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Vulnerability, Exposure, and Sensitivity in Restoring and Maintaining the Adaptive Capacity of Forest Landscapes in the Northern Region of the Northern Rocky Mountains

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Introduction

Recently the Draft National Climate Change report has been issued that summarizes in Chapter 7 how forests in the U.S. may respond to climate change and related disturbance processes. (Joyce 2013) This draft report was partially informed by the National Climate Change Assessment published in 2012. (Vose 2012) In the context of that information, this paper will review assessment of forest composition and structure and processes specific to the forests of the Northern Region, and how that has changed from a historical range of conditions. We have summarized how climate and other stressors have affected and may increase the vulnerability of these forests in the future, including which forests and conditions are particularly sensitive to exposure of climate change driven effects. We have also summarized how forests might adapt to climate perturbations and change, and offer some insights regarding adaptation options, actions and tactics that we should consider to restore and or maintain a more resilient forest landscape for the future forest in the Northern Region**.** This paper should be reviewed with the associated R1 primers as context:

1. Primer on Northern Rockies Climate Change: Dr. Amy Snover () (CIG) [will link to document]

2. Primer on Wildland fire and climate change: PI – Dr. Rachel Loehman – RMRS – Stu Hoyt, Barry Bollenbacher – RO contacts [will link to document]

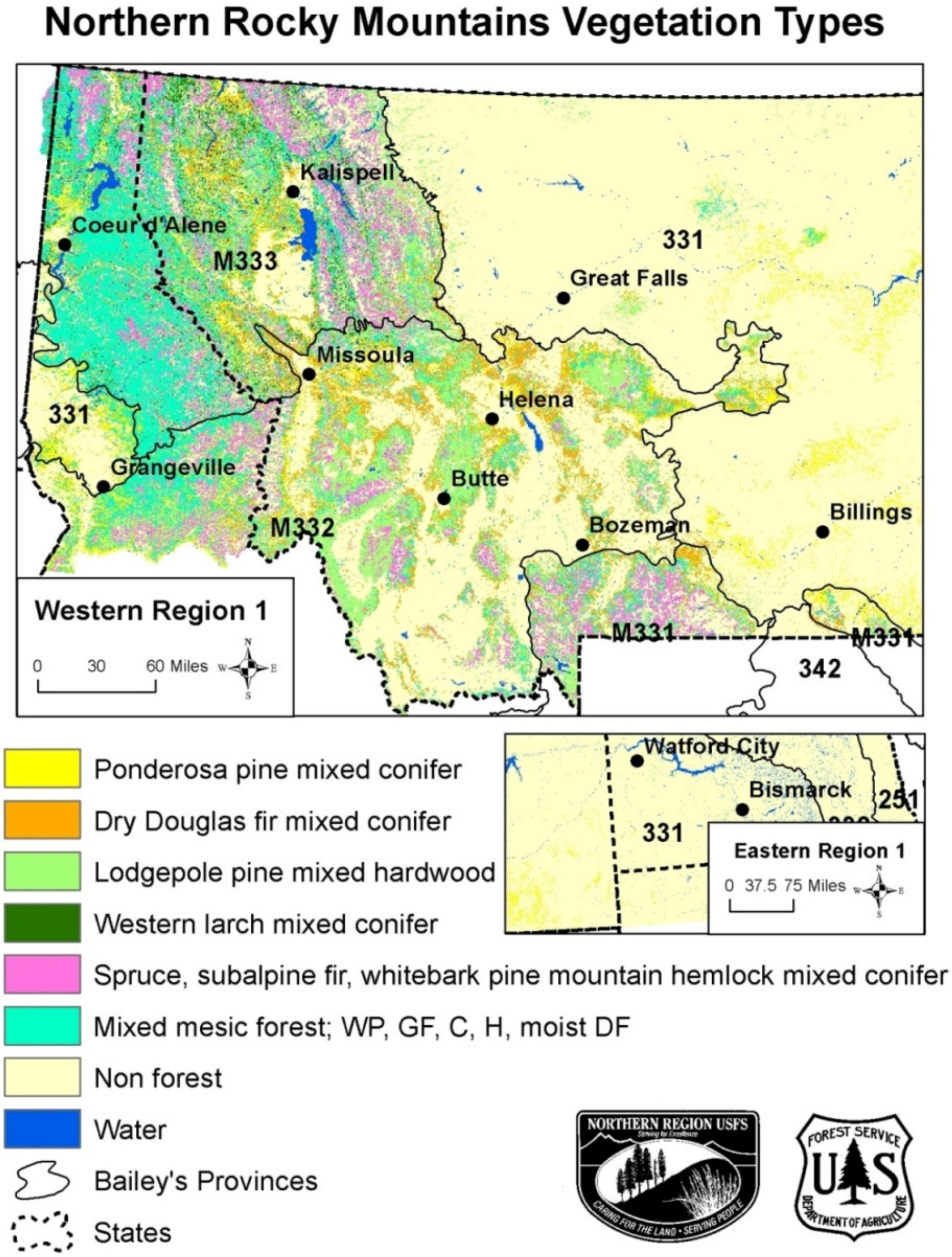
3. Primer on Climate Change and watershed ecology (snow, streamflow, aquatic ecosystems) – PI - Dr. Charlie Luce –RMRS – RO contacts: Scott Spaulding/Cameron Thomas RO [will link to document]

4. Primer on Forest Regeneration – Glenda Scott – RO [will link to document]

5. Carbon Management Framework – Dr. Sean Healey – RMRS (IW-FIA) [will link to document]

Key forest tree resources

The forested region of the northern Rockies can be coarsely lumped into 5 or more distinct ecological zones, based on the tree species that can grow there. The driest true forest is characterized by the ponderosa pine zone, defined by inability of any other tree species (with the exception of Limber pine and Juniper) to grow there because it is simply too dry. As more moisture is found, Douglas-fir can establish. This species is the most adaptive tree species we have and can occur in all forest zones as mixed conifer forests except the very driest. The zone is defined as too dry for this species to grow at one end, and more shade tolerant species such as grand fir or subalpine fir at the other, and is the largest ecological forest zone present, and is most often associated as mixed conifer forests including western larch in northern Idaho and western Montana. As more moisture occurs, less drought tolerant species can survive that are also more shade tolerant, thus eventually dominating the site in the absence of disturbance as they out compete drought tolerant species for light and nutrients. At the warmer end grand fir and eventually western red cedar and western hemlock and formally western white pine dominate. At higher elevations, deep snow and cold adapted species such as subalpine fir subalpine larch, Engelmann spruce, lodgepole pine and whitebark pine dominate and is most similar to the Boreal forests of northern Canada. It is important to note that each zone has its own unique cohort of species, life histories and adaptations to disturbance processes. The spatial distribution of these dominate types are displayed in this map of the dominate types in the northern Rocky mountains.



Observed and projected climate

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 (see figure below). For example, the 1960s were cooler and wetter than the last 10 years in the the northern Rockies. Springs tend to be wetter than summers. Over periods of month, years, and decades, and over broad areas such as the northern Rockies 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.. 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.

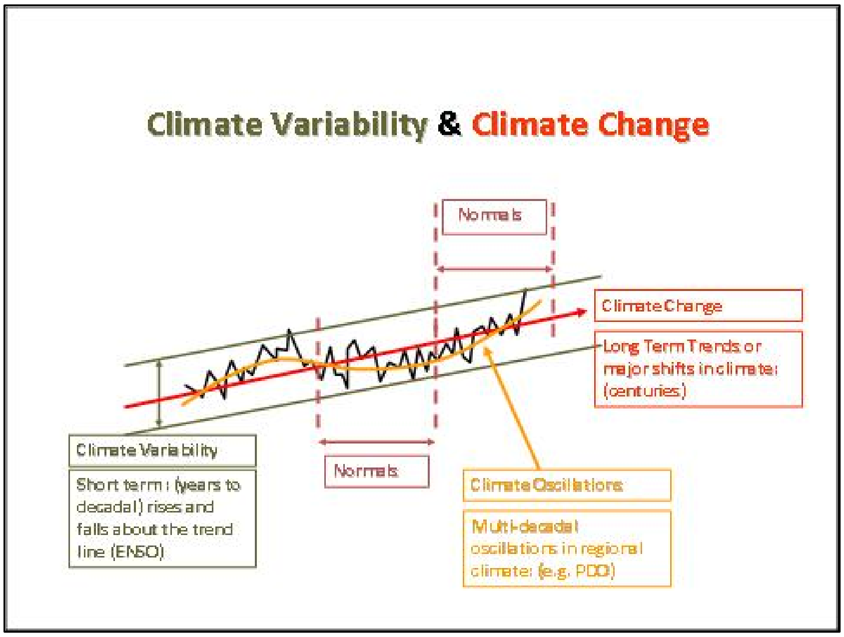


Figure 1. Climate will continue to vary year-to-year and decade-to-decade around long-term climatic trends. The primary large-scale drivers of climate variability in Pacific Northwest and Northern Rockies are the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Source: Rick Lee, Pacific Climate Impacts Consortium, Victoria, British Columbia, Canada.

Observed 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% 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 (US EPA 2008). The rate increased to 0.59°F per decade during the period 1976 to 2006 (US 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. (US 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% over the period of 1901 to 2005, with significant variability over time and by region. 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). 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).

The Pacific Northwest1

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 Winter temperatures increased more than summer (Mote 2003; Hamlet and Lettenmaier 2007;). Minimum daily

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temperatures rose faster than maximum daily temperature through the mid-20th century (Mote 2003; Hamlet and Lettenmaier 2007).

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) 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 Region One National Forests. The annual mean temperature there increased 2.5°F from 1913 to 2002, based on the average of five weather stations. (Murdock et al. 2007). Again, minimum (nighttime) temperatures increased more than the average daily maximum temperature. Annual precipitation increased 26% from 1913 to 2002, but changes were highly variable among the five stations.

[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.

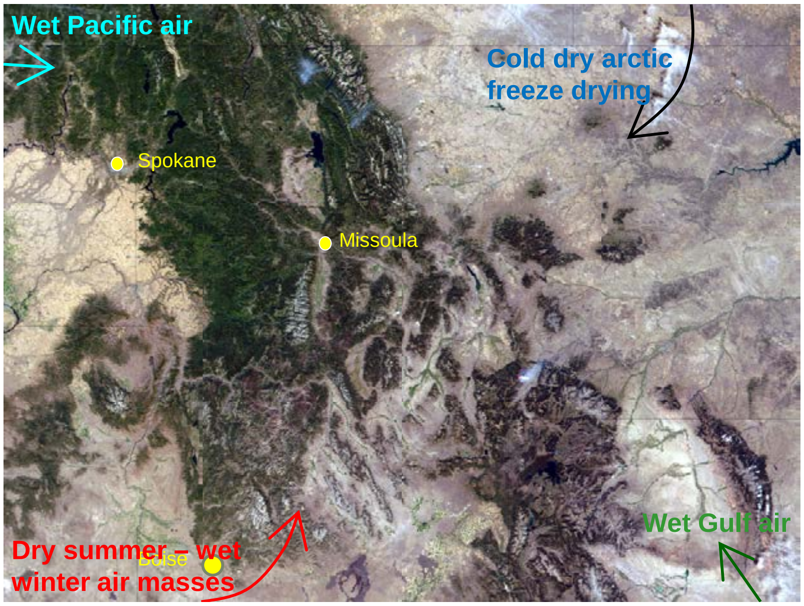
Weather and Climatic Extremes

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;).

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 in 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. 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.

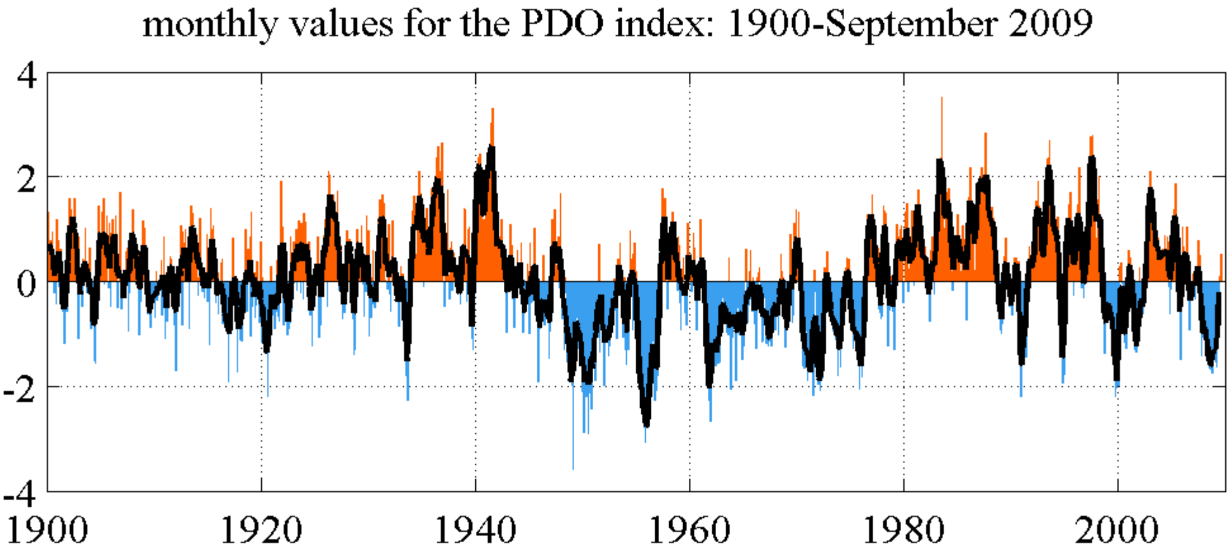
Trends in the northern Rockies

The ecological context for management in the northern Rocky mountain forests is the interaction of effective water availability (moisture, temperature and soils), disturbance processes, and the pattern of vegetation resulting from those interactions. As we take a look at a satellite image of the northern Rockies forest ecosystem, several important climatic observations can be made.

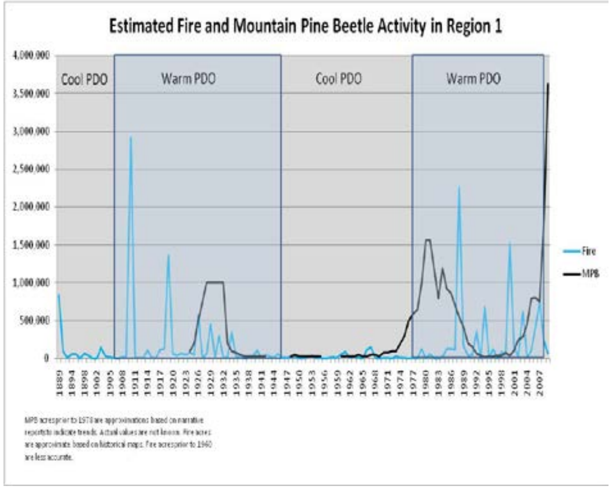


The pattern of forested region is surrounded by high prairie or desert – scablands to the west, great basin desert to the south, and shortgrass prairie of the Great Plains to the east, all of which do not receive more than 11 inches of annual precipitation per year. Naturally trees start to establish where precipitation is greater than 15 inches per year in the semiarid west. This occurs where ever you have mountains, that lift air masses coming from the Pacific and cause them to cool, thereby causing condensation to occur and rain or snow to fall. This orographic effect is the reason we have forests here. In the western portion of the northern Rocky Mountains the warmer pacific maritime air mass dominates producing upwards of 30-40 inches of precipitation each year resulting in grand fir western red cedar, white pine and western hemlock dominated forests in northern Idaho. There are also air masses that can move across this region from the SW – crossing California and Nevada and bringing little moisture, but dry thunderstorms with lightning when they hit the mountains and valleys of southern Idaho and Montana. Also, dry cold air masses sometimes are pulled out of north-central Canada, bringing high winds, very dry air, and in winter, very cold temperatures with them. The big fire years we have had have been the result of dry lightning storms causing ignitions followed by a shift in weather that pulled dry winds from the North East. Finally, central and eastern Montana may get humid air masses circulating northward from the Gulf of Mexico. Although these rarely reach western Montana, they are responsible for providing moisture to the Bull Mountains, Custer National Forest and Black Hills. Normally these areas are too far East for Pacific Moisture to reach them. Looking at the big scale, water availability is the primary determinant for our western forests, and because summer drought is a common phenomenon, and lightening caused wildfires are another important factor.

In addition to a spatial arrangement, forests have been affected by climate, weather and disturbance in a temporal context as well. Over the past century the occurrence of wildfires has varied greatly. Shown below are the numbers of acres that have burned. First analysis of the phenomenon seemed to show that after the wildfires of the early 1900's and the development of the US Forest Service as an effective fire fighting force, that fire suppression was very effective until fuels built up through natural forest growth and mortality to the point where fires were unstoppable, hence the increase in fires over the recent decades. However, an analysis of climatic patterns over this time period has shown another significant influence. The northwestern U.S. is heavily influenced by a cyclic phenomenon called the Pacific Decadal Oscillation. Similar to El Nino and La Nina this weather trend is related to oceanic temperatures in the northern Pacific Ocean. Fluctuation in the last decade is illustrated below as well. Clearly cool wet trends, such as the past few years resulted in lower wildfire occurrence regardless of the fuel loading across the region. Climate is the most controlling factor for wildfire and the one we can least influence.



When these trends are overlayed on the fire statistics an interesting correlation is seen. A period between 1940 until 1980 was in the cool wet phase, which would have limited wildfires while at the same time promoted tree growth, regeneration and significant increases in forest density. An increase in Mountain Pine Beetle in the Northern Rockies, including three MPB outbreaks in the last 100 years, all have occurred during the warm phase of the PDO. The current outbreak is within the spatial footprint of millions of acres of young forests being created by disturbance factors around the turn of the century 1880-1930.

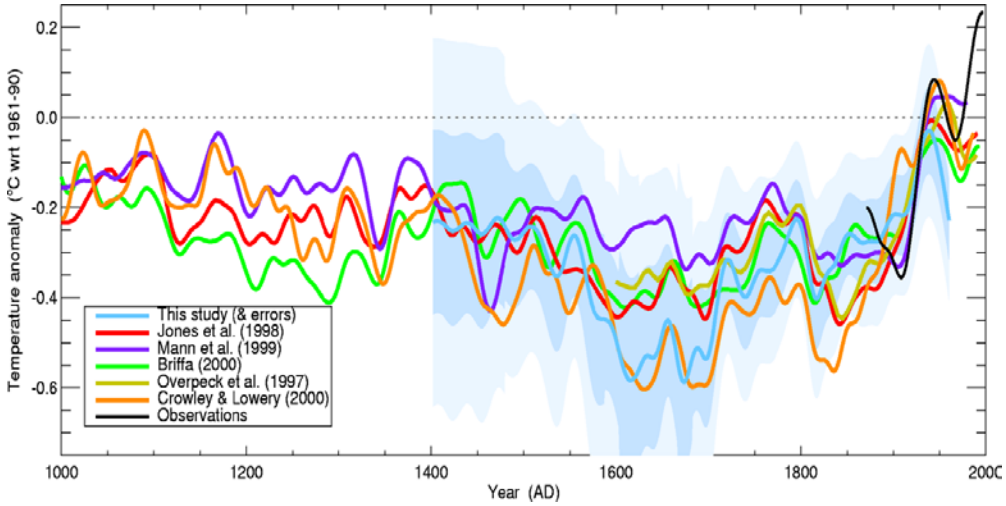


MPB acres prior to 1978 are approximations based on narrative reports to indicate trends. Actual values are not known. Fire acres are approximate based on historical maps. Fire acres prior to 1960 are less accurate.

A more detailed comparison between PDO fluctuations and documented extreme forest wildfire years shows another correlation. When these are compared to PDO fluctuations is becomes clear that severe fire years tend to occur almost exclusively when warm weather spikes follow cool wet weather cycles. The cool wet weather promotes rapid vegetation growth whereas following warm dry cycles cause mortality and dry fuel conditions. This correlation is also supported by a more recent study of climate and fire correlations across the Northern Rockies by Heyerdahl, Morgan and Riser - Ecology 89(3) 2008. Climatic patterns therefore appear to be a major driver of severe and widespread wildfire effects across forests. This is more recently evidenced by the fire patterns between 2000 and 2007. Although our forests have not changed much, the cooler summers of 2008, 2009, 2010, and 2011 have resulted in few major fires in the northern Rockies although fuel conditions and fire suppression capabilities have not changed during this time frame.

Projected climate trends in the northern Rockies

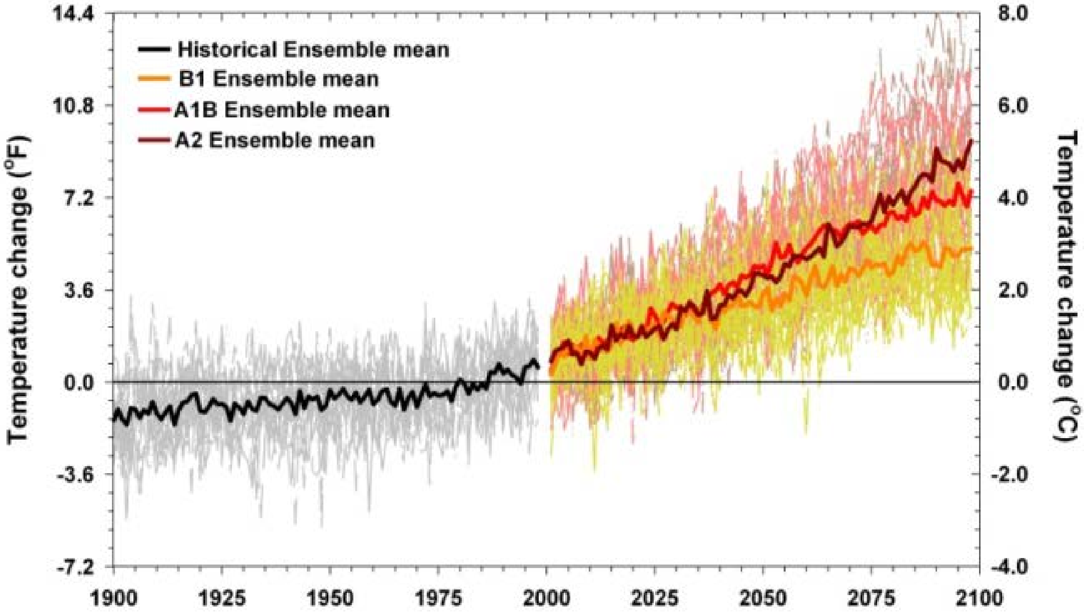
This brings us to climatic trends and what we can expect will influence the pattern of forests in the northern Rocky Mountains in the future. This is one example of a climatic reconstruction diagramed below and the rapid increase in mean seasonal temperatures in recent decades. (Briffa 2001) From historic reconstructions it becomes very evident that our climate has always been in a state of flux even without the more modern influence of human fossil fuel and land cover changes. The medieval optimum in the 1000 -1200 period was followed by the mini-ice age that we have only recently emerged from. Based on these trends, the warmer period we are currently in may naturally persist for many decades if not centuries.



Low-frequency temperature variations from a northern tree ring density network

In a recent study (Climate Change primer of the Northern Rocky Mountains) of climate trends by Littell, "summarized temperatures increased ~1.2°F (0.7°C) for maximum temperature and ~2.1°F (1.2°C) for minimum temperature averaged for Northern Rockies stations, 1916– 2006. (Littell 2011) (This is comparable to the U.S. national average of 1.1°F (0.6°C) for the same period. http://www.ncdc.noaa.gov/oa/climate/research/cag3/na.html 77% of stations had increasing maximum temperature, and 94% of stations had increasing minimum temperature. The change in annual precipitation, averaged over the region, was an increase of +9.0% since 1916 (Littell 2011), slightly more than the U.S. national average of about 8.1%. Precipitation increased at 81% of stations, and the increase was primarily in spring, summer, and fall (Littell 2012)."

For projected trends in that study "all global climate models (GCMs) (Meehl 2007) project surface temperature warming in the Northern Rockies in all seasons regardless of uncertainties in modeling or greenhouse gas emissions. (Nakicenovic 2000) These projected temperature increases exceed observed 20th century year-to-year variability, generally by the 2040s. Many climate models project increases in precipitation during the winter and decreases in summer, however, projected precipitation changes are comparable to 20th century variability. Beyond mid-century, climate change projections are less certain because they depend increasingly on greenhouse gas emission rates in the next few decades." For a more complete discussion of projected trends in temperature, moisture, snowpack declines and other related topics including uncertainty, refer to **"Climate Change Primer"** (LINK here) for those details.

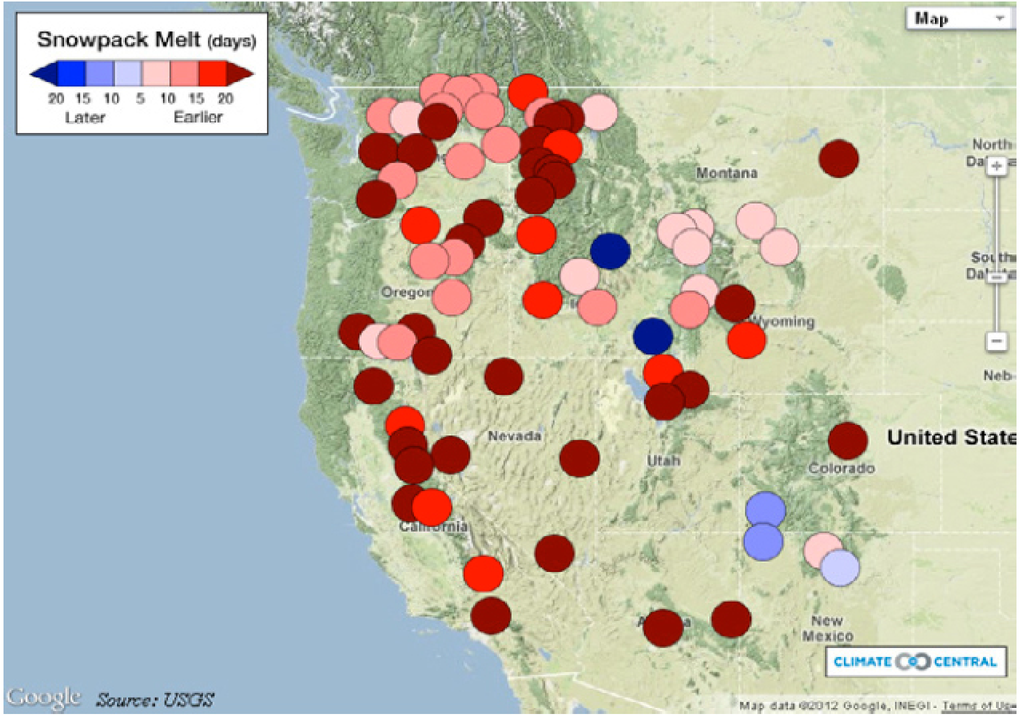


Northern Rockies and 2001-2099 (color). Heavy lines are ensemble (multiple climate model) averages for B1, A1B, and A2 emissions scenarios.

Projected trends in hydrologic processes as a result of projection of climate

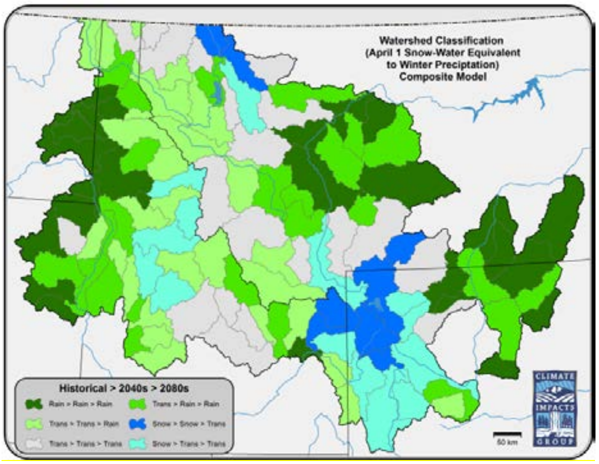
Referring to the same “Climate Change Primer” a study of hydrologic trends was assessed. Hydrologic models use future temperature and precipitation along with local information on soils, vegetation, and other conditions to simulate the hydrologic outcomes of climate change. In the Northern Rockies, snowpack is important in governing stream flow, soil moisture, and plant available water. Declining snowpack and soil moisture therefore are likely to affect the region by affecting water availability, plant growth, regeneration success and disturbance factors such as fire risk. This is a phenomenon across the west.

Snowmelt is Happening Earlier in the Spring in the West



Source: USGS

In watersheds where winter precipitation is currently dominated by rain instead of snow, changes in snowpack will not be as profound as "transitional" watersheds where more cool season precipitation currently accumulates as snow. In the highest watersheds, where most cool season precipitation currently falls as snow, temperatures are historically cold enough that watershed hydrology will be less affected by warming until later in the 21st century. Below are maps of watershed snowpack vulnerability, defined as "rain dominant" (<10% current cool season precipitation in April 1 snowpack), "transitional" (10% to 40%), and "snow dominant" (>40%). Most transitional watersheds become rain dominant, and all snow dominant watersheds become transient by the 2080s under this modeled scenario. (Littell 2012) Due to warming temperatures, a higher proportion of precipitation falls as rain during the cool season (Oct. – Mar.) and spring snowpack begins to melt earlier. Snowpack declines are largest at lower elevations. Warmer temperatures cause earlier snowmelt and higher summer evapotranspiration, leading to declines in summer soil moisture. Declining snowpack and increasing water balance deficit are therefore are likely to affect the region by affecting water availability, and plant growth.



Projected changes in the ratio of April 1st snowpack to total cool season precipitation (Oct. – Mar.) for the 2040s and 2080s in the Northern Rockies for the average of 10 climate models. Some watersheds remain transitional, but most historically transitional watersheds become rain dominant and most historically snow dominant watersheds become transitional.

Current Stressors

As we consider past variability and add to that the projections in temperature and precipitation, there may be significant changes occurring across our forests due to a changing water balance and the role of disturbances such as wildfires, insects and diseases. Whether it is invasive species (e.g., white pine blister rust), drought, uncharacteristic wildfires, elevated native insects and disease levels, loss of historically fire adapted tree species, unusually high forest densities compared to historical conditions or some other agent or combination of agents that serves to stress trees and forest ecosystems, recent research suggests that climate change will likely exacerbate those stressors and "stress complexes" will continue to manifest themselves (McKenzie et. al. 2009, Littell et. al. 2010,).

Landform and soils related to moisture deficit and drought as a stressor

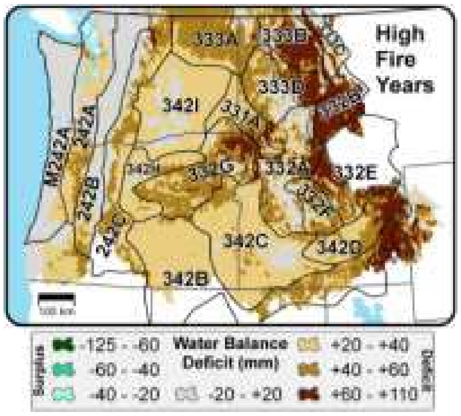
Aspect is another important part of mountain ecosystems as it determines how much sun energy influences microclimates, particularly site water balances. This is demonstrated by these pictures where there is just enough annual precipitation to allow trees to establish on more northerly aspects. Trees grow off soil stored moisture where the sun does not evaporate rain or snow off the soil surface before it can soak into the soil.

The soil type and depth, aspect, and elevation all contribute to effective moisture availability for tree establishment and growth producing patterns of forests in the semi-arid west.

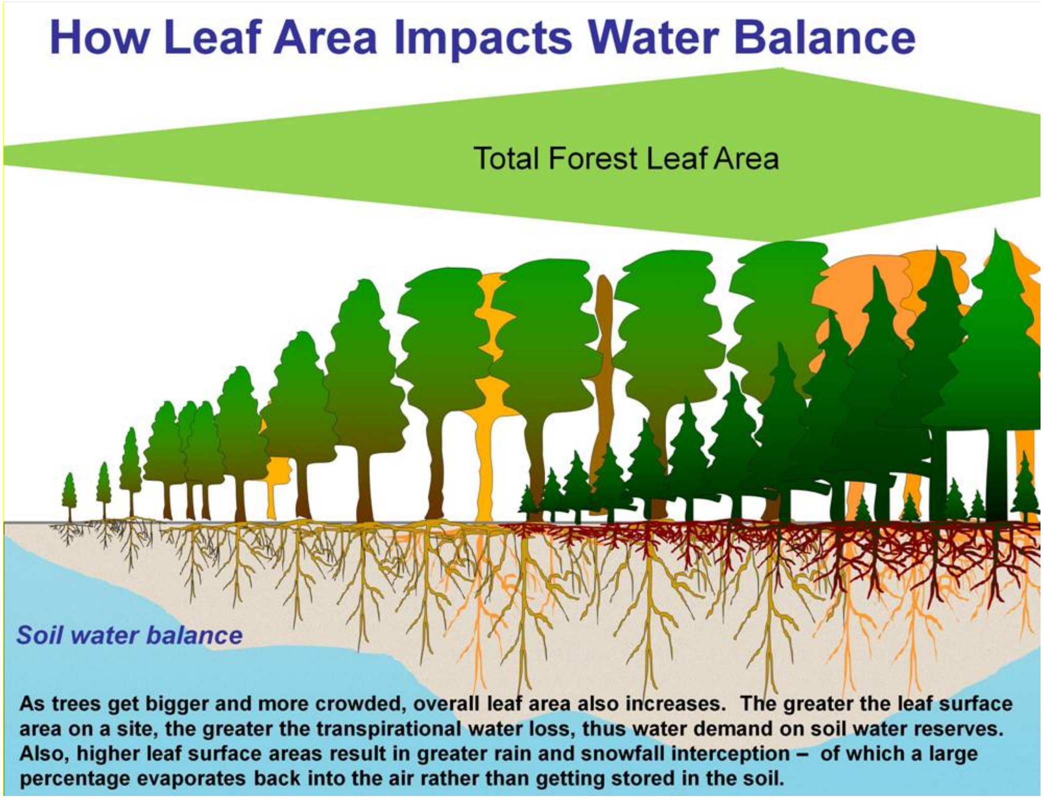
Additionally the impact of stand condition on overall water balance and the affect site and soil conditions impact moisture availability for forests is important to consider. In an effort by the Montana Natural Resources Conservation Service (NRCS) and the Natural Resource Information System of the Montana State Library, Relative Effective Annual Precipitation (REAP) was identified in a series of GIS maps across the State of Montana. http://nris.mt.gov/nrcs/reap/index.asp

“REAP is an indicator of the amount of moisture available at a location, taking into account precipitation, slope and aspect, and soil properties. Two sites that receive the same amount of precipitation may have very different **effective precipitation** due to other site factors. Depending upon the geographic location within Montana and varying with degree of slope, actual precipitation for southerly aspects may be adjusted downward and northerly aspects may be adjusted upward, also varying on degree of slope. Neutral aspects (all slopes less than 15 percent as well as neutral compass points regardless of slope) were not adjusted up or down.” These map data then provide a spatial pattern index for relative moisture availability across the landscape.

In other studies by Littell and others, high water balance deficits were correlated with large fire years reinforcing the relationship between climate, drought and severity of disturbance from fire, particularly in the northern Rockies. (Littell 2011, McKenzie and Littell. 2011) The diagram below illustrates this relationship.



As noted previously, future climate change models indicate that Northern Rockies forests will have longer drier summers and warmer conditions as well. The diagram below illustrates the overall water balance within a forest as it changes over time. Overall soil water balance determines which tree species can ultimately survive on a specific site. Pioneer (seral) species such as ponderosa pine have the unique ability to establish on bare soil surfaces where high surface temperatures (>150 degrees F) exclude other species. One of the adaptations of these seral species are deep rooting characteristics that allows the tree to find an adequate water supply and avoid extensive competition with shallow and fibrous rooted grasses and forbs. As the shade from these species limits sun loving grasses and forbs, shade tolerant tree species establish and grow, and these species usually have a shallower rooting characteristic that allows them to gather soil water from the nutrient rich soil surface. The overall rooting structure in essence becomes much more competitive as succession progresses. In addition the overall leaf surface area that develops over time on a given site increases. Grass/forb and shrublands usually develop a maximum total leaf area of about 3 ft^2 per 1 ft^2 of soil surface area. Forests can develop leaf areas in excess of 6ft^2 per 1 ft^2 of soil surface area. With increasing leaf area comes increased water transpiration that can deplete the soil water storage capacity needed to keep trees hydrated throughout the summer. The additional dense forest canopy interception of rain and snow, which directly evaporates back into the atmosphere (snow sublimation), further compounds this effect reducing soil water recharge. The end result is a water stressed forest, that not only becomes more susceptible to insect and disease, but also more prone to supporting severe wildfires because live fuel moisture is relatively low. Although live fuel moisture has historically not been considered highly important in impacting wildfire behavior, more recent evidence has indicated that the probability of a forest developing and supporting a crown fire is significantly increased when live fuel moistures are low, as would be the case for water stressed forests.


How Leaf Area Impacts Water Balance

As trees get bigger and more crowded, overall leaf area also increases. The greater the leaf surface area on a site, the greater the transpirational water loss, thus water demand on soil water reserves. Also, higher leaf surface areas result in greater rain and snowfall interception – of which a large percentage evaporates back into the air rather than getting stored in the soil.

Disturbance processes as stressors

Wildfire

Historically fire was a major disturbance process that shaped forests of the past.


However, fire is also not a simple process. Depending on the fuel loading - determined in part by site productivity – and the average climatic conditions and local topography and soils, different forest ecological zones typically experienced different wildfire regimes.

<u>Low-severity (nonlethal)</u> fires are typically underburns that kill very little of the overstory tree canopy. They are most important on drier habitat types where conditions are dry enough to burn more frequently. Mean fire return intervals typically range from 7 to 30 years (Smith and Fischer 1997). Low-severity fires typically remove most small understory trees, particularly the more shade-tolerant, fire-intolerant species. On drier habitat types where these fires are common, the frequent burns maintain a large portion of the

landscape in relatively open stands of large, shade-intolerant, fire-tolerant species (larch and ponderosa pine with some areas east of the continental divide open grown Douglas-fir).

With the aid of a cool PDO and a cool and moist regional climate from 1940 to 1980, the Forest Service has been suppressing wildfires for many decades. Suppression efforts have been particularly effective for low and mixed-severity fires, virtually removing this agent as a significant disturbance process for the last 60 years. Rapid suppression of all fire starts has also provided the opportunity for fires to grow in size and intensity to become stand-replacing fires.

Mixed-severity fires kill a moderate amount of the overstory tree canopy, but do not replace the whole stand. Areas that had variable periods of drought also had variable fire impacts. This "mixed" fire regime is defined as historically burning with a severity that killed trees across a range of 20 to 80 percent of the landscape – hence a patchy type of fire effect. Mean fire return intervals typically ranged from 55-85 years, depending upon landscape location. On very moist sites they may have been significantly less common, while on drier sites return intervals were 25 years or less (Smith and Fischer 1997; Zack and Morgan 1994). Mixed-severity fires create an irregular patchy mosaic of small to moderate-sized openings, thinned areas, underburned areas, and unburned areas. Mixed severity fires generally prolonged the period of dominance by early successional fire-adapted species and at a larger scale, allowed for the development of mature and old growth structural stages dominated by large trees. A classic example of this is the influence periodic under story burning has to release western larch from competing vegetation. This periodic thinning effect in stands of larch dominated Old Growth stands at Coram experimental forest allowed for this late stage seral species to be maintained in the forest. (Elzinga, Shearer 1997) Fire also played many additional ecological roles as a carbon and nutrient recycling agent, dormancy breaking and stimulating agent for herb and shrub seeds and sprouts, and creator of tree cavities and snags (used by wildlife). Historically, mixed-severity fires were extremely variable in size (less than one acre to more than 1,000 acres) and introduced both variable sized patches and internal diversity within larger blocks created by the less frequent stand-replacing fires.

Stand-replacing (lethal) fires are those that result in killing most of overstory tree canopy over a significant area and restarting the successional sequence. Historically, on landscapes dominated by moist habitat types such as those occurring in the warm/moist biophysical setting) , the mean fire return interval was approximately 200 years for stand-replacing fires (plus or minus 80 years), with slightly drier sites burning more frequently and wetter sites burning less frequently (Smith and Fischer 1997; Zack and Morgan 1994). Examples include moist areas in northern Idaho and portions of northwestern Montana and the cold areas around Yellowstone National Park. The fire-adapted, shade-intolerant tree species in these ecosystems commonly live 140 to 400+ years. Because the historic mean stand replacing fire return interval was shorter than the life-span of many shade-intolerant early successional tree species, these fire regimes trended forest succession towards dominance by fire-adapted, shade-intolerant, potentially long-lived early seral tree species (ponderosa pine, larch, white pine, whitebark pine and lodgepole pine east of the continental divide).

Major fire years occur most commonly during regional summer droughts. Lightning storms and wind contribute to the likelihood of a major fire year. During major fire years, stand-replacing fires were commonly on the order of tens of thousands of acres, with some individual fire patches 50,000 acres or larger (Pyne 1982; Zack and Morgan 1994). During major fire events some watersheds were almost entirely burned over, while other large areas were unaffected. In any particular watershed, major stand-replacing disturbances came in pulses, with long intervals between the pulses. These pulses during the last 100 years were synchronized with a warm PDO and resultant hot and dry local weather. (Morgan 2008)

While stand-replacing fires favor long-term dominance by early successional, shade-intolerant tree species, the mean time interval between stand replacing fires was long enough to allow development of mature and old growth forest structural stages, particularly in locations where fire intervals tended to be longest.

Re-burns of fires have occurred throughout history. Re-burns have been associated with, and have normally followed, severe fire years that have burned in high intensity conditions. Stand-replacing fires can create a high fuel loading in both standing and down wood. When these fuels season after several years, the load becomes a strong candidate for re-burn when high temperatures, low humidity, and winds combine.

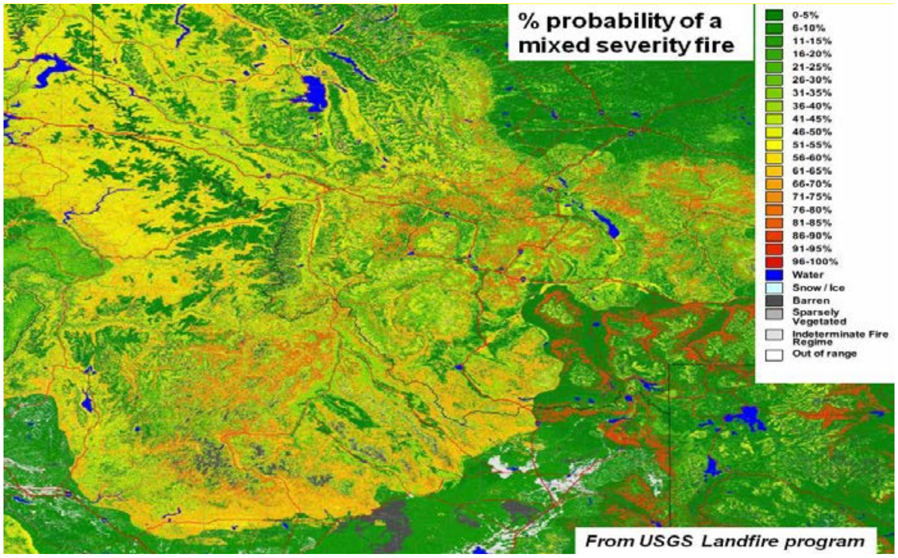
These disturbances of large, infrequent stand-replacing wildfires created a dynamic shifting mosaic of forest successional stages on a very large scale. In between the stand-replacing fires, vegetation, aquatic systems, and wildlife habitat had long periods to develop. Intermediate disturbances (low and mixed severity fire; some insect, pathogen, and weather events) introduced finer scale variability within these larger patches. As a result, blocks of wildlife habitat tended to be large, and blocks of mature/late-successional forest also tended to be large, but internally diverse.

The success of fire suppression efforts aided by a cool PDO, and resource management activities over the last 100 years has had a large influence on the structure and composition of forest. The function and process of ecological systems has changed and fire suppression and some management activities have altered fuel loadings. The influence that climate change may have upon the occurrence and types of wildfires in the future is that projected climate changes are likely to increase the frequency of large fire years in the Northern Rockies and that fire seasons will be longer. Some of the modeling efforts have suggested that by the 2080's, the amount of area burned by wildfires in the Pacific Northwest region (including Idaho and western Montana) would double or triple (Littell 2010). In addition the potential pattern of large scale fire due to the current homogeneity of the regional landscape could reduce the ability of forests to regenerate due to lack of seed source, thereby reducing the potential for ecosystem services society depends on. (Turner 2012)

Below are examples of a frequent low severity fire that only kills a few mature trees, many seedling and saplings thus keeping the forest open and that stays as a low intensity fire, acting as a nutrient recycling mechanism. In this case ponderosa pine is better adapted to frequent fire whereas Douglas-fir seedlings are not. The forest pattern in this case was dominated by a mosaic of open grown large diameter trees with some openings interspersed with younger sapling and medium sized trees.

Mixed severity fire regimes on 30 to 70% of the landscape produced lager patches of regenerating, previously severely burned forests in a mosaic pattern of patches of various sizes with some within patch tree surviving similar to below.

Data sources such as landfire and potential natural vegetation (Habitat types) were used to assess the historical mixed severity fire regime distribution. The mixed severity type likely was the dominate fire regime in many areas of Montana and northern Idaho. This likely enabled much diversity of species composition, and successional stage diversity to develop across large landscapes. This diversity enabled forest to cope with disturbance agents resulting in a resilient forest condition.



From USGS Landfire program

And lastly infrequent high severity fire affected > 80% of the landscape in a stand replacing fire.

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).

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 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,Westerling 2011);
- 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, Marlon 2012); and
- Increased risk of property and resource loss (Westerling and Bryant 2008; Nitschke and Innes 2008).

Also see the primer on Wildland Fire and Climate Change for more discussion.

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.

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).

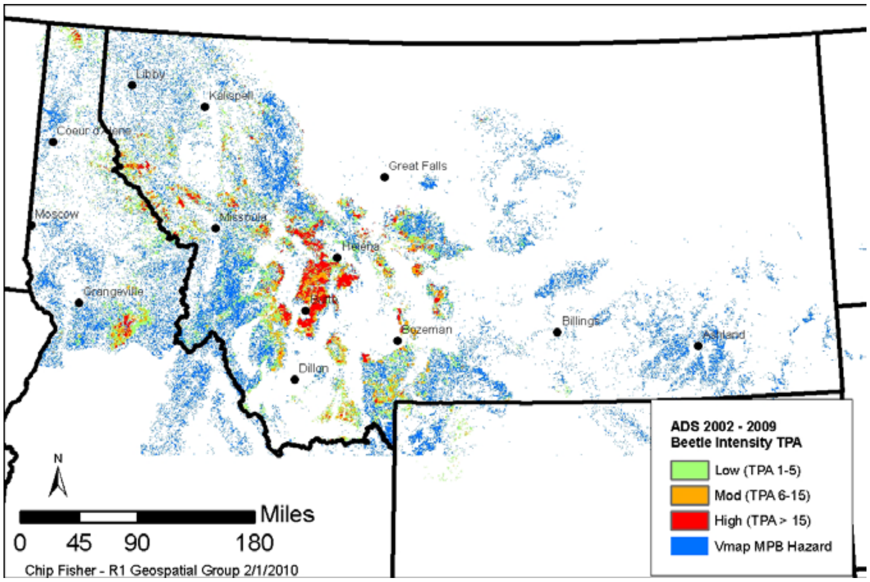
Climate change effects on ENSO and PDO —The El Niño Southern Oscillation (ENSO) has been shown to influence winter and spring temperature and precipitation in the Pacific Northwest, and the positive phase of the Pacific Decadal Oscillation (PDO) is associated with 20th century large fire years in the 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).

The influence of bark beetles as a stressor to forests

An additional effect of reduced amount of disturbance beginning in the 1940s under a cool PDO and fire suppression has been the homogenization of the size class of lodgepole pine forests. The departure in pattern of these lodgepole pine forests in central Montana, central and western Canada and further south into the central Rocky Mountains set up conditions for forests to be susceptible to the Mountain Pine Beetle (MPB) at the same time. In addition to wildfire disturbance, bark beetle outbreaks have influenced patterns of vegetation throughout the northern Rocky Mountains. Mountain Pine Beetle and lodgepole pine have coexisted for thousands of years and have influenced the pattern of vegetation in many locations. MPB is very responsive to habitat and climate conditions. Bark beetle outbreaks require large expanses of susceptible-aged and homogenous forest. Outbreaks tend to occur during warm and dry conditions and can cease following extreme winter cold (Logan wt al, 1998) Outbreaks also require an abundance of suitable habitat for the insect to attack and reproduce. (Amman and Anhold 1989;McGregor et al. 1981, and Safranyik 1992) Over the course of the 20th century, MPB has caused wide-spread tree mortality in the northern Rockies. (Evenden 1934; Evenden 1944) Outbreaks in Idaho and Montana during the 1920-1930s and from late 1970s to early 1980s including large areas in northwestern Montana, killed lodgepole pine to the extent similar to the most recent outbreak since 2000. (Cole and Amman 1980; McGregor and Cole 1985) Over the last decade MPB activity has increased in high elevation whitebark pine across much of the western US and Canada. (Gibson et al. 2008) Populations in these high elevation stands are at levels higher than previously recorded even though an outbreak did occur in the 1920s in whitebark pine.

The current outbreak and severity of mortality linked to the pattern of susceptible host tree species (Lodgepole pine, Ponderosa pine, whitebark pine) is illustrated in the map below.



Chip Fisher - R1 Geospatial Group 2/1/2010

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).

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.

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.

Pathogens, white pine blister rust as stressors

Historically, root pathogens most commonly acted as thinning agents. In natural mixed-species stands, root pathogens caused the greatest mortality in Douglas-fir, followed by true firs. White pine and larch were the most resistant tree species (Hoff and McDonald 1994; Monnig and Byler 1992). Root pathogens thinned out the Douglas-fir and favored the pines and larch, which increased the amount of pine and larch over the first 150+ years of stand life (Rockwell 1917).

Historically, western white pine was a common tree species, particularly within areas of western Montana and northern Idaho, and dominated a very large part of the mixed mesic forests types. (see map on page 48)In the early part of the 20th century, white pine blister rust (a Eurasian disease) was accidentally introduced to western North America. This exotic disease, combined with a MPB outbreak in WP in northern Idaho in the late 1930s , has been the primary cause for the loss of white pine in this area (Neuenschwander et al. 1999). With the loss of white pine, there have been large increases in the amount of Douglas-fir, grand fir and subalpine fir cover types, and a major acceleration of forest succession toward shade-tolerant, late-successional true firs, hemlocks, and cedars.

Efforts were made to control blister rust through eradication of the alternative hosts, currant and gooseberry. Although these methods had been somewhat successful in the eastern United States, topography and landscape scale in the west prevented success. The program was dropped in 1968 (Neuenschwander et al. 1999). Applications of antibiotics also proved unsuccessful and emphasis has shifted to development of genetically rust-resistant trees that can be planted throughout the natural range of white pine. There have been successes in genetically improving tree resistance, planting those trees and then using cultural treatments like pruning to improve survival (Schwandt, Marsden, and MacDonald 1994). These programs are continuing today. It is recognized that the best strategy to save white pines from blister rust is to increase the numbers of rust resistant white pines in these ecosystems by aggressively planting them in openings (Samman et al. 2003, p. ii; and Fins et al. 2001, p. 10). It is believed that this pine tree has a genetic memory that has persisted over the 190 million years since white pine's ancestors last had contact with the fungus (Millar and Kinlock 1991).

Historically, western white pine had an important ecological role in forests of the Interior Northwest (Harvey and others 1995; Monnig and Byler 1992). Especially important was this species ability to form a stable, relatively long-lived, forest that was perpetuated by a combination of mixed-severity and stand-replacing wildfires (Zack and Morgan 1994). Even though fire occurred in this forest type fairly regularly, old-growth structures often persisted for several centuries.. Across its range, western white pine is now estimated to be less than 5 percent of what it was at the turn of the 20th century (Neuenschwander and others 1999).

With the impact of white pine blister rust and the decrease in fire, the role of insects and pathogens as disturbance agents is growing and changing. White pine blister rust accounts for major changes in forest successional patterns, having removed more than 90% of two conifer species (white pine and whitebark pine) in the western portion of the Region. Mortality caused from white pine blister rust and mountain pine beetle in whitebark pine east of the continental divide has greatly accelerated in the past decade, decimating much of the forest type in that area. With the absence of white pine and decreased amounts of ponderosa pine and larch, root pathogens have been transformed from thinning agents into major stand-change agents in Douglas-fir and true fir stands. Root pathogens now produce significant canopy openings on many sites. Depending upon the habitat type, root pathogens may either stall stands in a diseased shrub/sapling/open pole successional stage, or strongly accelerate succession towards shade-tolerant species. Because of the large change in the composition of the forests in the area, it has been suggested that the genetic strategy of the dominant conifers may change (Rehfeldt, 1994). In the historic forests that were dominated by seral tree species, insect and diseases probably served as stabilizing agents, removing the maladapted late seral and climax species early in stand development, which would preserve only the best climax trees and favor the dominance of the long-lived seral species (Harvey and others 1999).

The two most significant native pathogens in the Northern Rockies 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. Root disease has on average reduced forest canopy cover by 20 to 30 percent in infected stands.

Native and non-native pathogens are also now responsible for a relatively much larger proportion of forest disturbance than they were historically. The impact of all these pathogens in the short-run is to strongly accelerate succession towards late seral, shade-tolerant tree species. An analysis of pathogen and insect impacts in northern Idaho and western Montana (ecosections M332a and M333d as described by Bailey et al 1994) by Hagle et al. (2000) examined successional changes for the period 1935 to 1975. This analysis shows that in 40 years, pathogens and insects changed forest cover types to more late-successional, shade-tolerant tree species on over 80% of the area dominated by moist forest habitat types (Byler and Hagle 2000). The same analysis of insect and pathogen impacts also showed that almost 40% of the moist habitat type area analyzed was either stalled in small tree structures or was actually moving back towards the small tree structures as a result of the removal of the largest trees.

Root diseases have a substantial, and perhaps the most significant, effect on forest carbon stocks and flux on forests of western Montana and northern Idaho. Thus, moderate and high severity root disease centers are a major source of forest mortality and a long-term constraint on forest carbon sequestration rates.

Typical root disease centers of moderate severity. Note the dead standing trees, reduced stand density, loss of crown cover, and substantially lower productivity. Because these effects persist for long periods until disease resistant tree species are able to occupy the site, root diseases limit forest carbon stocks and sequestration rates for longer periods than other disturbances.

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). In Kliejunas et. al. (2009) a literature review is presented of climate change and forest diseases of Western North America. It is generally believed that climate change will lead to reductions in tree health and will improve conditions highly damaging pathogens such as root disease.

Noxious weeds/invasive species as stressors

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, 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.

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, the western portion of the Region 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.

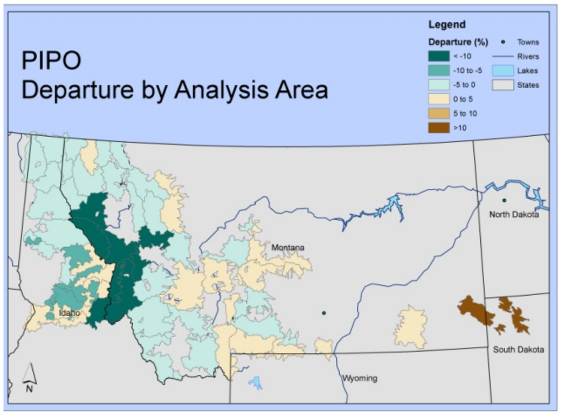
Trends in historical range of variation (HRV) and departure as related to forest vulnerability and resiliency

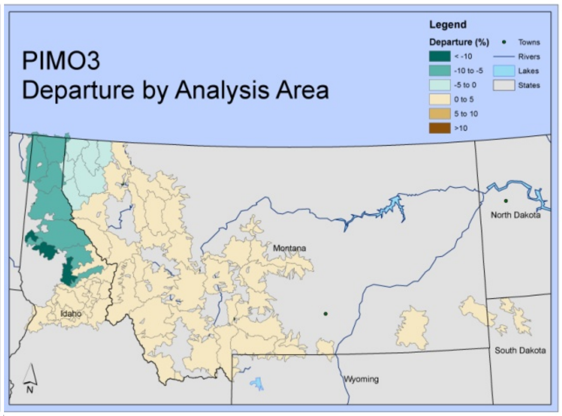
As a way to understand the various ecosystems on the Forest and sustain the biodiversity within them, it is necessary to have some reference for understanding the potential productivity of the land, the natural diversity of the relevant ecosystems, and what processes sustain this productivity and diversity. During the last two decades, ecologists have increasingly relied upon reconstructions of historical ecosystem structures and processes to gain ecological understanding. These historical reconstructions have come to be called the Historic Range of Variability (HRV) and utilize the concept of historical/natural conditions and processes within some range (Dillon 2005; Meyer 2005; Nonaka 2005; Brown and others 2004; Tinkler and others 2003; Veblen 2003; Reynolds 2003). The concept of ecosystem ranges of variability has been suggested as a framework for coarse filter conservation strategy (Landers et al. 1999). Historic Range of Variability concepts were developed in part to better understand how disturbance, vegetation, and other ecosystem components interact, and in turn how interaction affects biophysical characteristics such as plants, animals, fish, and soil and water resources. Historical perspectives increase our understanding of the dynamic nature of landscapes and provide a frame of reference for assessing current patterns and processes (Swetnam et al. 1999). The Northern Region Forests have followed this process in developing a HRV for vegetation and defines it as the range of variation in spatial, structural, compositional, and temporal characteristics of ecosystem elements as affected by climatic fluctuations and disturbances. The major fluctuations in climate that have happened over the last 100 Years have dramatically influenced vegetation. The HRV analysis focuses on forest composition, structure, landscape pattern, and processes (disturbance and succession) and has been used to help inform desired conditions for the future. The concept of comparing current vegetation conditions to both the historical as well as the potential future conditions is described by Gartner et. al. (2008). In summary, this approach is designed to provide insights into how ecosystems have changed, and how vulnerable they have become to stressors. As the % departure levels increase across the regional landscape, and as we factor in climate change affecting the increase in stressors that have been identified, this has become useful information to assess sensitivity and vulnerability to climate change related exposure. The knowledge gained from this approach can then be used to help "inform" adaptation activities and tactics in regard to management decisions that may need to be made regarding how climate change may affect future landscape conditions and how adaptation strategies are developed. (Keane et. al. 2008, Hayward et. al. 2012). Given these insights, climate change adaptive strategies such as fostering "resistance" and "resiliency" in the forest ecosystems can be considered.

Results of a comparison of HRV (translated into desired conditions in Forest Plan revision efforts) to current conditions for 55 analysis areas covering the forested landscapes in the Region One area can be viewed in a series of spreadsheets and viewed in relative departure maps in Appendix B. This information was summarized as part of the R1 Integrated Restoration and Protection Strategy (IRPS, http://www.fs.usda.gov/goto/r1/irps).

All Forests except the Gallatin, Helena, Custer, and Lewis and Clark used desired conditions identified in Forest Plan revision efforts that were informed by HRV. For those four Forests, HRV assessments were used as those Forests have not begun Forest Plan revision and so did not have desired conditions identified. These assessments were completed during Forest plan revision on assessment areas at the approximate scale of a 4th code watershed, averaging approximately 400,000 acres, using the landscape simulation modeling program SIMPPLLE as one of the tools to identify HRV for vegetation. VMAP, a map of current vegetation map for the Northern Region, was used in SIMPPLLE to help identify HRV values. Other data consulted were historical vegetation inventories, maps, reports, and pond pollen data. More information can be found in the Scenario 1B narrative and supporting documents (Reynolds et al. 2013).

Below are examples of departure from desired conditions (informed by HRV) for two species, ponderosa pine and western white pine. A more complete series of maps can be found in Appendix B.





Trends in tree species distribution

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 forests in the northern Rocky Mountains 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 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. 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% 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). The 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[2] 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, northern Idaho 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 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

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projecting moderate to substantial reductions. Appendix A 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-specific competition, species dispersal and migration processes, phenotypic and genetic responses of species, forest management actions, and other influences such as soils. 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 within 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 considers 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).

Summary of projected climate change related impacts and vulnerabilities

Extent	Potential climate change related impacts and vulnerabilities throughout the northern Rockies with exposure to warmer temperatures and dryer summers
Landscape	Warmer temperatures
	Less summer precipitation
	Longer growing season
	Greater moisture deficits, less available moisture for trees
	Increase in disturbance from insects and pathogens, fire, and potentially invasive species
	Altered disturbance regimes could lead to change in successional trajectories
	Tree species may have changed suitable or realized niche
	Noxious weed risk to native grassland and shrub-land communities may increase
	Landscape heterogeneity could be significantly reduced which will result in larger disturbance patterns and difficulty for regeneration of forests

Tree species

Ponderosa pine

Adaptive capacity	Ponderosa pine is a long lived seral species that is adapted to growing season soil moisture deficits and occurs to the dry portion of forests thus can compete with other vegetation by allocating resources to deep rooting capacity for regeneration success in dry environments. Adapted to fire in open forest conditions, and is moderately susceptible to bark beetles in those conditions. Ponderosa pine has a low susceptibility to root disease.
Departure	Decrease in aerial extent from HRV largely replaced by Douglas-fir, and significant increase in forest density in all settings and successional stages.
Sensitivity	Moderately sensitive to increasing moisture deficits, highly sensitive to uncharacteristic wildfire behavior. Very sensitive to regeneration success with loss of seed sources from large fires.
Exposure	With warming temperatures, and possible decrease in summer moisture drought may increase and affect distribution of ponderosa pine and associated stressors may increase in abundance.
Vulnerability	High vulnerability to uncharacteristic fire behavior and severity. Increase in susceptibility to bark beetle morality. Moderate change in species distribution expected away from driest margins. High potential for natural regeneration failure due to reduced seed source from large wildfire.
Uncertainty	Some uncertainty exists in the level and timing of precipitation in the future. Moisture deficits will increase even with moderate levels of increase in precipitation such that the stressors will still be in play with differing levels of magnitude of the increase.

Douglas-fir

Adaptive capacity	Highly adaptive to a large range of moisture and temperature gradients. In moist forest settings Douglas-fir is limited to a relatively short lived seral species due to the influence of root disease.
Departure	Increase in distribution in many forest settings. Has replaced ponderosa pine, larch and western while pine, and has added significantly to the densification of forest structure largely due to fire suppression.
Sensitivity	Moderately sensitive to increasing moisture deficits, highly sensitive to uncharacteristic wildfire behavior, root disease and very sensitive to spruce budworm defoliation especially in central Montana.
Exposure	With warming temperatures, and possible decrease in summer moisture drought may increase and affect distribution of Douglas-fir and associated stressors may increase in abundance.
Vulnerability	High vulnerability to uncharacteristic fire behavior and severity due to increased densities. Increase in susceptibility to Douglas-fir bark beetle morality uncertain but probably an increase. Moderate change in species distribution expected away from driest margins. High potential for natural regeneration failure due to reduced seed source from large wildfires and difficult micro climate especially on southerly exposures with increasing moisture deficits expected. On moist sites (mixed mesic forest), increases in root disease mortality due to increasing moisture stress on sites where western white pine, ponderosa pine and larch occurred historically. Less carbon sequestration expected in Douglas-fir in those forest settings.
Uncertainty	Some uncertainty exists in the level and timing of precipitation in the future. Moisture deficits will increase even with moderate levels of increase in precipitation such that the stressors will still be in play with differing levels of magnitude of the increase.

Grand fir (Mixed mesic forest)

Adaptive capacity	Grand fir is adapted to moist forest settings and is well adapted where fire frequency is historically low as it can regenerate in many forest structure settings as it is a tolerant to shade species.
Departure	Significant increase in distribution and density increase within the mixed mesic conifer portion of the Region due to fire suppression and intensive harvest of western white pine (western larch and ponderosa pine as well) after the introduction of white pine blister rust.
Sensitivity	Moderately sensitive to increasing moisture deficits, highly sensitive to increase in wildfire.
Exposure	With warming temperatures, and possible decrease in summer moisture drought may increase and affect distribution of grand fir and associated stressors may increase in abundance.
Vulnerability	High vulnerability to increased fire behavior and severity due to increased densities and less adapted to fire. Moderate change in species distribution expected away from driest margins. High potential for natural regeneration dificutly due to reduced seed source from large wildfires and difficult micro climate especially on southerly exposures with increasing moisture deficits expected. On moist sites (mixed mesic forest), increases in root disease mortality due to increasing moisture stress on sites where western white pine, ponderosa pine and larch occurred historically. Less carbon sequestration expected in those forest settings. Ponderosa pine, western larch and western white pine may have a restoration role in the mixed mesic setting where grand fir is currently abundant, but historically less common due to the inability to cope with stressors.
Uncertainty	Some uncertainty exists in the level and timing of precipitation in the future. Moisture deficits will increase even with moderate levels of increase in precipitation such that the stressors will still be in play with differing levels of magnitude of the increase. Fire stressor more certain and will not favor grand fir.

Cedar (Mixed mesic forest)

Adaptive capacity	Well adapted to warm and very moist settings with long fire return intervals.
Departure	Modest increase in distribution with loss of western white pine and effective fire suppression. Increases have often been into areas with historically higher levels of moisture deficit or less suitable areas for cedar. Increases in forest density have occurred. However these forests are characteristically, some of the densest in the Region.
Sensitivity	Sensitive to increase in moisture deficits, but is often found on sites with lowest deficits.
Exposure	With warming temperatures, and possible decrease in summer moisture drought may increase and affect current distribution of cedar and associated stressors may increase in abundance.
Vulnerability	High vulnerability to increase fire behavior and severity due to increased densities and less adapted to frequent fire. Moderate change in species distribution expected away from driest margins. High potential for natural regeneration difficulty due to reduced seed source from large wildfires and difficult micro climate especially on southerly exposures with increasing moisture deficits expected. On moist sites (mixed mesic forest), increases in root disease mortality due to increasing moisture stress on sites where western white pine, ponderosa pine and larch occurred historically. Less carbon sequestration expected in those forest settings. Ponderosa pine, western larch and western white pine may have a restoration role in the mixed mesic setting where cedar is currently abundant, but historically less common due to the inability to cope with stressors.
Uncertainty	Some uncertainty exists in the level and timing of precipitation in the future. Moisture deficits will increase even with moderate levels of increase in precipitation such that the stressors will still be in play with differing levels of magnitude of the increase. Fire stressor more certain and will not favor cedar dominance on dry margins.

Hemlock (Mixed mesic forest)

Adaptive capacity	Well adapted to warm moist settings with long fire return intervals.
Departure	Increase in distribution with loss of western white pine and effective fire suppression. Increases have often been into areas with historically higher levels of moisture deficit or less suitable areas for western hemlock. Increases in forest density have occurred. However these forests are characteristically, some of the densest in the Region.
Sensitivity	Sensitive to increase in moisture deficits, but is often found on sites with lowest deficits.
Exposure	With warming temperatures, and possible decrease in summer moisture drought may increase and affect current distribution of western hemlock and associated stressors may increase in abundance.
Vulnerability	High vulnerability to increase fire behavior and severity due to increased densities and less adapted to frequent fire. Moderate change in species distribution expected away from driest margins. High potential for natural regeneration difficulty due to difficult micro climate especially on southerly exposures with increasing moisture deficits expected. On moist sites (mixed mesic forest), increases in root disease mortality due to increasing moisture stress on sites where western white pine, ponderosa pine and larch occurred historically. Less carbon sequestration expected in those forest settings. Ponderosa pine, western larch and western white pine may have a restoration role in the mixed mesic setting where cedar is currently abundant, but historically less common due to the inability to cope with stressors.
Uncertainty	Some uncertainty exists in the level and timing of precipitation in the future. Moisture deficits will increase even with moderate levels of increase in precipitation such that the stressors will still be in play with differing levels of magnitude of the increase. Fire stressor more certain and will not favor cedar dominance on dry margins.

White pine (Mixed mesic forest)

Adaptive capacity	Well adapted to elevation gradients in warm and moist forests in northern Idaho and western Montana. It was a dominant long lived large diameter seral tree species in a mixed severity fire regime in much of the western portion of the Region before the white pine bister rust decimate much of the type. White pine has high genetic plasticity so should be able to adapt to a changing climate well.
Departure	Loss of 95% of western white pine due to a combination of white pine blister rust, mountain pine beetle, and follow-up salvage harvests.
Sensitivity	Sensitive to increase in moisture deficits, but is often found on sites with lowest deficits. Very sensitive to blister rust.
Exposure	With warming temperatures, and possible decrease in summer moisture and associated drought, may increase the range to areas previously having low occupancy of white pine.
Vulnerability	Within settings that had previously been strongholds of western white pine and now are dominated by Douglas-fir, western hemlock, grand fir and cedar there is high vulnerability to increase fire behavior and severity due to increased densities and less adapted to frequent fire. High potential for natural regeneration of western white pine difficulty due to difficult micro climate on southerly exposures with increasing moisture deficits expected and currently poor seed source of naturally rust resent white pine trees. On moist sites (mixed mesic forest), increases in root disease mortality due to increasing moisture stress on sites where western white pine, ponderosa pine and larch occurred historically. Less carbon sequestration expected in those forest settings. Western white pine may have a significant restoration role in the mixed mesic setting where species such as cedar, Douglas-fir, grand fir, western hemlock is currently abundant, but historically less common due to the inability to cope with stressors. Without the benefit of planting rust resistant white pine, an aggressive restoration program with white pine will not be possible in the near future.
Uncertainty	Some uncertainty exists in the level and timing of precipitation in the future. Moisture deficits will increase even with moderate levels of increase in precipitation such that the stressors will still be in play with differing levels of magnitude of the increase. Fire stressor more certain. Blister rust impacts somewhat uncertain as to long term effects to rust free white pine. Distribution on deep soils with less soils moisture deficits in northern Idaho and western Montana will be favored.

Larch (Mixed mesic forest and mixed species cool moist subalpine forests)

Adaptive capacity	Larch is adapted to warm moist and cool moist settings. It does best on northerly cool aspects. It is a prolific light seed cone producer but in sporadic years. Can seed longer distances than many associates so can take advance of newly opened areas due to harvest of fire as an early seral species. Larch has few insect and disease stressors unlike associates, and is adapted to fairly frequent fire. Given this, it is a dominate long lived seal tree species in much of the western portion of the Region, and due to the large diameters it can attain is important to many cavity nesters as habitat when it reaches ages over 200 yrs.
Departure	Larch forests have been reduced significantly in extent due to successional effect from fire suppression, and preferential harvest. Forest density increases have been substantial, and it now exists in uncharacteristic dense forest conditions.
Sensitivity	Very sensitive to changes in temperature. Spring frosts often reduce pollen, cone and seed production that leads to sporadic seed years. Very sensitive to warm temperatures to establish regeneration on high energy, southerly slopes. Rising temperatures and increasing soil moisture deficits will affect potential distribution. Increasing amount of fire will likely benefit larch as long as it is not in overly dense forest conditions with poor vigor.
Exposure	With warming temperatures, and possible decrease in summer moisture and associated drought may decrease distribution of western larch which could mean that it will retreat to low energy northerly slope settings.
Vulnerability	Highly vulnerable to increase in temperature and uncharacteristic fires in dense forest settings. Increases in soil moisture deficits could retract the range of western large to more northerly slopes with deep soils. Cone production could be positively affected. High forest density compared to HRV may put at risk medium, large, and old growth larch stands due to moisture deficits and stand replacing fire.
Uncertainty	Some uncertainty exists in the level and timing of precipitation in the future. Moisture deficits will increase even with moderate levels of increase in precipitation such that drought may be a factor on many aspects. Fire stressor more certain. Distribution on deep soils with less soil moisture deficits in northern Idaho and western Montana will be favored. Cone production could be positively affected.

Whitebark pine (Mixed with cool moist subalpine forests)

Adaptive capacity	Adapted to cold dry high elevation sites. Regeneration adapted with Clarks nutcracker to spread seed after openings created by fire.
Departure	Higher density and losses to white pine blister rust and mountain pine beetle have created a situation where it is warranted but precluded for listing under ESA at this time.
Sensitivity	Very sensitive to successional competition with subalpine fir and spruce. Very sensitive to stressors with increasing temperatures.
Exposure	With warming temperatures, and possible decrease in summer moisture and associated drought may decrease distribution of competitors such as spruce and subalpine fir especially on more southerly slope settings.
Vulnerability	Highly vulnerable to multiple stressors such as large stand replacing fire, increases in mountain pine beetle, and white pine blister rust. Warming climate may lessen the more vulnerable to drought species that compete with WBP such as spruce and subalpine fir.
Uncertainty	Uncertainty exists regarding how increasing temperatures will affect the stressors for whitebark pine compared to the current setting associates of spruce and subalpine fir. It is unknown whether increasing temperatures and soil moisture deficits may be a benefit to whitebark pine as an adaptive advantage over spruce and whitebark pine.

Spruce, subalpine fir, subalpine larch, and mountain hemlock (Mixed cool moist subalpine forests)

Adaptive capacity	Highly adapted to high elevation cool moist settings.
Departure	In many areas there has been an increase in dominance due to succession in the absence of fire due to fire suppression. Subalpine larch is an exception as higher densities of the forests may be restricting its range within these high elevation forests.
Sensitivity	Highly sensitive to increasing temperature and moisture stress. Sensitive to large stand replacing fires, and potentially increases in insect stressors.
Exposure	With warming temperatures, and possible decrease in summer moisture and associated drought may decrease distribution of these species especially on more southerly slope settings.
Vulnerability	Uncharacteristic fire and increased risk where homogeneity is uncharacteristic at the landscape scale within Subalpine fir Mixed cool moist subalpine forests. Distribution may contract to the northerly aspects and soils with potential to have least moisture deficit.
Uncertainty	Most uncertainty exists relative to the magnitude of increasing soil moisture deficits in there high elevation forests. The higher the deficits the more these forests will change due to multiple stressors.

Lodgepole pine

Adaptive capacity	Highly adapted to a heterogeneous forest landscape at mid to high elevations. Serotinous cones are an adaptation to fire disturbance. Not adapted to frequent stand replacing fire on the same acres.
Departure	High departure for diameter class being more homogeneous across the northern Rockies.
Sensitivity	Sensitive to warming temperature and associated mountain pine beetle and large stand replacing fire stressors.
Exposure	Higher temperature and associated soil moisture deficits could affect regeneration potential as stand replacing fires increase frequency.
Vulnerability	Primary vulnerability associated with current lack of landscape heterogeneity that may result in increase in mountain pine beetle outbreaks and very large stand replacing fire. If fire frequency increases with double or more burns in a matter of decades, the cone serotinous adaptive trait may no longer be a successful regeneration strategy for lodgepole pine. This could lead to large areas, especially on more southerly slope settings, devoid of seed source for natural regeneration. Higher temperatures and increasing moisture deficits may restrict lodgepole pine on southerly aspects.
Uncertainty	Fairly certain that fire will play a very active role in shaping the future of these lodgepole pine forests. What is not certain is how much, how frequent the spatial arrangement of fire within these forests actually will be.

Aspen

Adaptive capacity	Highly adapted to frequent disturbance including fire. Adapted to moist micro sites within a larger setting that may be more moisture limited.
Departure	Very significant reduction in extent of aspen due largely to conifer competition especially Douglas-fir and lodgepole pine in central Montana. Aspen has lost the successional battle in many areas due to lack of disturbance from fire over the last 100 years.
Sensitivity	Sensitive to a warming climate especially where soil moisture deficits may increase on southerly exposures. Aspen may respond well to fire disturbance associated with climate change.
Exposure	Increase in temperature may affect species distribution.
Vulnerability	Species distribution may recede to more northerly aspects and higher elevations where soil moisture deficits are less pronounced. Aspen could benefit on more northerly slopes and could increase in prominence with conifers with more frequent fire.
Uncertainty	Fairly certain that fire will play a very active role in shaping the future of these aspen mixed conifer forests. What is not certain is how much, how frequent the spatial arrangement of fire within these forests actually will be.

Key forest tree restoration opportunities

Spatial distribution of these key types can be found in the map of Northern Rocky Mountain Vegetation Types on page two of this report. Also see appendix C for amounts of these types by National Forest most accessible for restoration opportunities.

The western white pine mixed conifer moist forests of northern Idaho and western Montana

Climate

These forests evolved on deep well drained soils having abundant moisture from precipitation and soil moisture retention. The climate and weather is very unique to the inland area of the western U.S. Strong maritime air flow carries high levels of moisture to this area. Moist maritime air that moves across the Northwest carries significant moisture descending from the Cascade Mountains and across the Columbia Plateau. When this warm/moist air is driven into northern Idaho and the very northwestern potion of Montana heavy/wet snows can occur. These storms often result in significant windthrow and breakage in species of trees such as Douglas-fir, western hemlock and grand fir, especially when the ground is not frozen. The narrower crowns of western white pine, the deep rooting habits of ponderosa pine and the deciduous nature of western larch make them less susceptible to this damage. Root diseases make Douglas-fir especially vulnerable to windthrow events.

In the northern Rocky Mountains, precipitation tends to vary on a decadal basis, with wet periods and dry periods each lasting several years to decades (Finklin, 1983). Extended droughts both raise the fire danger and stress trees, especially the more drought intolerant species. The tree species that is more prevalent today than historically are generally those that are the most affected by extended drought. Western hemlock and grand fir are two of the more moisture-demanding tree species in the inland empire, and are highly stressed during drought periods. In an ecosystem subject to periodic droughts, the historically unprecedented acceleration of forest succession to shade-tolerant due to the loss of western white pine from white pine blister rust, drought and fire-intolerant forest types creates an increased risk of large-scale insect and disease mortality. This creates a positive feedback mechanism where more insect and pathogen activity accelerates trends to shade tolerant/drought-intolerant forest types, resulting in even more insect and disease mortality, and more shade-tolerant/drought-intolerant forests. During droughts these stressed trees are less able to resist insect and pathogen attacks. This climatic variability creates an environment prone to a high frequency and variety of disturbances. Lastly, the combination of air masses with different moisture and temperature conditions, and topography with lots of relief, creates ideal conditions for summer thunderstorms and associated lightning.

Wildfire

Wildfire greatly influenced the composition, structure, and function of vegetation across the landscape. Where fire disturbance was common, ecosystems favored the long-lived, fire-adapted, shade-intolerant tree species (ponderosa pine, larch, white pine, and whitebark pine). Shorter-lived, shade-intolerant, fire-adapted tree species (Douglas-fir, and lodgepole pine) were also present in significant amounts, particularly in younger stands, but declined through time due to effects of insects and pathogens. Shade-tolerant, fire-intolerant tree species (cedar, western hemlock, grand fir, and spruce-alpine fir) were certainly present, but rarely survived long enough to dominate stands, except where the interval between fires was unusually long and where root disease was not severe.

The dominant, historical fire regime that occurred within forested vegetation in the inland empire can be characterized as a variable or mixed-severity fire regime (Zack and Morgan 1994, Kilgore 1981, Brown 2000). This type of fire regime commonly had a moderately short fire return interval for nonlethal or mixed severity fires, with lethal crown fires occurring less often. Relative to the other two common fire regimes that are often recognized for forested vegetation- the nonlethal and stand-replacement regimes, the mixed-severity fire regimes are the most complex (Agee, 2004). Individual mixed-severity fires typically leave a patchy pattern of mortality on the landscape, which creates highly diverse communities. These fires kill a large percentage of the more fire-susceptible tree species (e.g.,hemlock, grand fir, subalpine fir, lodgepole pine) and a smaller proportion of the fire-resistant species- including western larch, ponderosa pine, whitebark pine and western white pine (Arno et al. 2000).

Insects and Pathogens

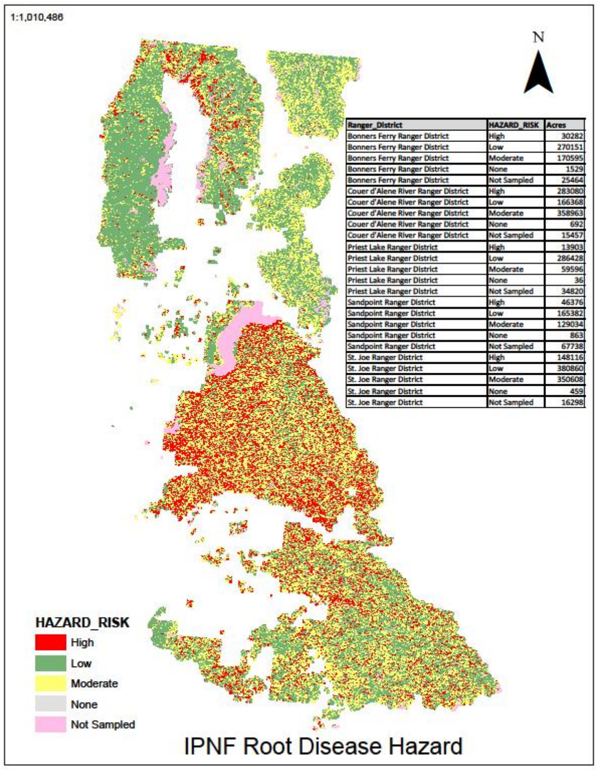
Mountain pine beetles in white pine and lodgepole pine (and occasionally spruce beetles) are capable of serving as stand-replacing agents. These beetles have a mixed effect on succession. They can open canopies enough to provide regeneration opportunities for shade-intolerant tree species, but more commonly they release shade-tolerant understory tree species. By the fuels they create, these bark beetles can influence the probability of large stand-replacing fires, which in turn can reset the successional sequence. In some situations, Douglas-fir bark beetle can also do the same thing on a smaller scale.

Historically, western white pine was a common tree species, particularly in northern Idaho, and dominated a very large part of the moist habitat types. In the early part of the 20th century, white pine blister rust (a Eurasian disease) was accidentally introduced to western North America. This exotic disease, combined with a MPB outbreak in WP in northern Idaho in the late 1930s , has been the primary cause for the loss of white pine in this area (Neuenschwander et al. 1999). With the loss of white pine, there have been large increases in the amount of Douglas-fir and subalpine fir cover types, and a major acceleration of forest succession toward shade-tolerant, late-successional true firs, hemlocks, and cedars. Western white pine had an important ecological role in forests of the Interior Northwest (Harvey and others 1995; Monnig and Byler 1992). Especially important was this species ability to form a stable, relatively long-lived, forest that was perpetuated by a combination of mixed-severity and stand-replacing wildfires (Zack and Morgan 1994). Even though fire occurred in this forest type fairly regularly, old-growth structures often persisted for several centuries. Across its range, western white pine is now estimated to be less than 5 percent of what it was at the turn of the 20th century (Neuenschwander and others 1999).

With the absence of white pine and decreased amounts of ponderosa pine and larch, root pathogens have been transformed from thinning agents into major stand-change agents in Douglas-fir and true fir stands. Root pathogens now produce significant canopy openings on many sites. Depending upon the habitat type, root pathogens may either stall stands in a diseased shrub/sapling/open pole successional stage, or strongly accelerate succession towards shade-tolerant species. In the historic forests that were dominated by seral tree species, insect and diseases probably served as stabilizing agents, removing the maladapted late seral and climax species early in stand development, which would preserve only the best climax trees and favor the dominance of the long-lived seral species (Harvey and others 1999).

The potential influence of climate change on some of the key forest insects and diseases of the Northern Rockies is discussed in Kliejunas et. al. (2009) presents a literature review of climate change and forest diseases of Western North America. It is generally believed that climate change will lead to reductions in tree health and will improve conditions for some insects such as bark beetles and highly damaging pathogens such as root disease.

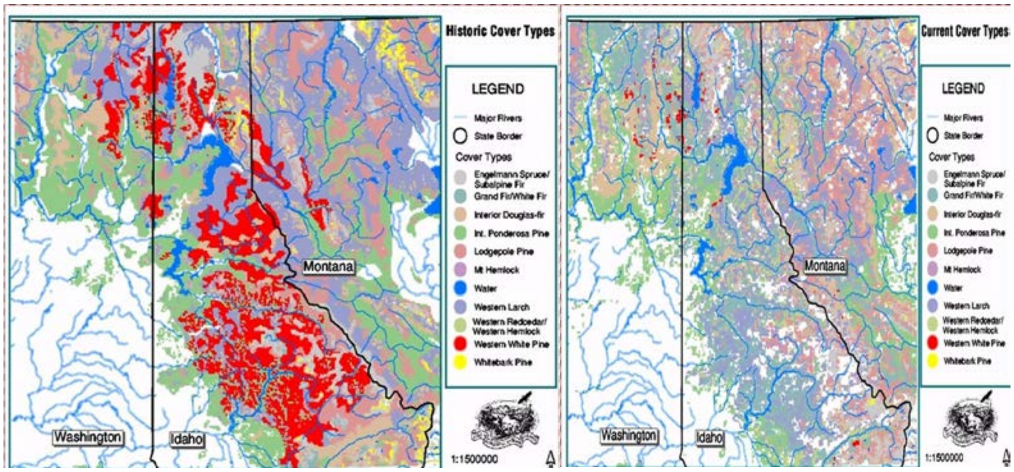
The spatial pattern of root disease hazard on the forests of northern Idaho appears something like the map below with the loss of western white pine (following maps) and resulting change of species composition reducing the resiliency of the forest.



Ranger_District	HAZARD_RISK	Acres
Bonners Ferry Ranger District	High	30282
Bonners Ferry Ranger District	Low	270151
Bonners Ferry Ranger District	Moderate	170595
Bonners Ferry Ranger District	None	1529
Bonners Ferry Ranger District	Not Sampled	25464
Couer d'Alene River Ranger District	High	283080
Couer d'Alene River Ranger District	Low	166368
Couer d'Alene River Ranger District	Moderate	358963
Couer d'Alene River Ranger District	None	692
Couer d'Alene River Ranger District	Not Sampled	15457
Priest Lake Ranger District	High	13903
Priest Lake Ranger District	Low	286428
Priest Lake Ranger District	Moderate	59596
Priest Lake Ranger District	None	36
Priest Lake Ranger District	Not Sampled	34820
Sandpoint Ranger District	High	46376
Sandpoint Ranger District	Low	165382
Sandpoint Ranger District	Moderate	129034
Sandpoint Ranger District	None	863
Sandpoint Ranger District	Not Sampled	67738
St. Joe Ranger District	High	148116
St. Joe Ranger District	Low	380860
St. Joe Ranger District	Moderate	350608
St. Joe Ranger District	None	459
St. Joe Ranger District	Not Sampled	16298

Root disease hazard on the Idaho Panhandle National Forest.

The maps below represent that massive change in this forest cover type pattern.



Historic vs. current cover types, showing a marked reduction in the distribution of western white pine.

Due to the loss of the large white pine forests, trees replacing the more long-lived seral white pine were often western hemlock, grand fir, and Douglas-fir. Root disease heavily affects the persistence and mortality of the grand fir, Douglas-fir, hemlock forests occupying these same sites today.

Western white pine forests (left) have largely been replaced by species vulnerable to root disease (right), such as western hemlock, grand fir, and Douglas-fir.

However, there has been significant progress developing rust resistant white pine for out-planting in many areas of northern Idaho (see photo below).

This stand (foreground and middle ground) was established through plantings of rust resistant western white pine.

Western larch mixed conifer forests

Climate

Western larch mixed conifer forests of northern Idaho and northwestern Montana evolved under a mixture of moist air masses from the west and cold air masses from Canada. This type of forest in northwestern Montana on the Kootenai, Flathead and portions of the Lolo National Forests, although influenced by the pacific maritime weather pattern these forests are also significantly influenced by the cooler continental air mass producing a patchy forest condition with a mixture of western larch, ponderosa pine, lodgepole pine, Douglas-fir and spruce subalpine forests, with many relic or legacy western larch trees from previous disturbance. Larch gains the most prominence on cooler, moist topographic positions, as such the influence of a warming climate may change the potential distribution of larch to the more northerly aspects with soils most capable of retaining needed moisture during the growing season

Wildfire, insects, and disease

These forests evolved under very similar fire regimes as in the western white pine forests with mixed severity fire regime being dominate. Although a bit dyer in northwestern Montana these forest evolved and produced a diverse pattern of intolerant to shade dominated western larch, ponderosa pine, lodgepole pine and Douglas-fir. On more moist and cooler sites, these mixed species forests including western larch mixed with spruce and subalpine fir were more dominated by lethal fire regimes producing very large patches with older legacy larch often represented.

Western larch is not very susceptible to insects and diseases common to other associated tree species. As such it makes an excellent candidate to feature in management due to its ability to cope with disturbance of all types including fire. Many old western large can be found with evidence of fire scars dating back centuries.

These forests are perhaps the most scenic with their October change in color.

An autumn landscape made colorful by larch.

These relic, old trees had periodic low severity fire visit many stands in the context of longer periodic stand replacing fires allowing old growth structures to persist for many centuries as larch can be a very long lived seral species. Examples of this forest composition and structure can be seen on the Coram Experimental Forest not far from Flathead Lake in NW Montana in the picture below. Now that these stand structures have become denser due to lack of periodic fire, these old growth forests may be at risk from high severity lethal fire if restoration of forest density is not completed as was the case in the Girard Grove near Seeley Lake on the Lolo NF. The largest known western larch "Champion" is in the center (in the smoke) of this photo on the right.

Old growth larch on the Coram Experimental Forest (left) and within the Girard Grove (right).

Walking with the Giants after restoration.

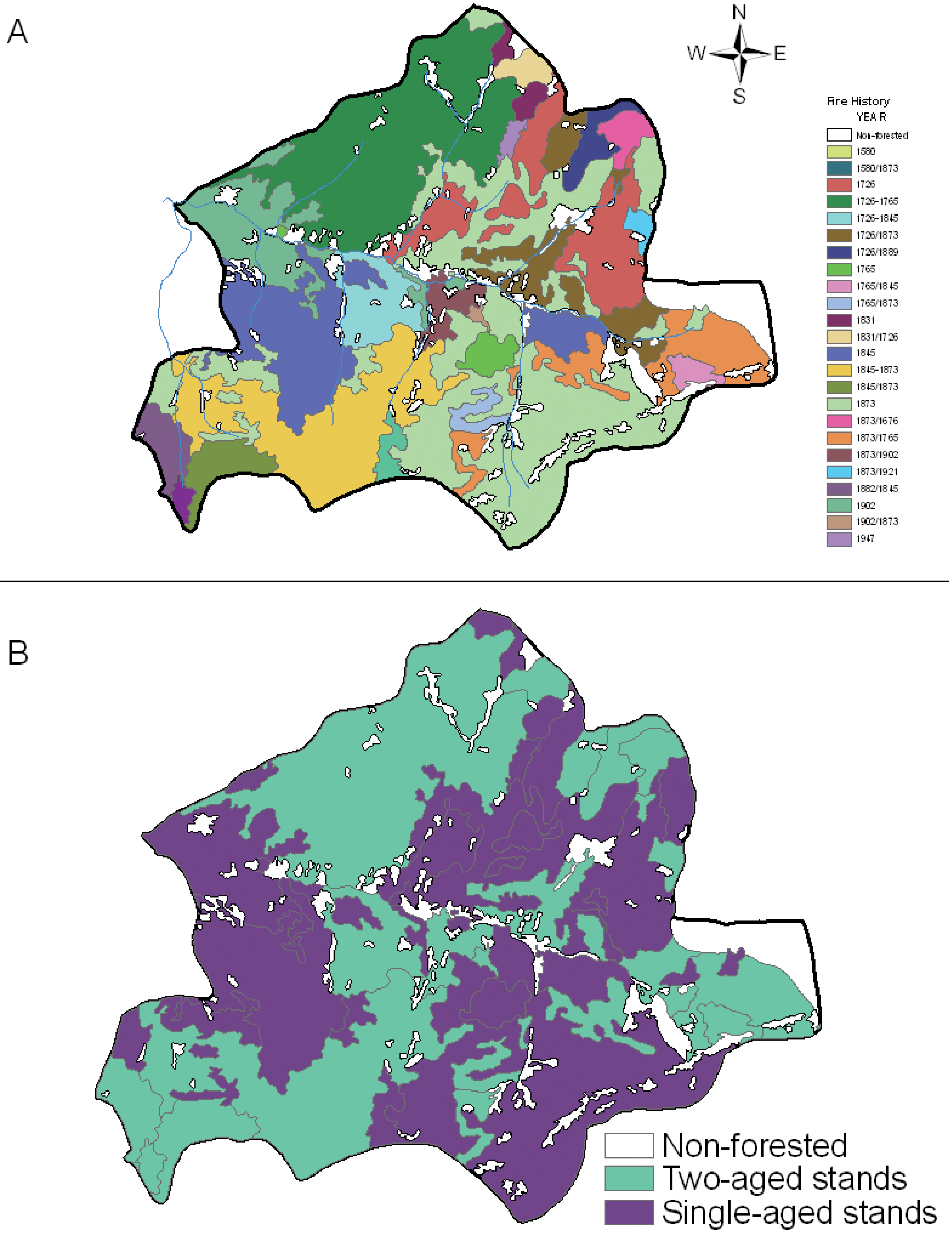
Lodgepole pine and aspen mixed conifer forests

Climate

Many of these lodgepole pine forests straddle and occur east of the continental divide are associated with the cold continental air mass that influenced their development over time and have allowed them to persist in many areas as long lived seral species. The higher elevation combined with a relatively dry cold climate has excluded many of the warm and moisture dependent tree species found on the Westside of the continental divide. On the west side of the continental divide, affected by the warmer maritime air masses, lodgepole pine generally exists as a shorter lived species generally following succession to mixed species composition beginning at approximately 100 years of age.

Wildfire

Lodgepole pine and aspen forests in central and portions of the western Montana and northern Idaho evolved with both lethal fire regimes and a mixed severity fire regime that was common in central Montana on flatter slope positions that produced a diverse pattern of various sized patches of different often having a two aged structure. (Hardy 2000,2006) Stand replacing fire return intervals were 100 to 500 years (Fischer and Clayton 1983). However stands reaching 60 to 80 years of age with stand size of over 8" in diameter, often experience severe mortality by mountain pine beetle creating snags and down fuel leading to potential severe fire effects depending on time since the infestation (Jenkins 2007). On lodgepole pine dominated sites, stand-replacing fire was common and severity was affected by periodic out breaks of mountain pine beetle that led to large fuel loads and pulse events for snags. Due to these disturbance events, and the influence of climate, there was significant diversity of the pattern of successional stages and stand ages within lodgepole pine dominated landscapes as in this example from Tenderfoot Experimental Forest in Montana. (Hardy 2000, 2006, Hood 2012)



(A) Fire history of the TCEF documenting a complex mosaic of fires dating from 1580 to 1947 (from Barrett 1993). (B) Approximately 50 percent of the Experimental Forest is two-aged resulting from low- to mixed-severity wildfires

Aspen, often in association with moisture seeps swales and other moist site topographic positions within lodgepole pine forests in central Montana, thrived in various locations due to the disturbance effect fire had on the re-sprouting ability of aspen and release effect from conifer suppression. Additional disturbance is needed to maintain aspen.

Bark beetles

Increasing the diversity of stand ages, size classes, and tree species in currently homogenous landscapes can reduce extent and continuity of highly susceptible stands at any one time period, and thus the severity of bark beetle-caused tree mortality during outbreaks in these lodgepole pine dominated areas. (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 and a more sustainable, resilient landscape pattern.

Diversity of the pattern of size classes of lodgepole pine forests on the Helena National Forest, Montana, shows that not all stands are susceptible to mountain pine beetle mortality at the same time.

Dry ponderosa pine and Douglas-fir forests

Climate

These forests are the driest forests in the northern Rockies. They occur throughout the area where precipitation is most limited and soil and topographic position limits soil moisture availability to species with higher moisture demands. This type is fairly rare in northern Idaho, more common in western Montana, and prominent in central and eastern Montana where moisture is most limited. This climate context, when the forest becomes overly dense, can set it up for uncharacteristic disturbance. A warming climate may result in the forest edge retreating up slope especially on southerly aspects where higher moisture deficits occur.

Wildfire

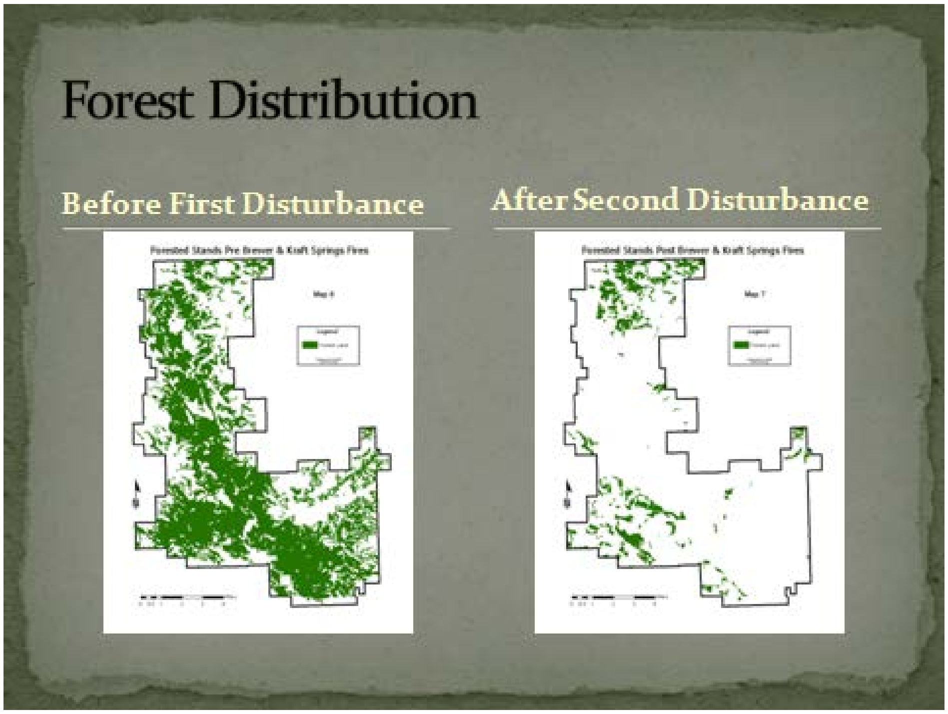
Forest structure can play an important role in wildfire behavior and severity, especially during warm dry climatic fluctuations. Most forest ecosystems in the Northern Rockies dynamically change in a process called “succession”. Forests recover from disturbed sites slowly transitioning from fire tolerant pioneer species to less fire tolerant shade tolerant “climax” species over time. Depending on the species this entire process can occur over 200 to 1000 years. Using ponderosa pine as an example, this species is often the only one that can colonize the hot dry surface conditions of a disturbed site. Over time, as it matures it provides a shaded environment where less heat tolerant Douglas-fir can establish. With frequent understory fires as part of the dominate low severity fire regime, the thick barked ponderosa pine survives and the thinner bark Douglas-fir or ponderosa pine seedlings do not. If frequent fires are sustained, the ponderosa pine forest can develop into large patches of open grown old growth structure intermixed with smallish openings that can persist for centuries provided moisture and temperature regimes do not dramatically change. During a cool wet climatic time-span, or through fire suppression ponderosa pine forests will allow for Douglas-fir or denser ponderosa pine to become established an in a period of decades may be dominated by this dense forest structure. The increased biomass and structural heterogeneity now allows fires to develop into large active crown-fires that bring this site back to the initial stand establishment phase or if fire re-burns these areas soon may limit forest establishment due to loss of seed source, limited soil moisture and high surface soil temperature.

A recent example from the Custer National Forest provides the possible effects of uncharacteristic succession into a dense forest structure not typical of the historical fire regime structure. Historically these forests were more open grown, however lack of disturbance led to high density stressed forests and a dramatic change in forest pattern after the Brewer fire in 1988, then a re-burn of the same area in the Kraft Springs fire in 2002.

Uncharacteristic Multiple Disturbances Within an Altered Fire Regime in Ponderosa Pine in Eastern Montana
Custer National Forest

Typical Conditions prior to effective Fire Suppression

Altered Forest Structure became much more dense

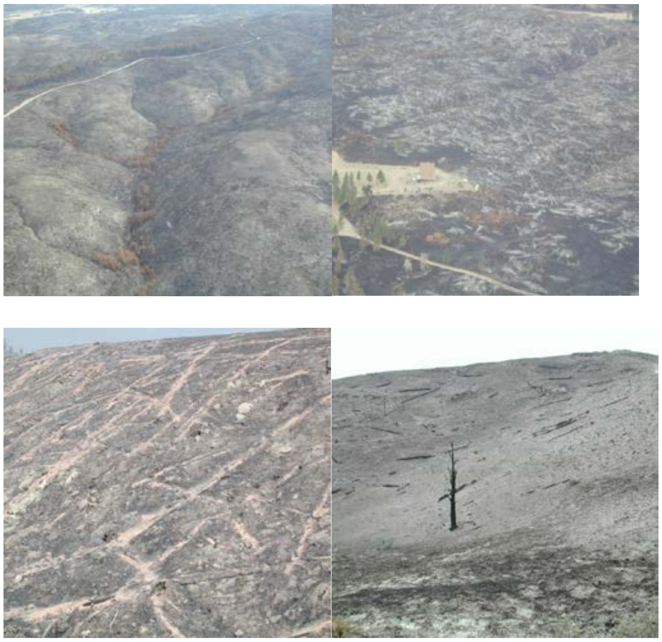


Forest Distribution

Before First Disturbance

After Second Disturbance

The pattern and structure of the forest, which once supported white-tailed deer and Flammulated Owls, now is changed to mule deer habitat and a non-forest condition for many years.



In another ponderosa pine forest near Lake Koocanusa on the Kootenai National Forest in northwestern Montana, commercial thinning returned the forest to a density more typical of a low severity fire regime, leading to a surface fire intensity on the right hand side of the road, as compared to a lethal crown fire on the left side of the road (Camp 32 fire, 2007).

The 2007 Camp 32 fire, Kootenai National Forest.

Dry Douglas-fir communities, especially on the east side of Montana, also function in a similar way as the ponderosa pine forests where density management and moisture deficits are key issues in developing more resilient forests. These areas are too cool currently to support ponderosa pine; however, that could change in a warming climate.

Dry Douglas-fir forest communities.

Whitebark pine forests mixed with spruce and subalpine-fir associates

Climate

Perhaps the most threatened forest, whitebark pine is a tree species that is associated with high elevation and the distribution has been primarily influenced by the cold continental air masses in Montana and higher elevations in northern Idaho. Forest associates are other high elevation species such subalpine fir, Englemann spruce, and mountain hemlock, subalpine larch in the area west of the continental divide. The spruce subalpine-fir types are home to Canada Lynx, a species listed under ESA, so is an important association of tree species at high elevations. Whitebark pine trees occur on some of the higher ridges and mountain tops and occurs on approximately 5 million acres in the northern Rocky Mountains. When they occur at the lower elevations within their range, they typically serve as a minor early seral species in mixed conifer stands. At the other extreme, where they are found at the uppermost elevations in rather pure stands, they can serve as a major climax species. In many area of Montana the cones and seeds have provided an important food source for grizzly bears. This tree is considered a "keystone" and "foundation" species because of its significant role in subalpine ecosystems (Keane and Parsons 2010, Tomback and Kendall 2001, Tomback et al. 2001). As the climate warms these higher elevation forests could produce suitable climate space that is less favorable for spruce and subalpine fir. WBP may be more competitive on moisture limited sites in the future.

Wildfire

Whitebark pine and its high elevation associates developed under both a stand replacing lethal fire regime on steep north slopes, and as part of a mixed severity fire regime on other aspects and flatter slopes positions. Various size patches are common within the range, with density variation depending on moisture availability adding to the diversity of these forests. The future could bring more intense fire that could further threaten whitebark pine distribution.

Mountain pine beetle and spruce beetle

There have been three outbreaks of MPB in the northern Rockies over the last 100 years. The first one in the 1920s-30s killed significant areas of whitebark pine in the Gallatin and Beaverhead National Forests and left many "Ghost Forests" as shown below (Evenden 1934; Evenden 1944). These snags can still be seen today. As quoted by a Park Ranger in 1934, "(t)he mountain pine beetle epidemic is threatening all of the whitebark and lodgepole pine stands in Yellowstone Park. Practically every stand of whitebark pine is heavily infested…and will be swept clean in a few years." Another interesting remark from that same time period was: "(t)he intensive fire protection of overmature lodgepole pine stands is not improbably producing a condition favorable to widespread epidemics of the mountain pine beetle" (Craighead, 1925).

There have been several outbreaks of Spruce Beetle as well. This beetle has a two year life cycle and can cause significant mortality in the large tree (20”+) size class. There are not vast areas of large diameter spruce forests so when there is an outbreak of spruce beetle, local mortality can be high, but acres infested are low compared to MPB in WBP and lodgepole pine.

Recently, the U.S. Fish and Wildlife Service completed a status review of whitebark pine for potential listing as a threatened or endangered species. They concluded that the species warranted listing but was precluded because of the need to address higher priority species. Whitebark pine is now designated as a Candidate species. In addition to the U.S. Fish and Wildlife Service’s review of the species, the regional forester has placed whitebark pine on the sensitive species list for Region One. The principal reasons for the concern over this tree species stems from the fact that mountain pine beetles, fire exclusion policies, and the introduced white pine blister rust disease have been found to be responsible for the significant decline of this species across its range in western North America (Keane and Parsons 2010, Schwandt 2006). In northern Idaho and Montana, white pine blister rust has killed a quarter to half of all whitebark pine trees, and since the late 1990s, mountain pine beetle-caused mortality has increased (USDA 2010). In addition, climate change could detrimentally affect this tree species; either directly or indirectly through interactions of bark beetles, blister rust, wildfires or a combination (Keane and Parsons 2010, USDA 2010, USDI 2010).

Active restoration efforts, such as those that are described in Keane and Arno 2001 and Schwandt 2006, are believed to be necessary in order to achieve these objectives. Without management intervention, losses of this tree across its range could have major consequences for biodiversity (Tomback 2007).

Adaptation options in context with vulnerability in the forest environment

First and foremost, intensively managing for species most able to cope with stressors such as but not limited to, moisture deficits, fire, root disease, and bark beetles, on appropriate biophysical settings will support their adaptive capacity. Intolerant to shade species such as ponderosa pine, western larch, western white pine, whitebark pine, and aspen are key species that have those traits.

Reducing density of the forest can be especially important on high energy sites in the management of ponderosa pine and Douglas fir on dry forest settings that will be facing increases in soil moisture deficit.

Early thinning (as early as seven years since establishment) offers western larch the ability to maintain its early heath growth advantage while increasing diameter growth to attain a height-diameter relationship to help it persist as an important attribute of west of the centennial divide landscapes. (McCloud 2012)

Re-think the level of stocking needed in the future to respond to less available water across all biophysical environments. Less may be more.

The collective benefits of thinning, prescribed fire, and moderate intensity wildland fire increase the ability of trees to survive natural disturbances including fire, insect outbreaks and root diseases. The effectiveness of such management actions is maximized when treatments occur at landscape scales.

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). A mixed species combination of lodgepole pine and restoration of aspen on more mesic micro-climates as an example can be especially beneficial in central Montana forests.

Reducing the density of trees susceptible to bark beetles 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).

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. It is important to note that of the 21 million acres in forested condition in Region One, 11 million acres occur in a combination of wilderness and roadless areas. What happens within those areas in terms of disturbance will influence forests having roads and resources contained within. 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). Benefits to regenerating forests and adjacent seed sources for natural regeneration become an important attribute of a diverse pattern. (Turner 2012) Strategic placement of treatment units to create a more sustainable pattern is perhaps a critical priority to help develop the desired level of landscape heterogeneity. (Finney 2003)

In the case of whitebark pine within the whiltebark pine spruce subalpine fir forests mixes, 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). This may be especially effective during moderate fire years such as 2008-2001 where 68,000 acres where burned in various levels of severity in Region

One within this zone. Creating heterogeneity within this zone may also in the long run, provide more sustainable spruce fir multistory forest pattern that is the most limiting habitat for Lynx in the winter.

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.

A very aggressive reforestation effort to regenerate western white pine (and western larch and ponderosa pine where appropriate) within the mixed mesic forests of western Montana (and of course northern Idaho) should be undertaken following regeneration harvests, and wildfires that occur within these areas. This is perhaps one of the most important strategies to combat the increase in root disease that is reducing the productivity, carbon sequestration ability and resiliency of those forest areas. In the future, considering increasing soil moisture deficits a real possibility, white pine (and western larch) should be emphasized on more northerly aspects, lower and flatter slope positions, with deep productive soils. Natural Resources Conservation Service (NRCS) and the Natural Resource Information System of the Montana State Library, Relative Effective Annual Precipitation (REAP) was identified in a series of GIS maps across the State of Montana to help identify the most water limited sites in Montana. http://nris.mt.gov/nrcs/reap/index.asp

Prompt regeneration of disturbed areas. Rapid tree planting in areas severely disturbed by wildfire can accelerate carbon accumulation. Develop inventory techniques and commit budget in roadless areas to assess severely burned areas post fire for reforestation needs.

In the context of a potentially warmer and dryer climate, with increasing soil moisture deficits, species preference to be managed for by habitat type group will need to be adjusted. The R1 Reforestation Primer contains the most current recommendations. (U.S. Forest Service 2012). Employ monitoring and adaptive management to explore directions of change and natural response at local scales.

Continue to assess genetic implications of current seed transfer guidelines in view of a warming and dryer climate.

Adaptation tactics considering projected climate change related impacts and vulnerabilities

Extent	Adaptation tactics to consider
Landscape	Create a greater landscape heterogeneity forest pattern that may limit the extent of very large uncharacteristic disturbances using mechanical and fire as tools (Turner 2012) Greater moisture deficits, less available moisture for trees will require consideration of appropriate species distribution and forest density in the future (Chmura 2011)

Tree species

Ponderosa pine	• Reduce forest density in all successional stages • Consider some shift in distribution on dryer margins, plant ponderosa on sites where Douglas fire has replaced PP considering HRV, in areas not on dryer margins
Douglas-fir	• Reduce forest density in all successional stages • Consider some shift in distribution on dryer margins • On moist sites, shift to western white pine, ponderosa pine and larch where they occurred historically to reduce impacts of root disease • Maintain lower forest density during all stages of succession
Grand fir	• Shift to western white pine, ponderosa pine and larch where they occurred historically to reduce impacts of root disease • Maintain grand fir on dryer margins within the current mixed mesic forest area
Cedar	• Consider shifts in distribution to areas where less moisture deficit will occur in the future
Western hemlock	• Shift to western white pine, ponderosa pine and larch where they occurred historically to reduce impacts of root disease
Western white pine	• Aggressively plant rust resistant white pine, especially on sites where less soil moisture deficit is expected
Whitebark pine	• Plan for a diversity of successional stages primarily using fire to achieve this resource benefit and reforest via planting improved stock where the opportunity exists relative to access • Role of management of wildfire to achieve multiple resource benefits a significant tool to restore whitebark
Spruce	• Distribution may contract to the northerly aspects and soils with potential to have least moisture deficit: manage spruce more intensively on these sites
Subalpine fir	• Distribution may contract to the northerly aspects and soils with potential to have least moisture deficit: manage for subalpine fir on these sites
Larch	• Distribution may contract to the northerly aspects and soils with potential to have least moisture deficit: manage more intensively on these sites • Reduce forest density during all successional stages
Mountain hemlock	• Distribution may contract to the northerly aspects and soils with potential to have least moisture deficit: manage mountain hemlock on these sites
Lodgepole pine	• Manage for landscape heterogeneity of pattern of successional stages • Manage for reduced stocking levels
Aspen	• Encourage increases in disturbance by more regeneration of aspen within current lodgepole pine forests • Plan for potential distribution to contract to the more northerly aspects and or where soils have the potential to have least moisture deficit and manage aspen more intensively on these sites

Adaptive management and monitoring

National Restoration Policy and Guidance

In 2008, The National Restoration Policy and Guidance was finalized as manual policy (Forest Service Manual 2020). The manual provides direction for restoration on National Forest Systems (NFS) lands. It does not set program priorities, but rather provides the conceptual policy guidance for the agency. Specifically, the policy in FSH (2020.3) states:

> 1. *All resource management programs have a responsibility for ecological restoration including, but not limited to, management of vegetation, water, wildland fire, wildlife, and recreation. Management activities may range from monitoring resource conditions to manipulation of terrestrial and aquatic ecosystems to regulation of human uses.*
>
> 2. *Establish ecological restoration goals and objectives in strategic plans to maintain the adaptive capacity of ecosystems - recognizing uncertainty related to climate change. Identify opportunities to sustain ecological refugia that may serve as vital sources of ecological diversity. Develop goals and objectives within the framework defined by laws, Indian treaties, regulations, collaboratively developed public and Indian tribal values and desires, historical conditions, current and likely future ecological capabilities, a range of climate change projections, the best available scientific information, and technical and economic feasibility —to achieve desired conditions* (Forest Service Manual 1905) *for National Forest System lands.*
>
> 3. *Ecological restoration activities should be planned, implemented, monitored, and evaluated in consideration of current and desired conditions and the potential for future changes in environmental conditions, including climate change.*
>
> 4. *Where appropriate, integrate resource management programs and projects to achieve complementary or synergistic results contributing to ecological restoration.*
>
> 5. *Collaborate across ownerships and jurisdictions to achieve landscape restoration objectives.*
>
> 6. *Within existing authorities, revenue from commercial uses of natural resources may be used to help fund restoration activities.*

In addition, the following direction is provided (Forest Service Manual 2020):
Apply the following guiding principles when planning and implementing restoration projects:

> 1. *Ecosystems are dynamic and change is inevitable.*
>
> 2. *Public involvement and consultation with Indian Tribes is important in setting objectives for restoration.*
>
> 3. *Knowledge of past and current ecosystem dynamics, current and desired conditions, climate change projections, and human uses is fundamental to planning restoration activities.*
>
> 4. *Adaptive management, monitoring, and evaluation are essential to ecological restoration.*

Adaptive management. A system of management practices based on clearly identified outcomes and monitoring to determine if management actions are meeting desired outcomes, and if not, to facilitate management changes that will best ensure that outcomes are met or reevaluated. Adaptive management stems from the recognition that knowledge about natural resource systems is sometimes uncertain (36 CFR 219.16; Forest Service Manual 1905).

Monitoring. The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a resource or management objective. A monitoring activity may include an information needs assessment; planning and scheduling; data collection, classification, mapping, data entry, storage and maintenance; product development; evaluation; and reporting phases.

Evaluation. An appraisal and study of social, economic, and ecological conditions and trends relevant to a unit. The analysis of monitoring data that produces information needed to answer specific monitoring questions. Evaluation may include comparing monitoring results with a predetermined guideline or expected norm that may lead to recommendations for changes in management, a land management plan, or monitoring plan. Evaluations provide an updated compilation of information for use in environmental analysis of future project and activity decisions.

Adaptive management and monitoring approaches implemented in the Northern Region

In addition to a multi-scale monitoring framework produced in the Northern Region in 2010, two new approaches dealing with adaptive management and monitoring were added and implemented in the Northern region in 2012. The Adaptive Management Framework (AMRF), which is a partnership with RMRS, will on an annual basis, have a technical steering committee composed of R1 and RMRS employees, review opportunities to use the activities within the forest management accomplishment foot print each year, to track and evaluate those treatments to ascertain how restoration outcomes may be achieving desired condition outcomes including leading to a more resilient forest in the Northern Region in the context of changing climate and multiple stressors. (LINK) To help inform the AMRF a new report was developed referred to as the Restoration and Resiliency Report. This report, using the FACTS database, summarizes outcomes from outputs within R1 management footprint year that lead toward achieving desired conditions and resiliency within the Northern Region. (LINK)

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Glossary of terms

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

Adaptation tactic – A specific action described in management and planning documents that supports adaptation strategies and is implemented on the ground (e.g. reducing stem density and surface fuels in a dry mixed conifer forest, increasing culvert size on roads along a stream that is expected to have higher flood volumes).

Climate (change) scenario – A plausible and often simplified representation of the future climate, based on a consistent set of known principles about the climate system used as input to climate change impact models. A ‘climate change scenario’ is the difference between a climate scenario and the current climate.

Climate change adaptation – An adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Adaptation is often referred to as preparedness, and is based on scientifically supported strategic and tactical activities that support sustainable resource management. Adaptation addresses specific aspects of the sensitivity of resources to an altered climate.

Exposure -- The nature and degree to which a system is exposed to significant climate variations (Glick and Stein 2010).

Scenario -- A plausible and often simplified description of how the future may develop based on a set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a ‘narrative storyline’.

Sensitivity -- Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Stressors — any physical, chemical, or biological entity that can induce an adverse response. Stressors can arise from physical and biological alterations of natural disturbances, increased unmanaged demand for ecosystem services (such as recreation), alterations of the surrounding landscape, chemical alterations in regional air quality, or from a legacy of past management actions (Joyce et al. 2008).

Resilience -- The degree to which systems (e.g., a forest ecosystem) can recover from one or more disturbances without a major (and perhaps irreversible) shift in composition or function. Example of managing for resilience: periodic reduction in stem densities and surface fuels to reduce fire severity in dry forest.

Resistance -- The ability of an organism, population, community, or ecosystem to withstand perturbations without significant loss of structure or function. From a management perspective, resistance includes both 1) the concept of taking advantage of and boosting the inherent (biological) degree to which species are able to resist change, and 2) manipulation of the physical environment to counteract and resist physical and biological change. Example of managing for resistance: placement of fire breaks on the perimeter of climatically sensitive wildlife habitat to reduce fire spread.

Uncertainty -- An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

Vulnerability - Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. (Unless noted, all of the above definitions are from the Glossary from IPCC 2007)

Appendix A. Climate envelope model comparison by species

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.

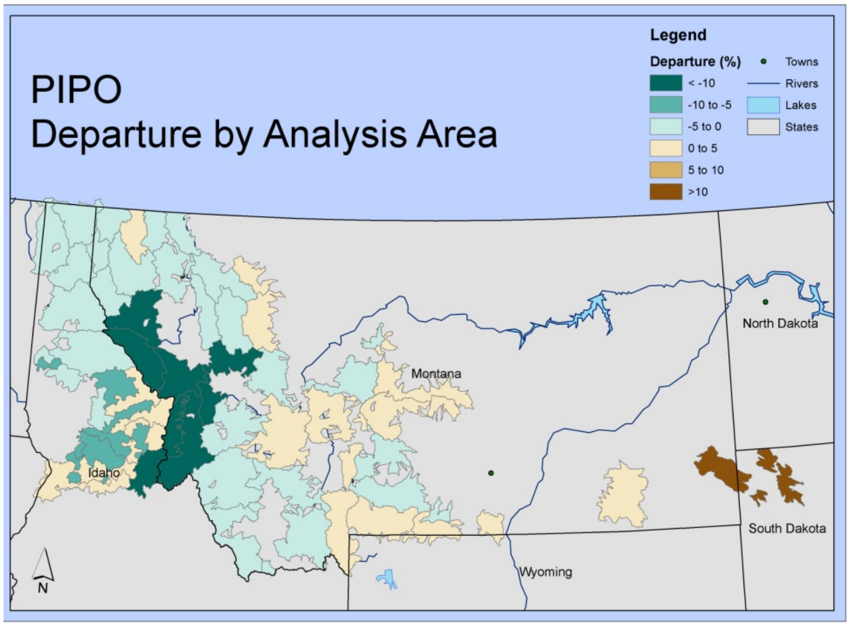
Species	Agreement Score	Modeling Group	Simulation Results
Western Larch	Agree	NRCan	All simulations show a reduction in the distribution of suitable habitat in the U.S. Northern Rockies. The NCAR simulations (both A2 and B2) show the least reduction. The HadCM3 simulations both project the near elimination 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

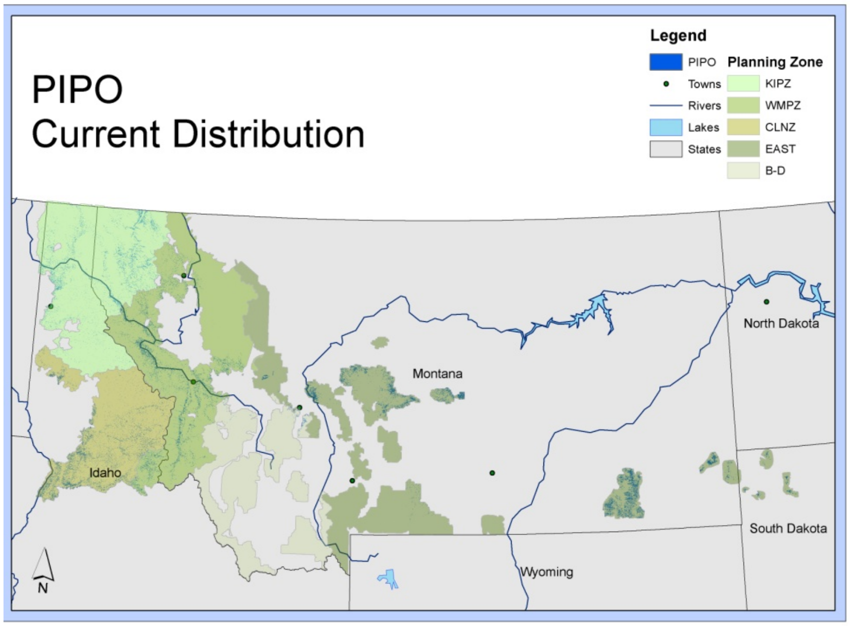
Species	Agreement Score	Modeling Group	Simulation Results
			50% reduction in core habitat in Montana and Idaho, while the CGCM2 and NCAR simulations show only slight reductions.
		RMRS	Projections are vary considerably among models in a spatially complex pattern. Most models project increased likelihood 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 pine	Strongly disagree	NRCan	All models project moderate to substantial reductions throughout the U.S. Northern Rockies. Core habitat is available in all models 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

Species	Agreement Score	Modeling Group	Simulation Results
			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.

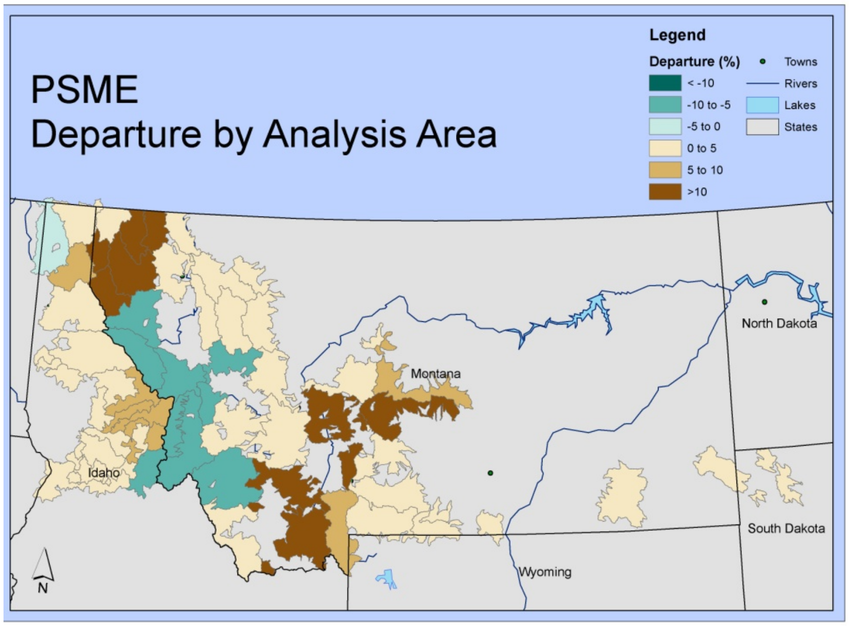
Appendix B. Departure maps and current distribution maps by species

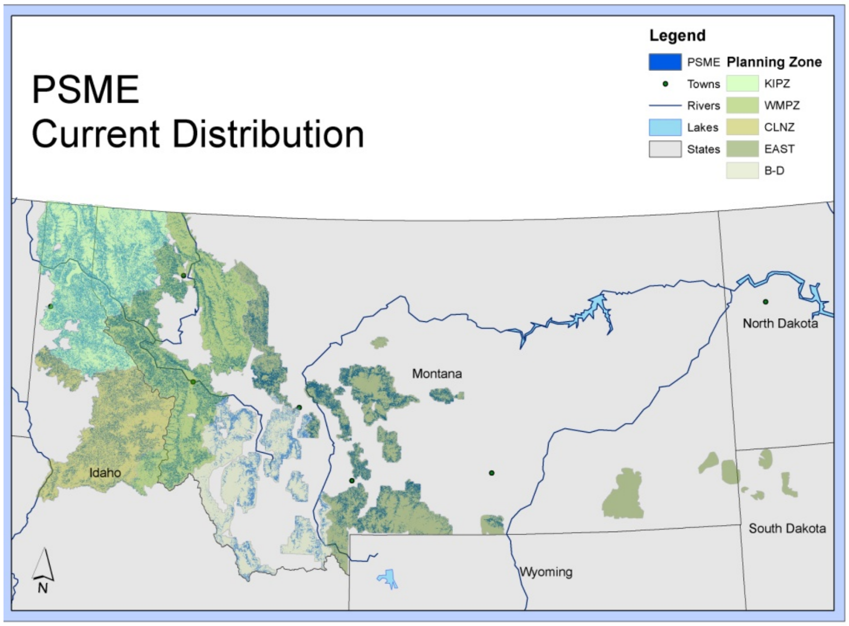
Ponderosa pine (PIPO)



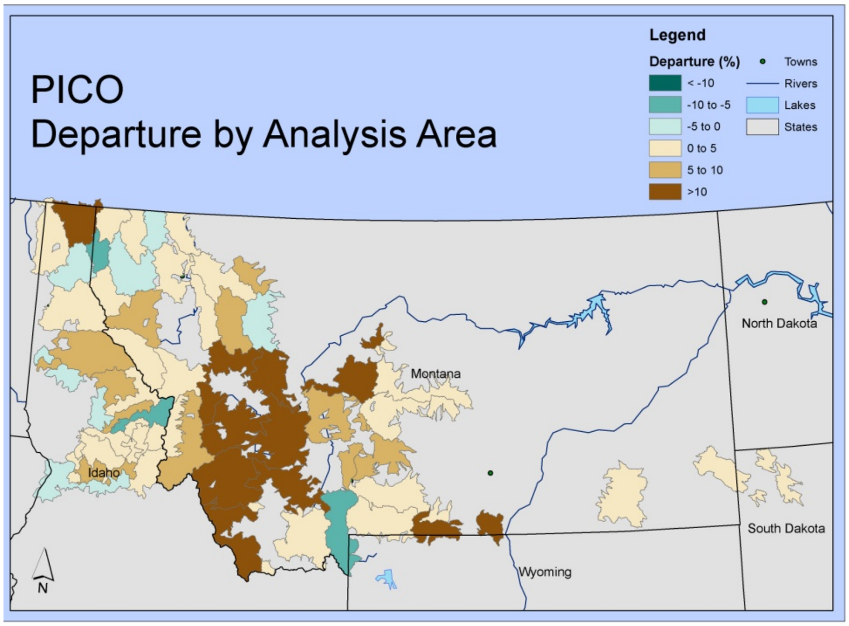


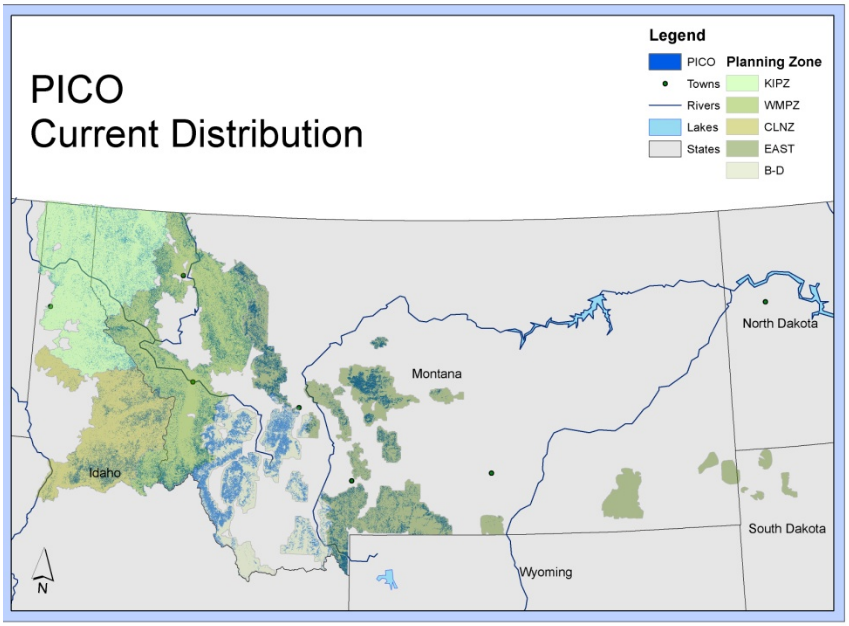
Douglas-fir (PSME)



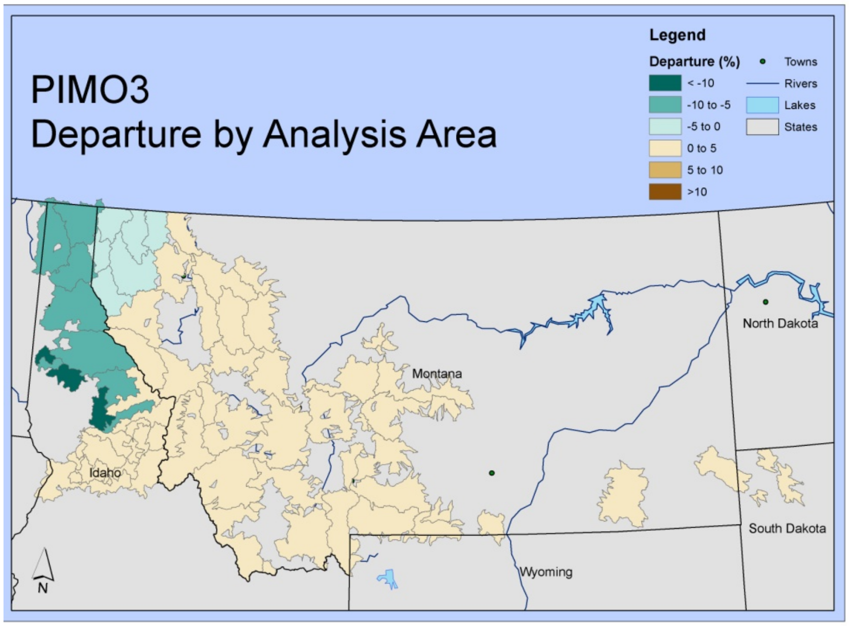


Lodgepole pine (PICO)



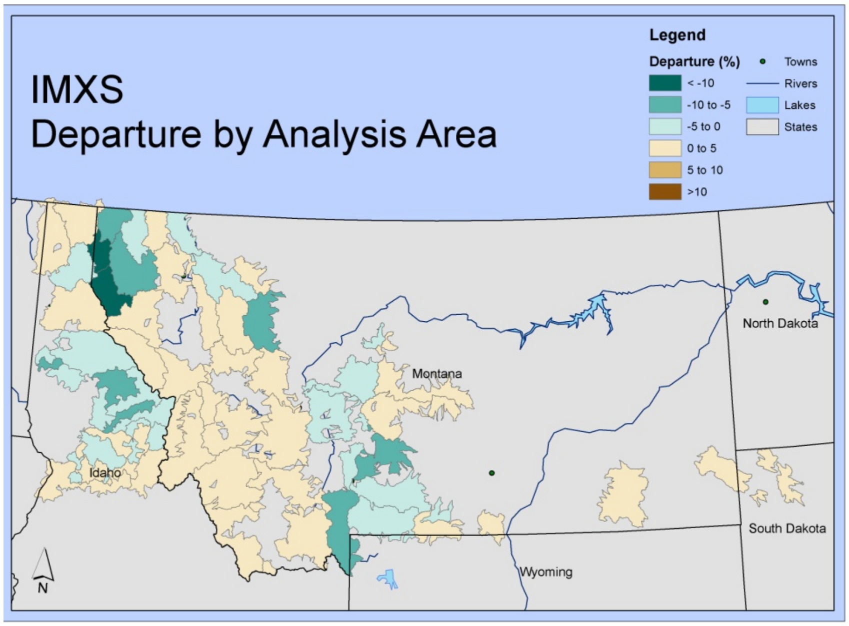


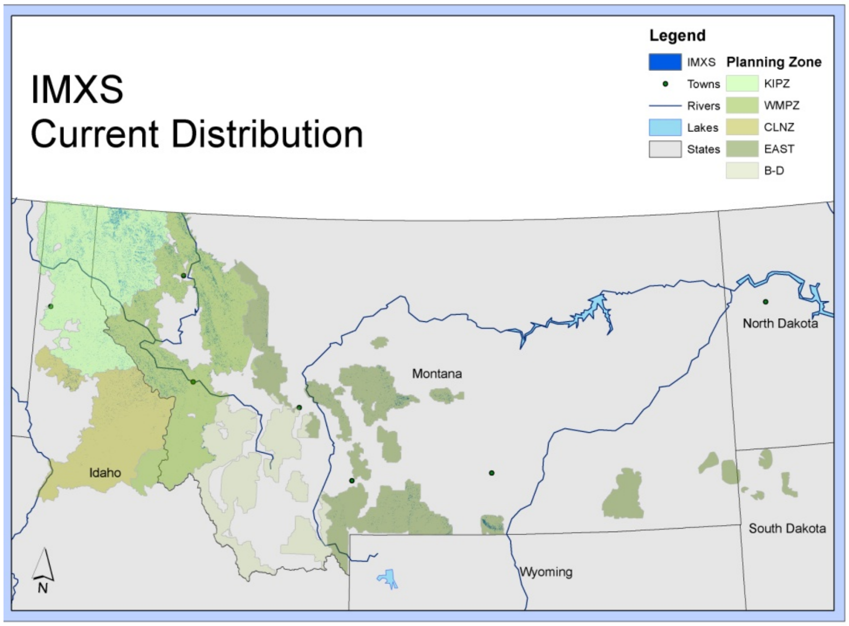
Western white pine (PIMO3)



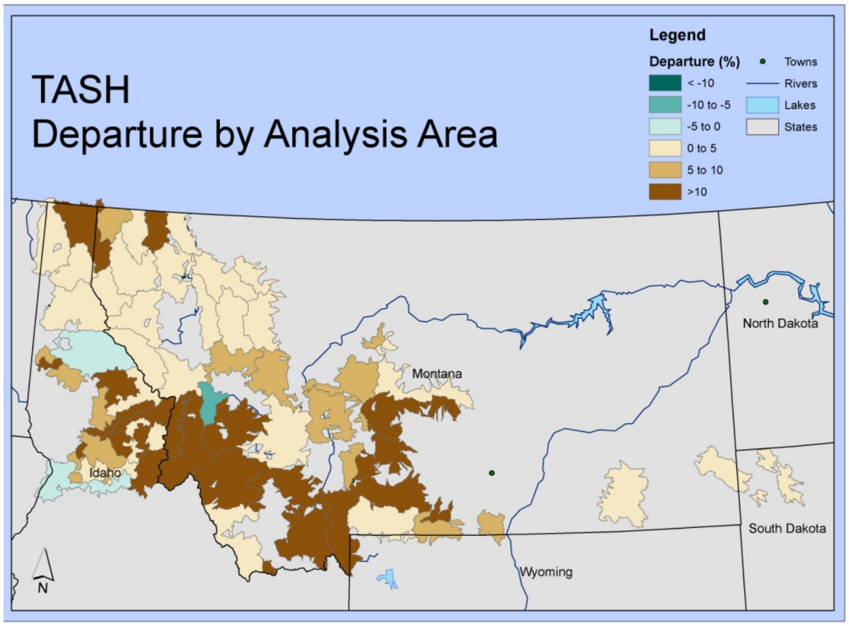
Type is currently not mapped in VMAP, so no current distribution map is available.

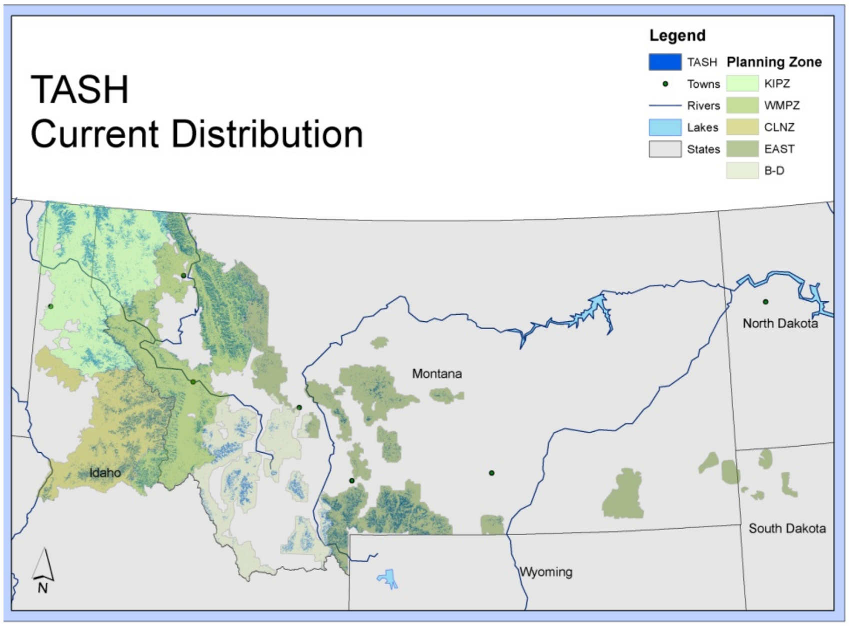
Shade-intolerant mix (IMXS)



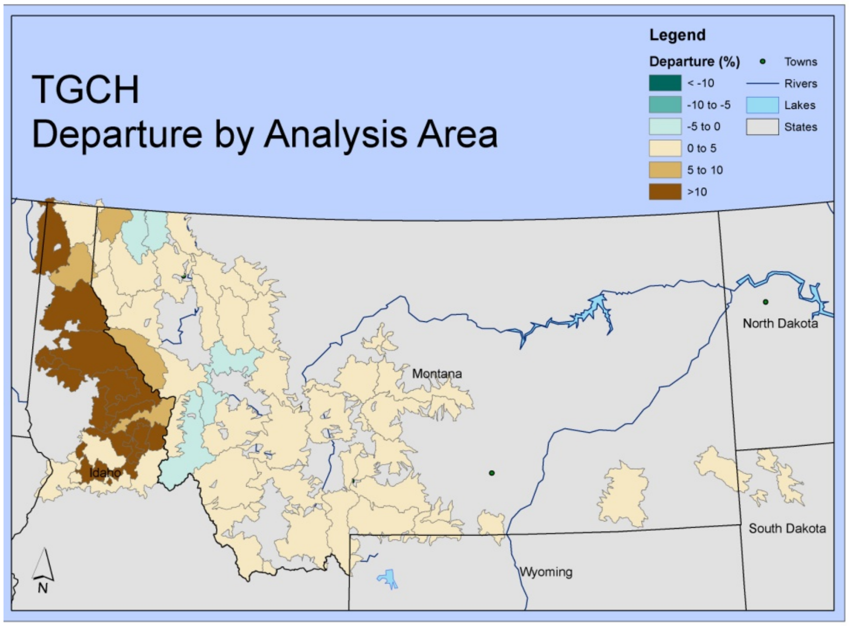


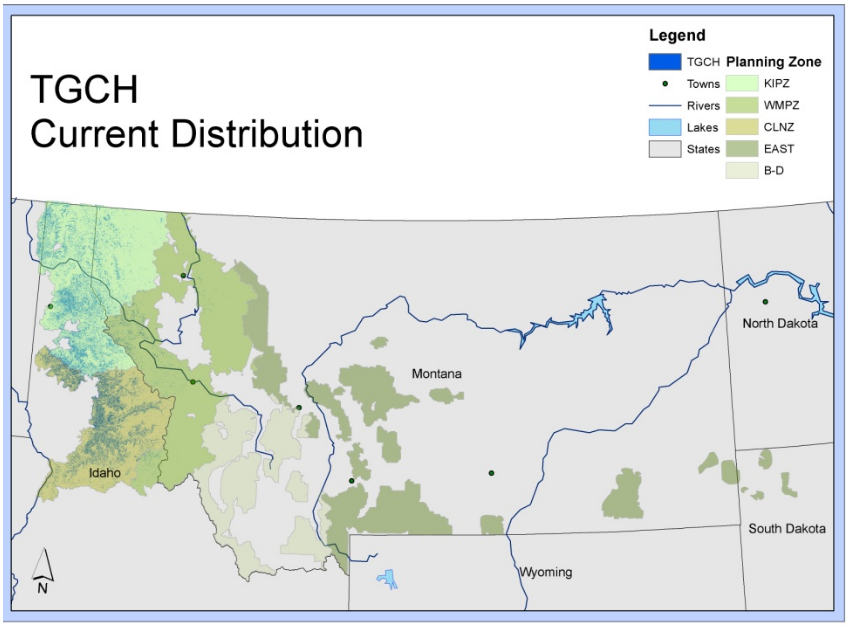
Shade-tolerant subalpine fir/spruce/mountain hemlock mix (TASH)



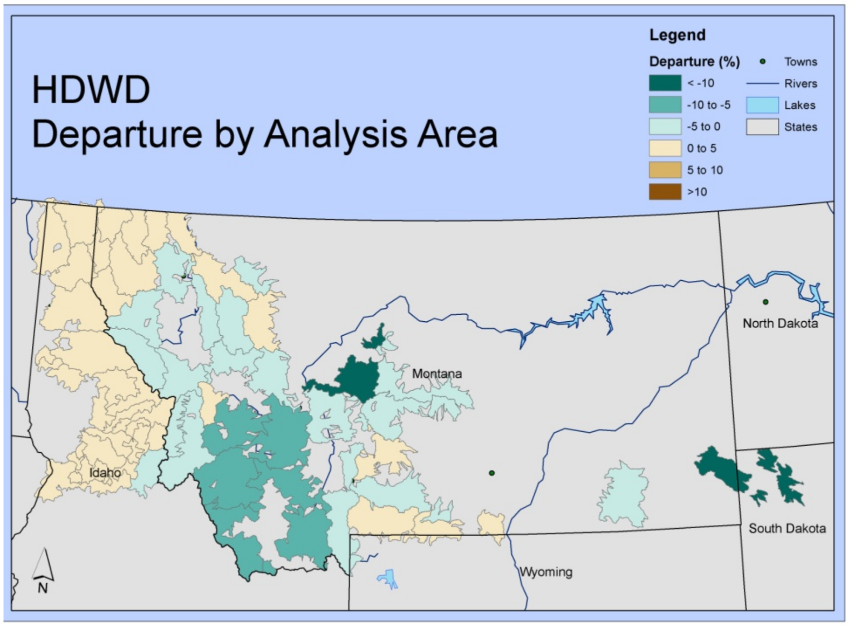


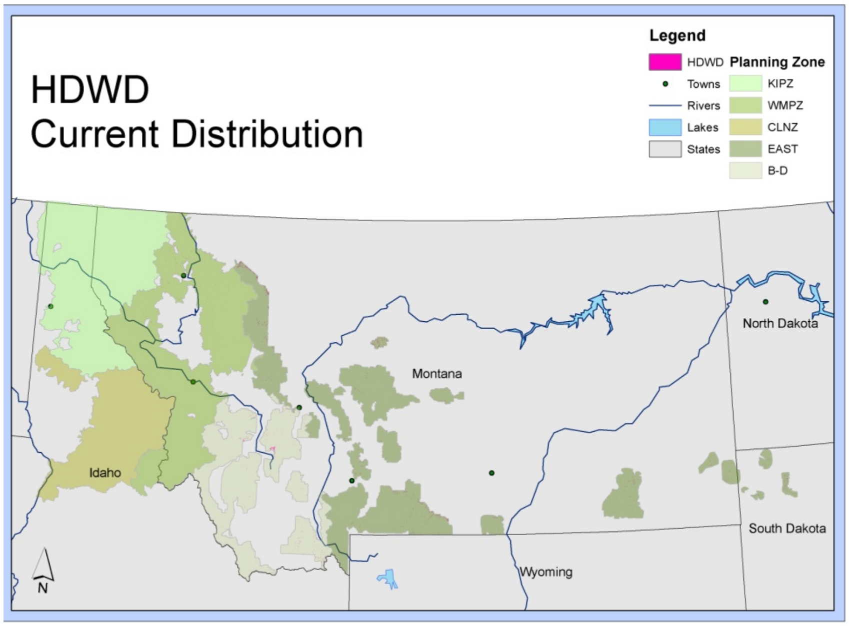
Shade-tolerant grand fir/cedar/western hemlock mix (TGCH)



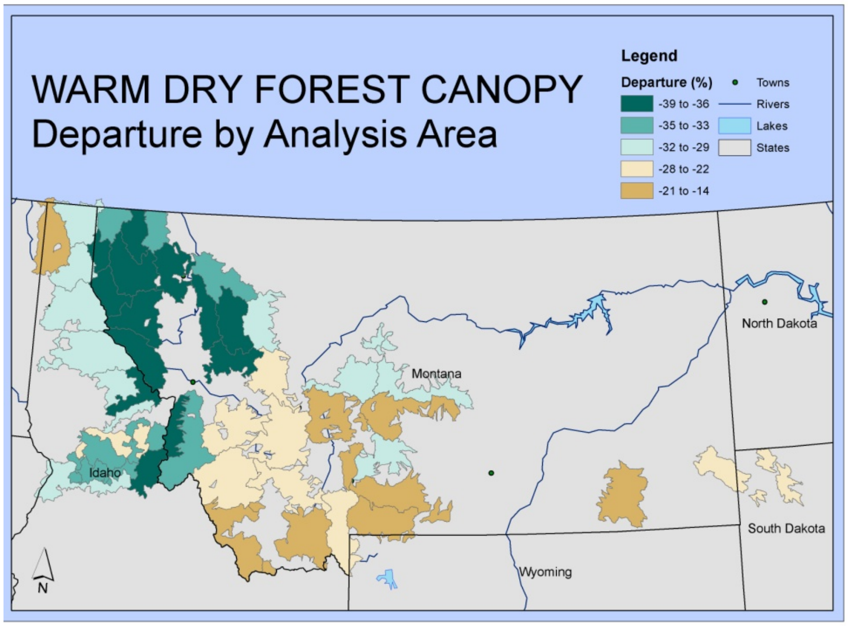


Hardwood (HDWD)





Warm dry forest canopy



Appendix C. Acres of suitable timber base by forest type group for each National Forest in the Northern Region

Beaverhead-Deerlodge NF	Acres 268,135
Dry Douglas fir mixed conifer	35,383
Lodgepole pine mixed hardwood	200,398
Mixed mesic forest; WP, GF, C, H, moist DF	26,397
Ponderosa pine mixed conifer	312
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	5,646

Bitterroot NF	368,480
Dry Douglas fir mixed conifer	103,090
Lodgepole pine mixed hardwood	137,888
Mixed mesic forest; WP, GF, C, H, moist DF	75,439
Ponderosa pine mixed conifer	21,984
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	29,611
Western larch mixed conifer	468

Clearwater NF	300,919
Dry Douglas fir mixed conifer	1,941
Lodgepole pine mixed hardwood	20,896
Mixed mesic forest; WP, GF, C, H, moist DF	234,101

Ponderosa pine mixed conifer	7,372
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	27,627
Western larch mixed conifer	8,982
Custer NF	**174,396**
Dry Douglas fir mixed conifer	18,453
Lodgepole pine mixed hardwood	18,719
Mixed mesic forest; WP, GF, C, H, moist DF	15,060
Ponderosa pine mixed conifer	110,438
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	11,727
Flathead NF	**657,634**
Dry Douglas fir mixed conifer	41,251
Lodgepole pine mixed hardwood	175,776
Mixed mesic forest; WP, GF, C, H, moist DF	175,111
Ponderosa pine mixed conifer	4,380
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	180,433
Western larch mixed conifer	80,684

Appendix C. Acres of suitable timber base by forest type group for each National Forest in the Northern Region

	Acres
Gallatin NF	**254,492**
Dry Douglas fir mixed conifer	43,909
Lodgepole pine mixed hardwood	97,659
Mixed mesic forest; WP, GF, C, H, moist DF	72,106
Ponderosa pine mixed conifer	346
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	40,471
Helena NF	**240,095**
Dry Douglas fir mixed conifer	74,058
Lodgepole pine mixed hardwood	104,181
Mixed mesic forest; WP, GF, C, H, moist DF	51,657
Ponderosa pine mixed conifer	3,654
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	6,544
Idaho Panhandle NFs	**891,708**
Dry Douglas fir mixed conifer	42,535
Lodgepole pine mixed hardwood	59,508
Mixed mesic forest; WP, GF, C, H, moist DF	662,387
Ponderosa pine mixed conifer	10,466

Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	77,413
Western larch mixed conifer	39,400
Kootenai NF	**1,515,277**
Dry Douglas fir mixed conifer	126,116
Lodgepole pine mixed hardwood	176,775
Mixed mesic forest; WP, GF, C, H, moist DF	863,010
Ponderosa pine mixed conifer	39,769
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	158,850
Western larch mixed conifer	150,758
Lewis & Clark NF	**283,075**
Dry Douglas fir mixed conifer	47,694
Lodgepole pine mixed hardwood	149,271
Mixed mesic forest; WP, GF, C, H, moist DF	47,720
Ponderosa pine mixed conifer	21,669
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	16,720

Appendix C (continued). Acres of suitable timber base by forest type group for each National Forest in the Northern Region

	Acres
Lolo NF	**1,050,995**
Dry Douglas fir mixed conifer	219,358
Lodgepole pine mixed hardwood	250,483
Mixed mesic forest; WP, GF, C, H, moist DF	316,746
Ponderosa pine mixed conifer	54,958
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	137,754
Western larch mixed conifer	71,696
Nez Perce NF	**470,557**
Dry Douglas fir mixed conifer	12,145
Lodgepole pine mixed hardwood	127,652
Mixed mesic forest; WP, GF, C, H, moist DF	220,763
Ponderosa pine mixed conifer	61,492
Spruce, subalpine fir, whitebark pine mountain hemlock mixed conifer	48,271
Western larch mixed conifer	234
Grand Total	**6,475,765**