal observation of resource management professionals of the U.S. Forest Service. No citation needed.
8	3	4	What's that? Ability to control weeds?	Text changed to: "In the Northern Region, climate change may increase the risk of invasion by non-native plants. Climate change may also decrease the risk of invasive plant competitiveness if conditions become climatically unsuitable (Bradley et al. 2009). "
8	3	4	You're using common names for other weeds, but here you use the latin genus. Consistency?	Text changed to "tamarisk."
8	3	7	Dominance?	Text changed to: "…will likely maintain their current distribution of climatically suitable habitat in northern Idaho and western Montana (Bradley et al., 2009)."
8	3	12	Citation?	Added citation to Bradley et al. 2009.

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8	3	18	And what would that change? Climate is already variable, and somehow we manage to make decisions. Isn't the bigger source of uncertainty ecological?	Sentence deleted.
8	3	19-20	I'd like to see a citation of this. I suspect that there is considerable literature on climate and rangeland dynamics, thought it may come from other countries.	Text changed to: "Ecosystem susceptibility to invasion by nonnative plant species is poorly understood (Chambers et al. 2007)."
8	3	21-23	Translate this into impacts on invasive species and why it matters. Chapter one says that there are some pretty clear trends, and chapter two shows substantial data in support of this. However, no data is presented here to suggest that it is up to interpretation, particularly with respect to impacts on invasive species.	Text changed to: "Habitat suitability of many western invasive plant species is constrained by precipitation. Climate model projections of future changes in annual and seasonal precipitation are highly variable. Thus, for many invasive plant species changes in climatically suitable habitat is highly uncertain."
8	4	1	Watersheds vary tremendously in scale – you mean level, right?	Text changed to substitute "local" for "Watershed."
8	4	2	What does this mean? Does it mean that invasive species projections relative to future climate have yet to arrive on the horizon of important topics for the USFS in the region?	Phrase deleted.
8	4	3-4	So more guidance is desired?	Sentence deleted.
8	4	9-13	This seems like a different author?	No change.
8	4	19	This is the first in press citation I've noticed. There is a lot of material in press that pertains directly to other chapters in this document but that is not cited.	Text change to include publication date.

Chapter 9 Forest Insects & Diseases				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
9	1	9	I am not sure the point of this sentence: “At endemic levels, bark beetles typically infest individual or small groups of weakened trees, and root pathogens play a key role in nutrient cycling, succession, and plant species diversity (Jenkins et al. 2008; Burdon et al. 2006).”	Deleted reference to root disease. Added reference to Furniss and Carolin.
9	1	10	That’s the critical function, that they go after weakened trees?	No change
9	1	11	Jenkins et al. 2008 is probably not a good reference for saying that root pathogens may play a role in bb outbreaks.	Deleted reference to Jenkins et al and replaced with Furniss and Carolin
9	1	14-19	“In some situations, insect and disease outbreaks may result in conversion of forests to herbaceous vegetation if tree regeneration does NOT occur (Ryan et al. 2008; Holsten et al. 1995). “ “These direct impacts of some forest insects and pathogens may produce undesirable and costly changes in forest composition, wildlife habitat, timber supply, wildfire hazard, watershed processes, and carbon storage (Dale et al. 2001; Ryan et al. 2008).”Comment – these 2 sentences together suggest that regeneration limitations follow insect outbreaks. Often regeneration following an insect outbreak is limited due to a management intervention, such as salvage logging. Also, regeneration of some species, in particular long-live species at high elevation, may be limited due to climate change. Offspring of high elevation conifers that were established 500 to 1000 years ago may not be adapted to grow in the current climate.	Added missing word 'not'. As stated the effect on regeneration may occur in some situations. It is not intended to imply this is true in most or all situations. The reviewer's comments are correct, but do not alter the intent of the statement on the varying effects of insect/disease outbreaks.
9	2	3	Others disagree? Seems like there should be a citation in there about “but see conflicting evidence in [aper, data].	No change
9	2	4	This comment, and the fact that it is second, implies indirectly that climate change has not YET done this, which would be equivalent to saying the current outbreak of mountain pine beetle, for example, isn’t driven by climate change. If that’s so, you should state it up front and directly.	There is no evidence that the current MPB outbreak is a result of climate change. All that is in the literature is speculative.
9	2	9	In general, I think the term ‘forest sustainability’ is more descriptive than ‘forest health’. Forest ‘health’ means different things to different people.	No change
9	2	19	Seems like it might have been longer than that – isn’t there paleo evidence of MPB in lake sediments back at least 10,000ybp?	Changed to millenia
9	2	19	Citations?	Added reference of Brunelle et al.

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9	2	20	“Outbreaks tend to occur during warm and dry conditions and can cease following extreme winter cold (Logan et al. 1998).” – Actually, Logan et al. 1998 suggest that mountain pine beetle does not necessarily respond to drought conditions they way some other bark beetles (e.g., ips species) do. Warm conditions yes, but drought is not a necessary requirement, and extended drought could reduce outbreak potential.	Added additional citation Thomson and Shrimpton to reflect evidence of influence of drought.
9	3		“Amman (1978) states that 25 to 50 percent of a stand that is 4 inches dbh and larger will be killed over a 6 to 10 year period during an outbreak.” This statement is specific to lodgepole pine.	Correct. Added lodgepole pine to sentence
9	3	3	Maybe cite: Hicke, J. A., and J. C. Jenkins, Mapping lodgepole pine stand structure susceptibility to mountain pine beetleattack across the western United States, Forest Ecology and Management, 255, 1536-1547, 2008.	References already cited are more accurate. Hicke uses results of their work.
9	3	5	For a non-technical reader, define at first use of abbreviation even though it seems silly for dbh.	Done
9	3		Mountain pine beetle and western pine beetle are indeed often found infesting the same tree, especially when both populations are at low levels. Fire injury is another stressor that attracts both these bark beetle species to host trees.	Both of these bark beetles may infest the same tree, but disagree with the reviewer that it is often true. It is more an exception. True that fire is another stressor, but the other factors listed are more common to be the ones increasing ponderosa pine susceptibility.
9	3	15	Is there a monitoring document that could be cited here for that observation and for ongoing monitoring efforts?	Several citations added
9	4	6-8	“Outbreaks in Idaho and Montana during the 1920-1930’s and from the late 1970’s to early 1980’s killed lodgepole pine to an extent comparable to the most recent outbreak (Cole and Amman 1980; McGregor and Cole 1985) (Figures 5.5.1 and 5.5.2).” High elevation white pines were also significantly impacted by MPB.	Figure numbers will be corrected by editors
9	4	8	This is areal – point being that total area under the curve from 1978 to 1985 is greater than the period under the curve from 2000-2008? Also the graphs show nothing about the 1920s and 30s	Comparable data not available for 1920-30's outbreak. Statement based on observations Citation added
9	4	9	Figure numbers are wrong (should be 9.2, 9.3?). Where is 9.1?	Figure numbers will be corrected by editors

Chapter 9 Forest Insects & Diseases				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
9	4	12-13	“The epicenter of this activity is in Wyoming and Montana where the bulk of whitebark pine occurs. “ I think this statement is wrt to Region 1. There are large expanses of whitebark in other regions.	There are large expanses of whitebark outside of WY and MT, but in total they still do not equal the extent in these 2 states. Also, current mpb activity in whitebark is most notable in WY/MT
9	4	18	That’s a really important statement. It needs to be cited or deleted.	Added citation to aerial survey data.
9	4	22-23	“Collectively, the recent bark beetle-caused tree mortality is the largest and most severe in recorded history (Bentz et al. 2009). “Bentz B, Allen CD, Ayres M, Berg E, Carroll A, Hansen M, Hicke J, Joyce L, Logan J, MacFarlane W, MacMahon J, Munson S, Negrón J, Paine T, Powell J, Raffa K, Régnière J, Reid M, Romme W, Seybold S, Six D, Tomback D, Vandygriff J, Veblen T, White M, Witcosky J, Wood D (2009) Bark Beetle Outbreaks in Western North America: Causes and Consequences. University of Utah Press, ISBN 978-0-87480965-7, 42 p.	Bentz et al 2009 reference became available after the draft was written. It has been added to the document
9	5	9-11	Douglas-fir beetle (DFB) has a strong preference for stands of Douglas-fir with larger diameter trees, low vigor or growth rate, high tree density, and a high proportion of Douglas-fir in the stand (Negron 1998; Shore et al. 1999).	corrected typos
9	5	12	“DFB is a less aggressive bark beetle than MPB. “ I don’t agree. Populations of both species can remain endemic for years, then erupt to kill large areas of trees.	True that both species can erupt, but MPB is a much more aggressive insect. DFB generally responds to triggers, such as windthrow, fire damage, drought, and returns to endemic levels after a few years. MPB responds more to susceptible forest conditions and can continue for a decade or longer until susceptible trees are no longer available.
9	6	14	Need a better description of the sampling intensity – 94% of trees, acres, watersheds, what??	No change
9	6	22	Harvest didn’t have anything to do with this trend?	Added information on harvesting
9	8	17	What about the Amman 1978 citation earlier that claimed only 25-50% of stand?	Cole and McGregor publication based on 1970-80s outbreak to develop updated model
9	9	9	There is a table 9.1, but no appendix.	Changed to refer to Table 9.1.

Chapter 9 Forest Insects & Diseases				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
9	10	5	No quotes. It's a viable term.	Done
9	10	9	Hicke et al.?	Citation not appropriate to statement
9	10	10-12	"Cold tolerance models project that at the end of the 21st century, most areas in the western U.S. currently containing pine forests will have a moderate to high probability of cold temperature survival for MPB."	Change made
9	10	23	Maybe you should also cite this:Hicke, J. A., J. A. Logan, J. Powell, and D. S. Ojima, Changing temperatures influence suitability for modeled mountain pine beetle (Dendroctonus ponderosae) outbreaks in the western United States, Journal ofGeophysical Research-Biogeosciences, 111, G02019, doi:02010.01029/02005JG000101, 2006.	No change
9	11	3	But between now and 2075, there is a massive amount of terrain that IS susceptible (see Hicke et al. 2006, Littell et al. 2009 for PNW and why this is important)	And that is stated in the preceding sentence
9	11	8	But no increase between now and 2075? This is a very problematic conclusion to make from the Bentz paper alone – what happens between now and the end of the century? If that's uncertain, shouldn't that be noted?	And that is stated in the preceding sentence
9	11	21	They are not all equally plausible because they do vary in their ability to explain OBSERVED climate and their relative treatment of the physical aspects of the climate system. See Mote and Salathe 2009 for a discussion of some more and less plausible models in the Northwestern US, for example:http://cses.washington.edu/cig/files/waccia/Ch1_Mote_Salathe_final.pdf	No change. IPCC AR4 Report makes clear that all climate emission scenarios they report are equally plausible.
9	12	1-9	In addition to using different and more updated climate scenarios, different and potentially better methods for downscaling have been developed, and could increase certainty in the bark beetle model projections. The MPB model used for climate projections included in the assessment was developed using parameters from a MPB population in central ID. Therefore, this is the best model for making predictions for Region 1. However, if you were making projections for AZ and/or southern CA, the statement about geographic variability and model projections would be valid.	No change
9	12	9	Which are, specifically, what?	Sentence deleted

Chapter 9 Forest Insects & Diseases				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
9	12	9	“In addition, the adaptive seasonality model assumes that a univoltine life cycle is necessary for high probability of an outbreak, even though recent research suggests that MPB can be successful in areas that are not strictly univoltine (Bentz and Schen-Langenheim 2007). “Bentz, B.J. and G. Schen-Langenheim. 2007. The mountain pine beetle and whitebark pine waltz: has the music changed?, Proceedings of the Conference Whitebark Pine: A Pacific Coast Perspective. www.fs.fed.us/r6/nr/fid/wbpine/papers/2007-wbp-impacts-bentz.pdf	Change made
9	13	5	And the implication of that uncertainty are…..what? If this is the best available science, it should be used, right? Or is this uncertainty so great that no decisions should consider the information?	No change
9	13	8	Doesn’t it vary with southern vs. northern populations of the MPB	No change
9	13	14	It might be good to specifically state that climate change (e.g., precipitation and temperature) will have direct effects on tree defensive capacity which will indirectly affect bark beetle population success. Virtually no information is available on this interaction.	No change, since “virtually no information is available on this interaction.”
9	13	19-21	“Thus, actual population responses to climate change may differ from modeling results based upon existing thermal tolerances and life history phenology (Bentz et al. 2001).”Use this reference instead - Bentz, B.J., J.A. Logan, and J.C. Vandygriff. 2001. Latitudinal life history variation in Dendroctonus ponderosae (Coleoptera: Scolytidae) development time and size. The Canadian Entomologist 133:375-387.	Change made and reference added.
9	14		Maybe add the word ‘fungal associate’ to your list of community associates that will be directly affected by climate change, and therefore indirectly affect bark beetle outbreak dynamics. Another component we have no information on and therefore contributing to uncertainty in making predictions of bark beetle outbreak dynamics.	A statement and citation added.
9	14	15	By what mechanisms would cascades occur? Citation or description, please.	Phrase “and cascading effects” deleted.
	15	4-5	“Increasing the diversity of tree species within stands and across landscapes can reduce the susceptibility of forests to aggressive insects and pathogens (Bentz et al. 2009).“ This is a hypothesis based on conventional wisdom although there is currently no research to support this statement. It would be good to phrase it as such as is done further down in the document on page 16.	The statement has been changed to reflect the reviewer's concern and additional citations have been added.

Chapter 9 Forest Insects & Diseases				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
9	15	9	In what direction, what variables? This needs to be more explicitly stated as a mechanism.	No change
9	15	10	Many bark beetle species, including western pine beetle, mountain pine beetle and Douglas-fir beetle are highly attracted to fire-injured trees. Models have been developed (or are in the process of development) to predict bark beetle attraction to fire injured trees of many species. Would be good to add a cautionary note that when using prescribed fire, need to be aware that in addition to delayed tree mortality due to fire injuries alone, bark beetles can cause significant additional mortality.	The reviewer assumes there is significant fire injury from prescribed fire to be attractive to bark beetles. The intent of the statement is to reflect that fire can be safely used to improve stand growing conditions and reduce potential bark beetle activity. The use of fire within prescription should not injure desired trees sufficiently to result in significant bark beetle loss.
9	16	2-9	Is it important to note here that whitebark pine has been proposed for listing as an endangered species?	Don't see the relevance of this information to this paper.
9	16	4	Many whitebark stands are already low density and THEY have outbreaks NOW. How does reducing stand density promote selection for resistance to blister rust infections?	There is research that indicates reduced stocking density decreases whitebark susceptibility to mpb. All species need to be considered when evaluating density.
9	16	11-13	In addition to development of genotypes resistant to blister rust, it will be important to understand and determine genotypes that will do well at particular locales given climate change. This can be said for all tree species, and will be helpful in areas targeted for intensive restoration.	Good point and addressed in document
9	16	3-5	“Reducing the density of trees in whitebark pine stands may reduce their susceptibility to MPB and promote selection for resistance to blister rust infections (Gibson et al. 2008).”It is not clear to me how reducing density of whitebark pine promotes selection for resistance. Might be good to include some thoughts regarding gene conservation (e.g., cone collections) for rust resistance testing and future out-plantings in heavily impacted forests. Is there data for rust resistance of whitebark stands in the two NF’s ?	Sentence poorly worded and reworked to reflect how removing wpbr infected trees as part of density reduction may increase resistance. There are no data on rust resistance in whitebark particular to these Forests.
9	16	19-22	“A program designed to detect and rapidly respond to unexpected or invasive pathogens and insect outbreaks may allow land managers to take early action and prevent larger scale or irreversible effects that may threaten the sustainability of existing forest ecosystems (Millar et al. 2007).” Probably emphasize that early detection of invasive insect populations, not insect	Change made

Chapter 9 Forest Insects & Diseases				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
			outbreaks, is ideal. Hopefully they would be detected prior to the outbreak phase. FPM has a good early detection program.	
9	30	3	Need to better explain contents of cells and high, moderate, low, none, mean, etc. – this is potentially not evident to non FVS users?	No change
9	31	2	Does a continuous red swath mean 100% mortality? This needs a better caption to describe the detection limit and what gets red vs. what does not. It needs to be sufficiently quantitative that a map reader can infer what the various size polygons actually mean on the ground.	No change
9	32	6	Total within year, new acres, or total acres (that's not likely given the shape of the trends): are they additive?	No change
9	33	3	What's "cold", and over what time frame and frequency? For example, is this annual minimum T and p (beetle survival)?	No change

Chapter 10 Wildland Fire				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
10	General Comment		Good scientific background, inferences, and adaptation options.	Thanks.
10	2	4	Drama again. How about large, or very large, or better yet give it some acres.	"Dramatic" replaced with "large." Additional details provided by following sentences in the paragraph.
10	2	8	Period 1970 to 1980 is under reported, so the six-fold business is likely not correct. There is a large increase, though.	No change. We are trying to accurately summarize results reported in Westerling et al. 2006.
10	3	16-17	What's the threshold for "cold" and "dry" forest/ Is it just species? Seems like montane vs. subalpine is more appropriate.	No change. Since we are summarizing the findings of Morgan et al. (2008), we believe it is more appropriate to use the terms used by those authors. Morgan et al. (2008) describe cold and dry forests by the representative tree species, as we do here.
10	4	15	1980's. Plurals don't need apostrophes to help them.	Change made

Chapter 10 Wildland Fire				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
10	4	21	But no increase in fall and winter temperatures? I am certain that Mote et al. show increases in all seasons for temperature for the 2020s, 2040s and 2080s.	Sentence changed.
10	4	22	I don't think that's the kind of citation format the other chapters use- some consistency would be good. Just cite again.	Change made
10	7	14-15	With a mean of between -4.6 and -12%. Don't you think that's important?	Change made to include multi-model means.
10	8	20	It seems that preparing for large, severe fires and their impacts with a pre-approved strategy that considers (1) post-fire projects, seed sources, planting schedules, etc. and (2) larger, landscape level and watershed considerations that help make the landscape more resilient would be in order too (e.g., Joyce et al. 2008).	We agree. Options for considering post-fire seed sources and regeneration are discussed in Chapters 5 (Forest Composition) and 14 (Forest Productivity).
10	8	21	There is some debate about that. The largest fires don't seem to respond much to suppression efforts, but they burn about 95% of the area, correct?	No change. It's true that less than 5 % of fires (the large ones) produce 95 % or more of the acres burned. However, some suppression efforts under severe fire weather conditions can be successful, but the success rate is lower than under moderate fire weather conditions. The point of the paragraph is that suppression efforts become increasingly less successful over time due to fuel buildup, especially under severe fire weather conditions.
10	8	20	It is doubtful that suppression can actually control the large wildfires that occur under extreme weather conditions.	We agree. Paragraph modified to emphasize that suppression efforts are likely to become increasingly ineffective.

Chapter 11 Terrestrial Wildlife				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
11	General Comment		Reasonable discussion of a challenging topic. Most of the inferences and adaptations look fine.	Thanks.

Chapter 11 Terrestrial Wildlife				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
11	1	5	TC2: A good and thoughtful chapter. In some cases species are grouped too broadly. Be as accurate as possible when discussing various species and their issues.	See responses to specific comments below.
11	1	7	TC: deleted "array of"	Deletion accepted.
11	1	8	TC: "Some" suggested instead of "different"	Alternative wording accepted.
11	1	22	TC: Does Joyce et al. 2008 really say that synergistic climatic and non-climatic stressors influence wildlife?	Janetos et al. 2008 was substituted for Joyce et al. as the correct citation.
11	2	32	TC: Just those analyzed, right? The majority of the terrestrial biota isn't even monitored.	Wording changed to clarify: "...that the majority of terrestrial biota included in their analyses…"
11	2	41	TC: Citation?	Citations added: IPCC 2007 and Karl et al. 2009
11	2	46-47	TC2: There have been extremely rapid climatic shifts in the past 100,000 yrs. In this case very rapid change will be coupled with reduced and fragmented populations making natural shifting more difficult.	Text changed: "The rapid rate of present warming (IPCC 2007), however, exacerbates the challenge of maintaining and restoring already reduced and fragmented populations (Root and Schneider 2002; Janetos et al. 2008; Karl et al. 2009)."
11	3	63	TC: Range? Suite implies they are more related than I think they are?	Excellent point. Text clarified: "For instance, cold-limited species will likely expand their ranges, if suitable habitat exists. Among cold-limited wildlife, species with faster generation times (e.g., insects) will adapt more rapidly to changing conditions, which may also result in the range expansion of arthropod-borne infectious diseases (Daszak et al. 2000; Harvell et al. 2002)."
11	4	74	TC: That sounds like it will be good for them….is that what you mean? How about "more favorably" or "less negatively"?	Alternative wording accepted.
11	4	87	TC: Fish are limited by warm temperatures – be more specific.	Excellent point. Text clarified: "For instance, cold-limited species will likely expand their ranges, if suitable habitat exists. Among cold-limited wildlife, species with faster generation times (e.g., insects) will adapt more rapidly to changing conditions, which may also result in the range expansion of arthropod-borne infectious diseases (Daszak et al. 2000; Harvell et al. 2002)."

Chapter 11 Terrestrial Wildlife				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
11	5	104	TC2: Not particularly long lived, pikas probably more temperature limited than snow limited.	Text changed to reflect associations with snow and cold: "In contrast, longer-lived, cold- or snow-dependent mammals such as wolverines (Magoun and Copeland 1998; Copeland et al. 2007), lynx (Gonzalez et al. 2007), pikas and snowshoe hares (Beever et al. 2003; GAO 2007) will be dramatically affected by a warming climate." Since the life history comparison was made with insects, the claim of pikas being "longer-lived" remains valid.
11	5	114-117	TC2: Grizzly bears are habitat generalists, they are in the mountains because we don't allow them elsewhere. Bighorn sheep also can live in a wide variety of habitats, but disease problems are expected to increase with warming climate. Pikas mountain goats and wolverines, however do all appear to be cold climate specialists.	Sentence revised to eliminate speculation on causes for declines applied across all of the mammals mentioned: "Mammals inhabiting western public lands expected to experience noticeable effects of climate change include grizzly bears, bighorn sheep, pikas, mountain goats, and wolverines (GAO 2007)."
11	6	124-127	TC2: You should associate the proper cites with the factors in the list below.	Cites added to specific factors in list of uncertainties.
11	7	145	TC: Level? To a microbial ecologist, my thumb is a landscape.	Wording changed to clarify: "Consider multi-scale wildlife habitat needs when selecting reserves…"
11	7	152	TC2: Controlling or prescribing fire could maintain ecosystems as well	Statement added: "Use prescribed and wildfire to maintain ecosystems"
11	8	166	TC2: One can also (and this goes for plants as well) determine the prevalence of adaptive genes in a particular population. For example, movement of disease resistant organisms into an existing population is probably a lower cost and effective strategy than trying to move populations ahead of a disease wave.	Sentence added: "Determine the prevalence of adaptive genes within populations (e.g., introduce disease-resistant individuals into a population rather than translocating the population to accommodate the expanding range of a disease)"11
11	8	180-182	TC2: You do mention population monitoring above, but it could be reinforced here. Without good monitoring data you will have no idea what is going on and therefore how to deal with it.	Text added to reinforce the importance of monitoring

Chapter 12 Special Areas				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
12	General Comment		"…the goal of protecting historic communities and habitat types through the RNAs is probably untenable, except in areas that are small enough and important enough to merit continual management intervention to maintain a historic community… such areas should be identified and the FS should be explicit that the goal is to maintain the current community, even in the face of change, and that significant resources may be required to do so. … In all other RNAs, I would recommend abandoning the goal of retaining the currently present communities (and even designating new RNAs based on representative communities, although I like the idea of designating new RNAs based on elevation and soil type) as this will be largely impractical and potentially maladaptive. In other words, I am suggesting careful examination of the goals of these protected areas and explicit articulation of such goals in the context of climate change. If the target is no longer a particular historic community, what is the goal? Resilience, learning about change, providing connectivity for species to move? Specificity about goals is critical to conservation in these places."	These issues are actually national in scope, e.g., major changes to the goals of the RNA program need to be evaluated by the agency. For this CER chapter, some text has been added in the Potential Adaptation Opportunities section to acknowledge these recommendations – but the concerns pertain to the national program, not just to RNAs and other protected areas in KIPZ. Until such time as the national program objectives are adjusted to address these issues, I'm electing to retain the suggestions that are in line with the current program direction (such as the opportunity to add vegetation types to the regional RNA network that aren't currently represented in KIPZ).
12	General Comment		"The authors suggest that we need to retain the option to intervene and actively manage RNAs. I think this is appropriate, but would suggest careful thinking about whether some RNAs should be hands-off (no intervention) and some actively managed to assist with change to provide diversity for learning."	Text added to address this concern, as indicated above.
12	2	10	"Maybe add associated environmental conditions – for many the climatic influence is not direct."	Text revised to also mention environmental conditions.
12	4	12-13	"These aren't so much extremes as the kinds of changes we expect in climate in general, as opposed to extreme weather events… Droughts of long duration are climatic events, the others are trends in climate. Need to clarify."	Text revised to clarify meaning.
12	4	18	"There is serious question as to whether the signal can be plucked from the noise in (the van Mantgem analysis)…"	Text revised to acknowledge uncertainty.

Chapter 12 Special Areas				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
12	5	6	Regarding predicted decline in extent of montane forest in n. ID and nw. MT: “How much, and by when? Unfortunately, one needs to go to the Brown’s community projections on the Rehfeldt website to get the information to assess this.”	Added text comment referring reader to Rehfeldt et al. (2006) and associated website for information
12	7	2	Designation and establishment of new protected areas: “Is this synonymous with the expansion of existing protected areas where appropriate, or not?”	No. Added text to include expansion of existing protected areas as an adaptation opportunity.
12	9	4	Complete review of adaptation approaches: “Maybe it’s complete, but adaptation approaches are evolving continuously… This is a fairly definitive statement that doesn’t appear to recognize this fact – it suggests that if it’s not in Scott and Lemieux, it isn’t adaptation.”	Text changed to acknowledge this.

Chapter 13 Social and Economic				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
13	General Comment		The scientific uncertainty is definitely acknowledged but it is largely confined to one section (Key Sources of Uncertainty), rather than integrated throughout the discussion of specific resources. It is typical for these types of reports to discuss a range of temperatures associated with different GCM’s, and then discuss the implications of the lower, middle and high range of temperatures. For example, the range of temperature increases may have different magnitude of effects on the length of the ski season.	Several small changes were made to try and reflect the uncertainty throughout the chapter. For example, language was added to show that ski impacts would vary based on what temperatures are actually experienced.
13	3	61	As noted above uncertainty is acknowledged but not sufficiently described in terms of the consequences to other resources when discussing say timber or wildlife. For example, the one sentence that says hunting may be reduced if there are rapid transitions in habitat is probably	Changes were made to show that hunting may be affected positively or negatively.

Chapter 13 Social and Economic				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
			one possible outcome of climate change. However, I believe there is some literature on how climate change would actually increase elk populations since over-winter survival would be increased, and thus hunting opportunities could increase rather than be reduced. Some of this research is from Thomas Hobbs.	
13	4		There are primarily two weaknesses. Page 4, at the top of the page notes that forest product gathering could be enhanced by warmer scenarios. However, it is not just this limited recreation that benefits from warmer climate. Research on Rocky Mountain National Park indicates that a couple of degree warmer significantly increases early season and late season hiking opportunities due to earlier snow melt and later snowing in of trails. See Loomis and Richardson, An External Validity Test of Intended Behavior: Comparing Revealed Preference and Intended Visitation in Response to Climate Change. Journal of Environmental Planning and Management 49(4): 621-630. 2006. I would think this result is applicable to these NF's, and hiking has a higher participation rate than skiing.	Reference to Loomis and Richarson 2006 was added in a sentence that describes how summer seasons may be extended, increasing visitation. Citation added.
13	5		2. Top of Page 5, the author's scenario makes the implication that people living on east and west coastlines might react to climate change by moving inland as far as these two National Forests. The author never really comes out and says that, but presumably the reason it is in this report is that he/she expects some of these people to move to MT and ID. Of course that is possible, but I would guess that people with coastal and ocean tastes and preferences would just relocated slightly inland to be near the new slightly higher coast and that sea level rise would have little effect on migration to ID and MT. Rather, I believe a more plausible scenario is that higher temperatures in the mountainous portions of the southwest (NM, AZ) may cause some of those that like mountains (especially northern New Mexico and Flagstaff area of AZ) to move to ID and MT in search of cooler	Paragraph was rewritten to include consideration of people moving from other mountainous areas as well as flooded coastal areas as suggested by the reviewer.

Chapter 13 Social and Economic				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
			temperatures. This discussion of temperature driven migration would seem more relevant to these two National Forests.	
13	3	61	As with the previous chapter, information about uncertainties is accurately described. The authors do an excellent job outlining possible impacts to outdoor recreation. I recently heard that elk and deer populations in Montana may increase due to climate change, but I don't have a citation to support that claim. A few suggestions for this chapter follow.	Changes were made to show that hunting may be affected positively or negatively.
13	4	82-83	In the section on population growth, I think it is important to state that one of the ways that population growth potentially interacts with climate change is through increased development in the wildland urban interface, especially in the context of changing fire regimes.	elevate wildfire threats to communities was changed to elevate threats to the growing number of wildland urban interface communities (Stein et al 2007). Citation added.
13	General Comment		Also, another way that local communities will be impacted by climate change is that the National Forest landscapes around them will change and these changes will be unpredictable in many ways. Thus, the Forest Service will not be able to fully prepare local residents for what they might expect. This could result in increased public concern about forest management, especially if residents believe that the Forest Service should be doing something differently (possibly even preventing such changes). In this context, education about the impacts of climate change is important.	This is a valid comment, but I could find no usable references to discuss this possibility.
13	General Comment		Furthermore, public participation in planning is going to change. Because conditions are increasingly unstable, plans will need to be more flexible, continuously adapted as new information becomes available. But, the public may want more certainty, knowledge and a sense of commitment regarding where the Forest Service is headed in particular places. Thus, public involvement in planning will need to be ongoing, so that there can be continuous dialogue as things change. And planning will need to be	Again, this is another valid point, but I did not see a way to incorporate it into this concise chapter.

Chapter 13 Social and Economic				
Chapter	**Page**	**Line**	**Comment**	**Author Response**
			highly participatory, so that the trust required for flexibility can be fostered over the short and long-term.	
13	1	2	13?	Correct this is chapter 13 not 12. Change made
13	1	4	Hyphenate?	Now hyphenated
13	1	18	Westerling doesn't really comment on fire regimes per se, but one aspect of fire regimes.	I have changed fire regimes to fire frequency to be more specific
13	4	9-11	The fire chapter uses a different set of citations – Littell et al 2009 projections for the PNW are substantially higher.	Added the Littell et al 2009 In press, projections to create a range, added citation
13	4	17	Clearly	Cleary changed to clearly, also edited climate to climate change

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