Draft Assessment
Forest Plan Revision

Climate Change Impacts Assessment

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for:
Malheur, Umatilla, and Wallowa-Whitman National Forests

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Climate Change

Introduction

Climate change is a stressor that is currently affecting and is anticipated to have a large influence on future temperature and precipitation patterns in the Blue Mountains national forests. It is expected to compound drivers of forest change like fire, flooding, and drought – with profound effects on nearly every resource area.

Since 1750, atmospheric carbon dioxide concentrations have increased from 280 to over 390 parts per million (ppm) and are expected to continue rising, reaching 450 to 875 ppm by 2100 (Peterson et al. 2014). Pacific Northwest temperatures have increased already by about 1.3-1.6 degrees Fahrenheit during the twentieth century. Temperature and precipitation changes are expected to alter soil water availability by altering amounts and timing of precipitation, snowpack dynamics, and evapotranspiration rates (Peterson et al. 2014).

These changes in temperature and precipitation patterns affect ranges of plant and animal communities, species abundance, the productive capacity of natural and human systems, availability of recreation opportunity and access, and risks to natural and human systems from extreme events. Expected changes relative to present conditions include, but are not limited to: fluctuations in temperature, precipitation, and soil moisture; earlier snow melt with peak and low flows occurring at different times than expected; and extended periods of droughts and rain events with the latter resulting in floods (Halofsky and Peterson 2017).

These impacts may also be discussed in the Drivers and Stressors section of the Assessment as well as individual resource area reports.

Process, Methods, and Scale

This section compiles Best Available Scientific Information (BASI) to present anticipated effects of climate change in general terms and in relation to individual resources. Much of the language in this report is from the 2018 Blue Mountains Plan Revision Final Environmental Impact Statement (USDA Forest Service 2018), which still mostly describes observed and projected trends, and anticipated impacts of climate change with some updates regarding uncertainties about future precipitation. The FEIS (USDA Forest Service 2018) and updates found in this report were informed primarily by the 2017 Climate Change Vulnerability and Adaptation in the Blues Mountain report (Halofsky and Peterson 2017). This peer-reviewed Climate Change Vulnerability Assessment was completed via a partnership between the University of Washington, the Climate Impacts Research Consortium at Oregon State University, and the Forest Service Pacific Northwest Region and Pacific Northwest Research Station (which specifically included study areas within the Blue Mountains national forests). Updates are provided with current information and scientific understanding where appropriate.

Information in this report is based on assumptions built into the "standard" suite of Global Climate Models (GCMs) used to project climatic changes. Most climate assessments will bracket the range of potential futures using multiple scenarios or models. Representative Concentration Pathway (RCP) 4.5 and 8.5, used in the Climate Change Vulnerability Assessment, are two of the most used in scientific literature, representing a scenario (4.5) in which greenhouse gases are significantly reduced by year 2100 and one (8.5) in which global greenhouse gas emissions continue at similar rates to earlier in the 21st century through the end of 2100. The Climate Change Vulnerability Assessment (Halofsky and Peterson 2017) used both RCP 4.5 and 8.5 scenarios.

Most information is presented at a regional and multi-forest scale. Downscaled projections and models of climatic change are presented where available. Information provided in this document represent BASI as of the date of report release. Because there is uncertainty in the specific time, location, and degree of climate change effects in the future, models may be imprecise and subject to future refinement, particularly at smaller spatial scales or on longer time horizons.

Current Forest Plan Direction

There is no management direction from the 1990 forest plans or subsequent amendments related to climate change vulnerabilities or adaptation.

The 1990 FEIS (USDA Forest Service 1990) for the Wallowa-Whitman National Forest noted that the effect of forest management on global warming was not included in the analysis because it was outside the scope of the analysis but also noted this may be an issue for future forest plan.

The 2021 Decision Notice for the Forest Management Direction for Large Diameter Trees in Eastern Oregon and Southeastern Washington Forest Plans Amendment (USDA Forest Service 2021) states: "Management activities should consider appropriate species composition for biophysical environment, topographical position, stand density, historical diameter distributions, and spatial arrangements within stands and across the landscape in order to develop stands that are resistant and resilient to disturbance."

Gaps in Current Plan

The existing forest plans do not address management of national forest resources under a changing climate, nor did the 1990 analyses describe the effects that climate change is anticipated to have on these resources. In addition, the forest plans did not address the compounding stressors placed on the health and resilience of ecosystems that are highly departed from their natural ranges of variability (see Terrestrial Ecosystems and Aquatic, Wetland, and Riparian Ecosystems reports) in combination with projected climatic changes.

Any resource or activity that depends on historic climatic conditions will be affected, including:

- botanical resources
- seasonal recreation availability and timing
- ecosystem and forest composition, disturbance, health, and distribution

- wildlife abundance, community composition, and distribution
- water availability and timing; infrastructure resilience
- wildfire planning
- scenic values and safety
- travel infrastructure
- and rangeland health

Existing Condition

The existing condition of the Blue Mountains national forests is that climate change is occurring and is anticipated to continue. Both the anticipated changes and the uncertainty in the exact timing, degree, and apparent effects on individual resources are important aspects of characterizing the current condition.

Observed Trends

The plan area has experienced significant changes in climate over the past 50 years, and that trend is projected to continue.

The rate of warming during the last 50 years is nearly twice the rate of the previous 100 years (ISAB 2007). Average temperatures in the Pacific Northwest have increased by about 1 degree Celsius (1.8 degrees Fahrenheit) since 1900 (Halofsky and Peterson 2017). Mean annual temperatures in Northeast Oregon increased 0.06 °C per decade from 1895-2013 (Halofsky et al. 2018). Precipitation in the Pacific Northwest has increased by 13 to 38 percent since 1900 and showed substantial inter-annual and decadal variability during the 20th century (Mote 2003a, Mote et al. 2013).

As described in the climate change vulnerability assessment for the Blue Mountains (Halofsky and Peterson 2017), temperature and precipitation shifts have already resulted in observed changes in snow accumulation (Halofsky and Peterson 2017; Mote 2003a, 2005, 2018; McCabe and Wolock 2009; Kapnick and Hall 2011). Warmer spring temperatures have been linked to earlier snowmelt timing (Cayan et al. 2001) and earlier peak streamflow (Barnett et al. 2005, Stewart et al. 2005). Warmer temperatures have already resulted in more precipitation falling as rain instead of snow (Knowles et al. 2006) and lower summer streamflow across the Pacific Northwest (Luce and Holden 2009).

In snowmelt-dominated basins, there is an observed trend towards earlier spring runoff as seen by an increase in the fraction of annual streamflow occurring during March, April, and May (Knowles et al. 2006, Stewart et al. 2005). These changes are indicative of a shift in streamflow timing that is consistent with the expected effects of warming temperatures (Halofsky and Peterson 2017).

April 1 snowpack has declined in mountainous regions across the West (Mote 2003b, Mote et al. 2005, Luce et al. 2014, Mote et al. 2018), with observed changes largely being attributed to elevated temperatures in both winter and spring (Hamlet et al. 2005, Stewart et al. 2005).

Projected Trends

Different climate models (Global Climate Models – GCMs) project differing rates of change in temperature and precipitation because they operate at different scales, have different climate sensitivities, different assumptions about future emissions, and incorporate climate feedback differently. However, all climate models project increasing average annual temperatures over the coming decades (IPCC 2023).

Temperature

Compared to observed historical temperature (1950-1999), average warming for the Pacific Northwest is projected to be 2.4 to 3.1 °C (4.3 to 5.6 °F) by 2050 and 3.2 to 6.3 °C (5.8 to 11.3 °F) by 2100, depending on greenhouse gas emissions (RCP) (Halofsky and Peterson 2017). Note that the lower end of that range is possible only under RCP 4.5 (a significant reduction in global emissions by the end of the century).

The US Forest Service Climate by Forest tool (USDA Forest Service 2023) provides projections and statistical analyses for a range of climate variables through the end of the century by both the medium-low- (RCP 4.5) and high- (RCP 8.5) emissions pathways. Example projections of average daily max temperature for selected ecosystems on each of the Blue Mountains national forests are shown in

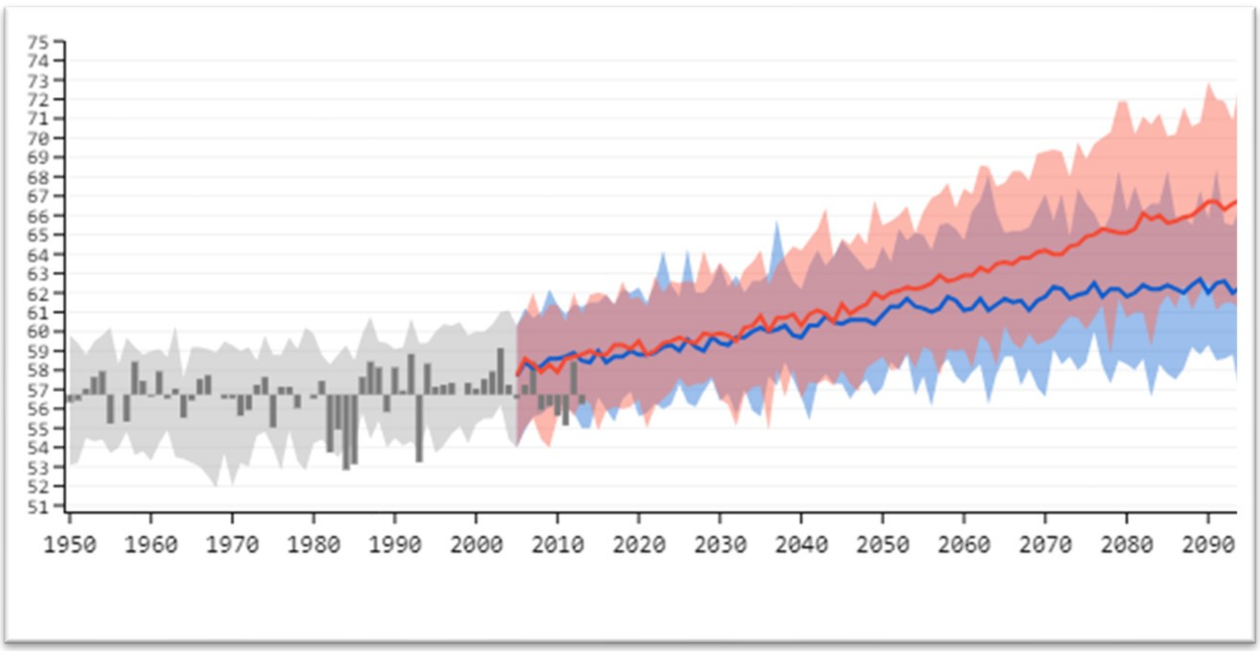

Figure 1,Figure 2, and Figure 3, displaying expected temperature trends. For all, the red line is the average of the RCP 8.5 scenario outputs, and the range of projections is in red. The blue line represents the RCP 4.5 model average with a range of modeled outputs in blue. Grey bars represent observed historical data starting in 1950 and ending 2013, and gray shading represents modeled historical data. Other variables available for viewing on the tool include days per year above minimum 90-105 degrees Fahrenheit, days per year below 32 degrees Fahrenheit, and several others.

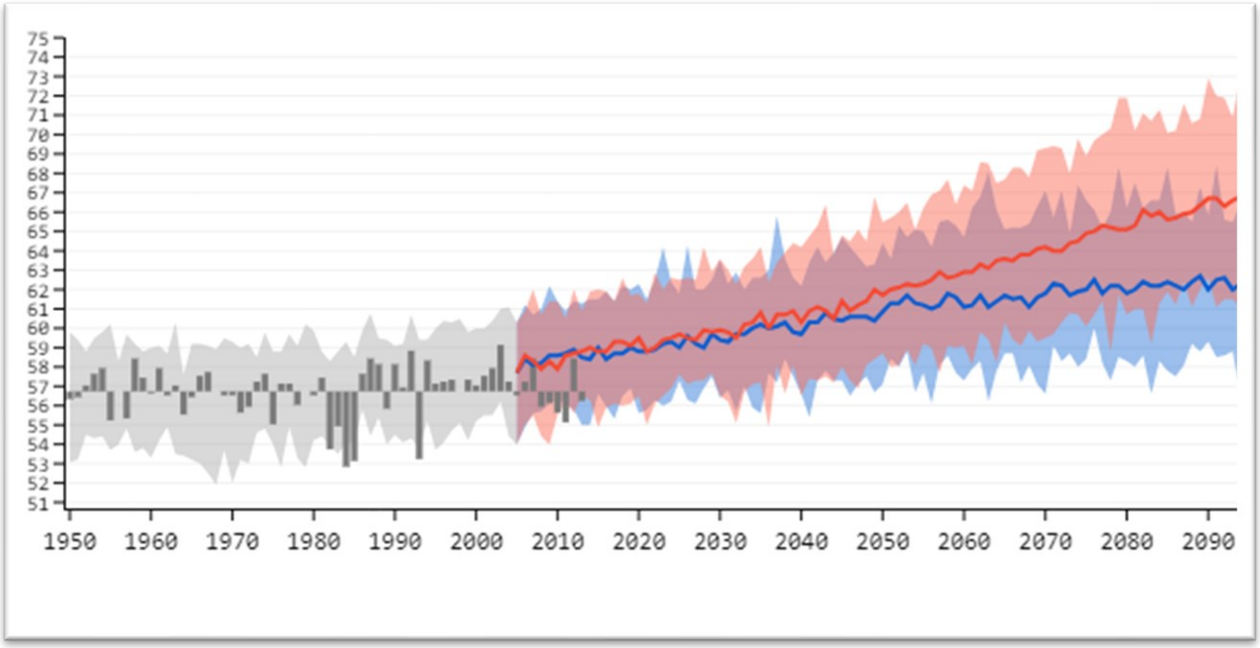

Figure 1. Projected average daily max temp in the continental highlands (~53% of the National Forest) of the Malheur National Forest (USDA Forest Service 2023).

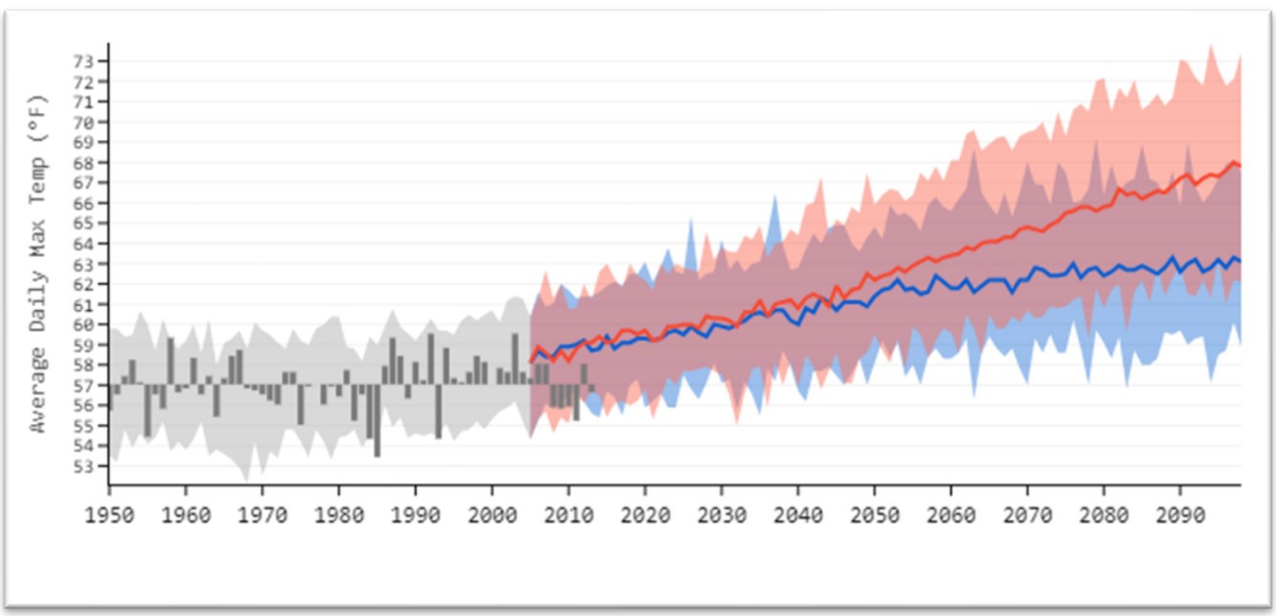

Figure 2. Projected average daily max temp in the cold moist volcanic ash forests (~46% of the National Forest) of the Umatilla National Forest (USDA Forest Service 2023).

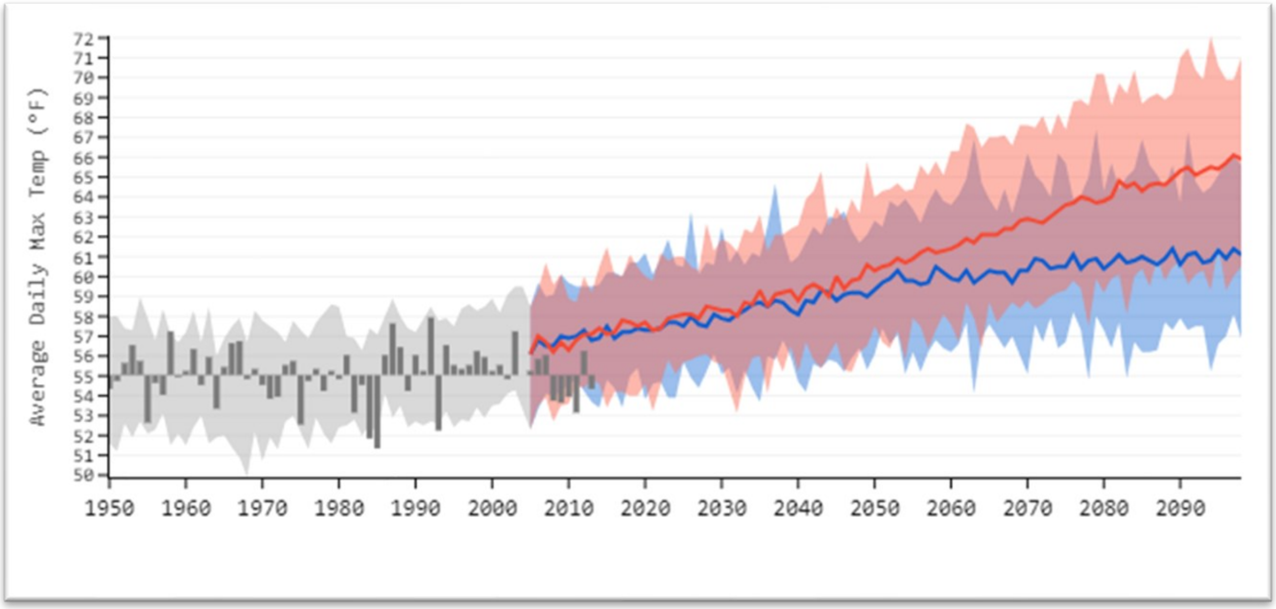

Figure 3. Projected average daily max temp in the Wallowa-Seven Devils Mountains ecoregion (~18% of the National Forest) of the Wallowa-Whitman National Forest (USDA Forest Service 2023).

Total Annual Precipitation

Precipitation may increase slightly in the winter, although the magnitude is uncertain (Halofsky and Peterson 2017). Projections of future precipitation are more uncertain with projected changes in total annual precipitation from individual GCMs varying from minus 10 percent to plus 20 percent change by 2080 (Halofsky and Peterson 2017).

Models show no clear projection for annual precipitation into the future; projections are variable and range from wetter to drier conditions. The models do show some potential agreement that summers may be drier in future (Halofsky and Peterson 2017).

Snowpack

Projected air temperature changes will result in gradual shifts in precipitation from snow to rainfall at successively higher elevations. Current climate projections suggest that snow accumulation will decline, snow-dominant watersheds will become mixed rain and snow basins, and mixed rain and snow basins will become rain dominated by the 2040s under an emissions scenario representing business as usual through the first half of the 21st century followed by substantial mitigation after 2050 (Tohver et al. 2014). Large areas of the Blue Mountains are expected to be snow free by the 2080s (Hamlet et al. 2013, Luce et al. 2014) with snow persisting only in high elevation areas (roughly 6,000'), such as the Wallowa, Elkhorn, and Strawberry mountains (Figure 4). In lower elevation areas where winter temperatures are at the threshold of freezing, winter precipitation is expected to become increasingly dominated by rain instead of snow (Mote 2003b, Hamlet et al. 2005, and Mote et al. 2005), and winter streamflow will become higher and more variable (Elsner et al. 2010, Isaak et al. 2016). Projected declines in snow residence time are shown in Figure 5.

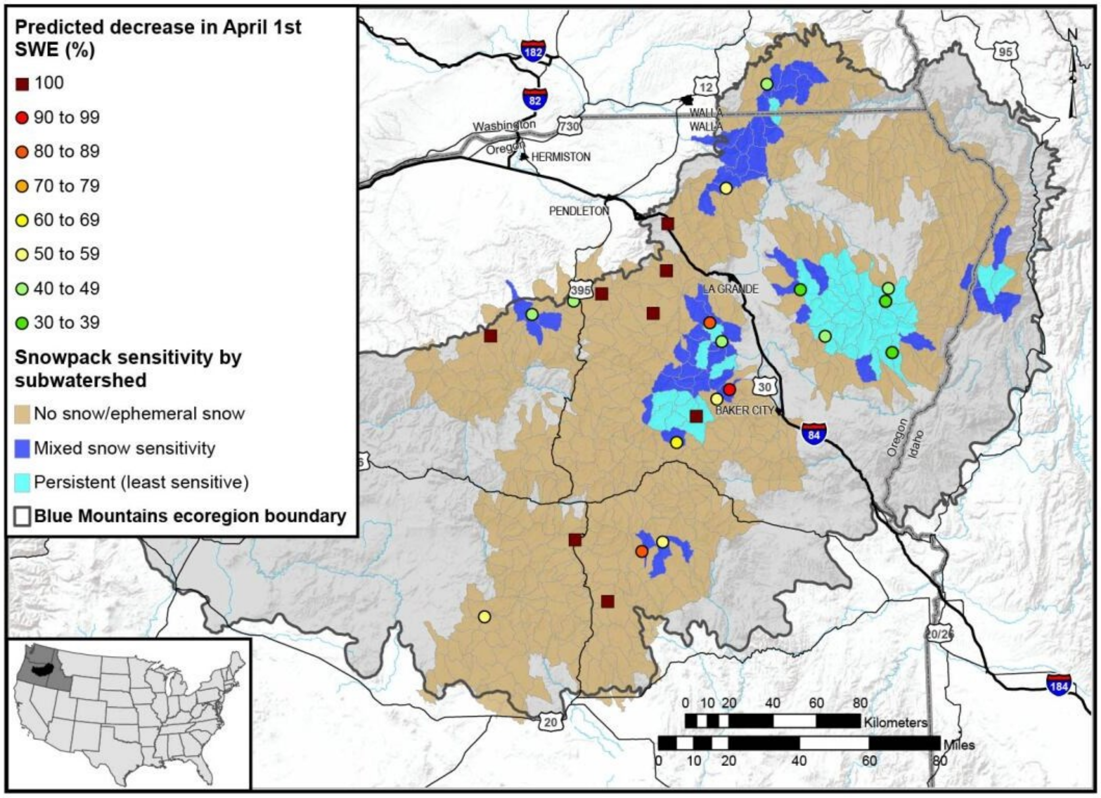

Figure 4. Projected change in snow water equivalent (SWE) for a 3° C increase in temperature in the Blue Mountains. Point data are projections at snowpack telemetry (SNOTEL) stations from Luce et al. (2014). Snowpack sensitivity classes (the same in both figures) reflect the amount of shift in snowmelt timing seen in two contrasting historical years (Kramer, see Table 1). (Halofsky and Peterson 2017)

Table 1. Snowpack sensitivity definitions used in Halofsky and Peterson 2017

Sensitivity class	Definition
Persistent—least sensitive	Timing of peak snowmelt differed by >30 days between the warmest, driest year and coldest, wettest year in >30 percent of the subwatershed.
Persistent—more sensitive	Timing of peak snowmelt in the warmest, driest year (2003, El Niño year) occurred >30 days earlier than the coldest, wettest year (2011, La Niña year) in >50 percent of the subwatershed.
Ephemeral snow	April 1 snow water equivalent was <3.8 cm during dry years (no snow) and >3.8 cm during wet years (snow cover) in >80 percent of the subwatershed.

Source: Kramer, M.G. Unpublished data. On file with: M.G. Kramer, University of Florida, Gainesville, FL 30503.

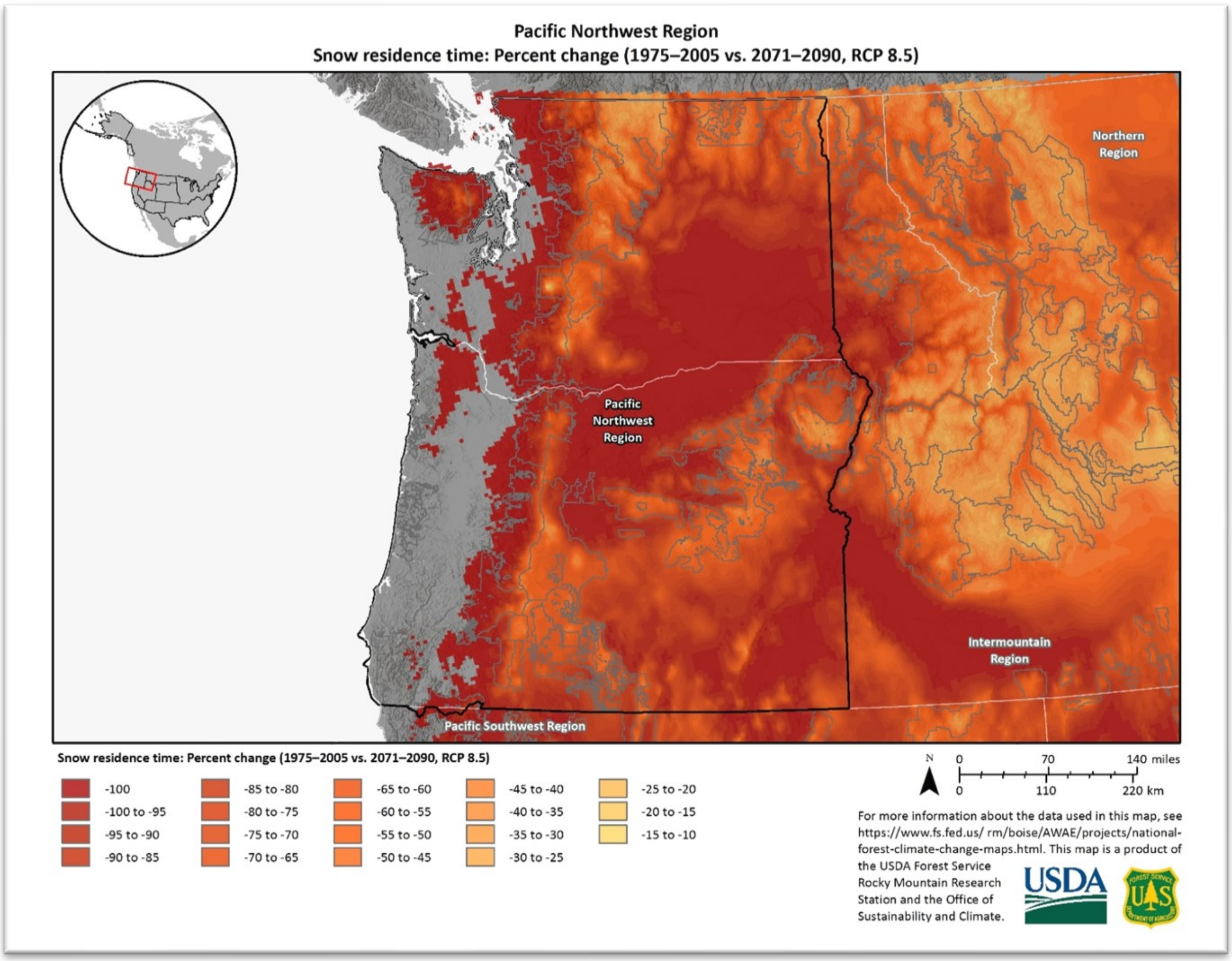

Figure 5. Projected percent change in snow residence time in the Pacific Northwest. National Forest boundaries are outlined in gray. (Luce et al. 2014)

Streamflow and timing

Changes in precipitation patterns and runoff already described are projected to result in reduced peak spring streamflow, increased winter streamflow, and reduced late summer flow (Halofsky and Peterson 2017). Overall, earlier snowmelt and longer warm periods are expected to lead to a shift of peak river runoff to early spring or winter (Barnett et al. 2005). Streamflow projections suggest that there will be higher annual streamflow with lower summer flows and higher and more variable winter flows (Hamlet et al. 2013).

As described in the Blue Mountains Climate Change Vulnerability Assessment (Halofsky and Peterson 2017), streamflow extremes are likely to increase, with higher peak flows (Hamlet et al. 2013) as well as lower low flows (Luce and Holden 2009, Tohver et al. 2014) (Figure 6). Low elevation areas within and surrounding the Blue Mountains may see less decline in low flows because they are already dry and have less soil moisture to lose (Tohver et al. 2014). Modeled projections using data from Wenger et al. (2010) predicted less than a 10 percent decline in summer streamflow for 47 percent of streams in the Blue Mountains by the 2080s (Figure 7). Other parts of the region, including the Wallowa and Greenhorn mountains are projected to have greater than 30 percent declines in mean summer streamflow by 2080 (Figure 7, Halofsky and Peterson 2017).

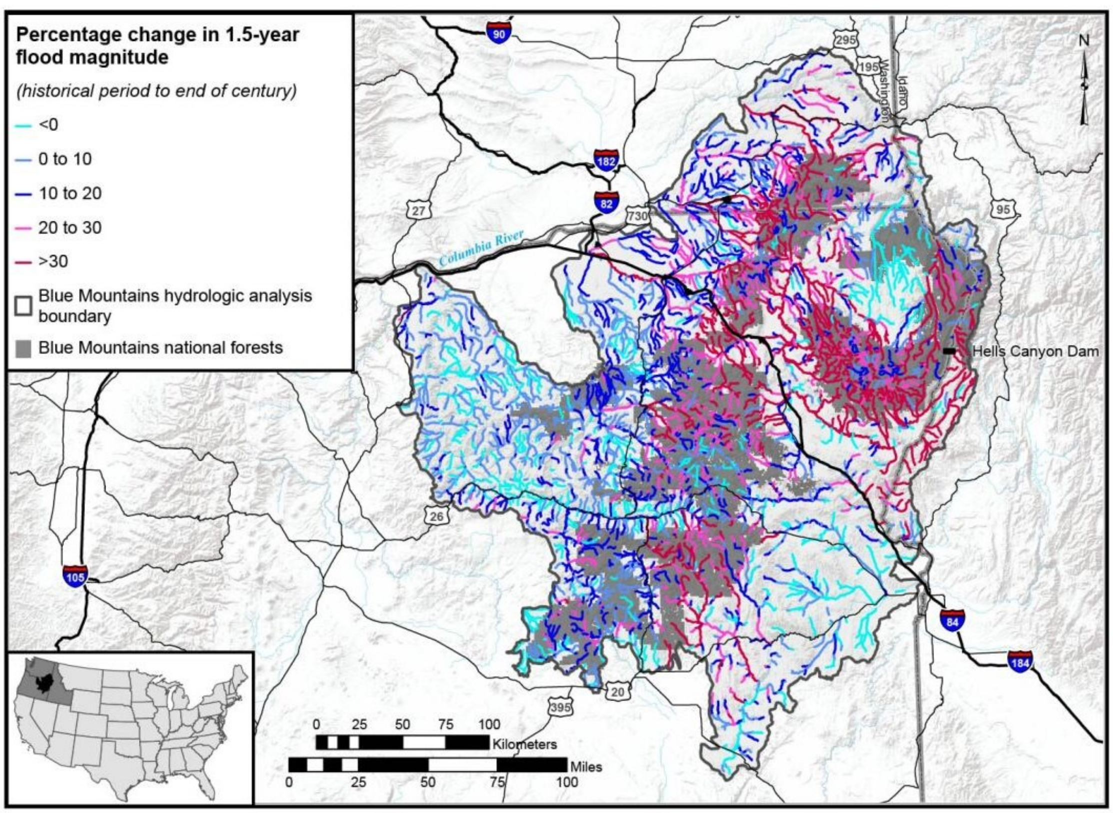

Figure 6. Percentage change in the 1.5-year flood magnitude (approximately bankfull) between 2080 and the historical period (1970 to 1999) for the Blue Mountains region. All projections are from the Variable Infiltration Capacity model, using data from Wenger et al. (2010). (Halofsky and Peterson 2017)

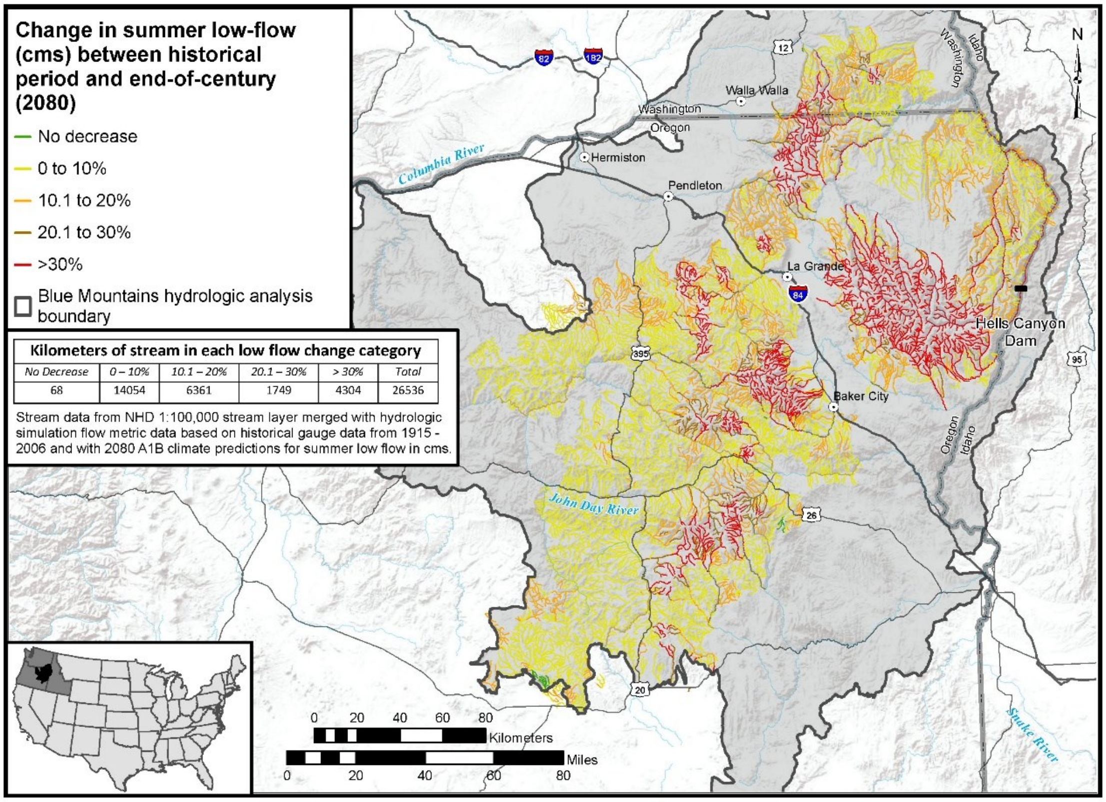

Figure 7. Percentage decrease in mean summer streamflow from historical time period (1970-1999) to 2080 for streams in the Blue Mountains region. Projections are from the Variable Infiltration Capacity hydrologic model using data from Wenger et al. (2010) routed through a linear groundwater reservoir model, using calibrated recession parameters for each watershed from Safeeq et al. (2014). [Source: Clifton et al. 2018]

Extreme hydrologic events

Weather events and extremes may become more frequent, more widespread, or more intense during the 21st century (Parry et al. 2007). An example of a recent extreme weather event in the Blue Mountains was in February 2020 when an atmospheric river with unusual orientations of moisture transports dropped snow at low elevations followed by heavy rain-on-snow. The peak flow that occurred set a record on the Umatilla River in Pendleton, Oregon (Dalton and Fleishman 2021). Climate change is expected to increase the frequency of rain-on-snow floods and winter flood peaks (versus spring snowmelt flood peaks). Increasing temperatures may also increase drought risk because of reduced water storage in vegetation and soil for summer use and the long-term variability of dry years and wet years in the Pacific Northwest. Flood magnitude is expected to increase in the Wallowa Mountains, Hells Canyon Wilderness Area, and northeastern portion of the Wallowa-Whitman National Forest by the 2080s (Wenger et al. 2010). Flood risk may increase locally as the frequency of winter rainfall increases and extends to higher elevations (Hamlet et al. 2007, Salathé et al. 2014, Guan et al. 2016).

Hydrologic cycle

Climate change is anticipated to result in changes in the hydrologic cycle due to changes in temperature and precipitation, which has the potential to fundamentally alter watershed processes and disturbance regimes over the next several decades.

While most of the Blue Mountain's streams are snowpack-recharged, groundwater may mediate in the short term some of the effects of variable precipitation due to climate change in groundwater discharge aquatic systems (Safeeq et al. 2014). However, most groundwater is ultimately recharged by precipitation and will eventually respond to changes in the type and amount of precipitation.

Drought, Wildfire, and Other Disturbance

For information on the anticipated effects of climate change on drought, wildfire, and other disturbance, see the Terrestrial Vegetation subsection of the next section.

Anticipated Impacts of Climate Change on National Forest Resources

Terrestrial Vegetation

Increasing air temperature, through its influence on soil moisture, is expected to cause gradual changes in the species composition and distributions of forest communities. Ecological disturbances, especially wildfire and insect outbreaks, will be the primary driver of changes to vegetation, and future forests may be dominated by younger age classes and smaller trees (Halofsky and Peterson 2017). Climatic changes have resulted and are expected to continue, resulting in earlier initiation of the growing season, longer growing seasons, and mismatches between climate characteristics and plant phenology (Peterson et al. 2014).

Plant species respond individually to changes in temperature and precipitation regimes, atmospheric carbon dioxide, and disturbance regimes. As such, new plant associations may develop in the future due to climate change. General increases in precipitation could result in expansion of woody species and shifts from grasslands to shrublands, or from grasslands and shrublands to woodlands and forests. Conversely, decreases in effective precipitation could cause declines in vegetation productivity and shifts from forests, woodlands, and shrublands to grasslands and deserts. Vegetation modeling work using several climate scenarios from Halofsky and Peterson 2017 generally suggests the latter, but there is a significant amount of area in the Blue Mountains where climate scenarios do not agree on vegetation type shift. Some species have the potential to expand upslope with increases in temperature (see sections on specific ecosystem types below). Specifically, vegetation modeling suggests that the area suitable for subalpine forests will decrease as warming increases growing season and productivity in these areas allowing lower elevation forest types to be more competitive and potentially outcompete subalpine forests (Halofsky and Peterson 2017). Changes in forest composition, structure, seasonality, and productivity could have consequences for wildlife species dependent on forested habitats.

In a warmer, drier climate (especially in summer), Halofsky and Peterson (2017) state the following may occur in the Blue Mountains by the end of the 21st century, although they note that there is considerable uncertainty about the future (Table 2):

- The importance of pine and sagebrush species may increase.
- The forest-steppe ecotone may move north of its present position or up in elevation.
- Ponderosa pine may be found at higher elevations.
- Subalpine and alpine systems are potentially vulnerable, and subalpine tree species may be replaced by high-elevation grasslands, pine, or Douglas-fir.
- Juniper woodlands, which have been increasing in recent decades, may be reduced if longer and drier summers lead to more wildfire.
- Grasslands and shrublands at lower elevations may increase across the landscape but shift in dominance towards more drought-tolerant species.
- Nonnative species, including annual grasses, may increase in abundance and extent.

Table 2. Summary of tree species vulnerability to loss from the landscape in the Blue Mountains

Vulnerability	Tree Species
Highly Vulnerable	Alaska cedar, limber pine, mountain hemlock, whitebark pine, subalpine fir, Engelmann spruce
Moderately Vulnerable	Western white pine, quaking aspen, grand fir, white fir
Less Vulnerable	Lodgepole pine, Douglas-fir, Western juniper, Western larch, ponderosa pine, big sagebrush, curl-leaf mountain mahogany, antelope bitterbrush

Source: Halofsky and Peterson 2017, Devine et al. 2012
Note: Results in the summary table are derived from species distribution models (SDMs), which often show reductions in suitable habitat because future novel climates do not correspond with current conditions – and models do not consider increasing complexity associated with novel environments. Species with large climatic amplitudes like lodgepole pine and juniper may be most competitive in novel environments.

Changes in Physiological Processes

Changes in the length of the growing season, the timing of bud break (phenology), and the availability of soil moisture are expected to produce large shifts (both positive and negative) in forest growth and mortality rates, forest floor decomposition, and species composition in forest ecosystems (Peterson et al. 2014). There is correspondence between earlier spring green up and the early onset of spring snowmelt runoff in western North America (Cayan et al. 2001).

Climatic variability and change can affect plant physiological processes, including altering growth and reproductive phenology, rates of photosynthesis and respiration, root and shoot growth, and seed production. Elevated carbon dioxide can influence many of these same processes, either enhancing or offsetting climatic influences (Peterson et al. 2014). Some species may respond positively to higher concentrations of ambient carbon dioxide as a result of increased water-use efficiency, although this “fertilization” effect may diminish as other factors, such as moisture, become limiting (Halofsky and Peterson 2017). Uncertainty exists about how climate change will affect species distribution, forest productivity, and ecological disturbance in the Blue Mountains.

There are also indications that evapotranspiration rates are increasing and extending to earlier in the year due to warming temperatures (Hamlet et al. 2007), and this has implications for moisture availability and drought stress on vegetation later in the growing season (Bumbaco and Mote 2010) and on the occurrence of wildfire (Littell et al. 2016, Marlier et al. 2017).

Changing climate phenomena are expected to cause changes in the abundance and distribution of tree, shrub, and grass species throughout the Blue Mountains, with drought-tolerant species becoming more competitive. Ecological disturbance, including wildfire and insect outbreaks, will be the primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees (Halofsky and Peterson 2017).

Changes in Disturbance Cycles

Inadequate water availability coupled with drying conditions could contribute to an overall increase in the vulnerability of forests to insects, fire, and drought. The combined expectations regarding increases in water limitation, wildfire activity, forest vulnerability to drought, fire, and insects, suggest that Blue Mountains national forests are likely to be fundamentally affected by altered disturbance regimes as the region's climate changes (Halofsky and Peterson 2017).

Drought

Droughts are prolonged periods of lower-than-average precipitation and are becoming more frequent and severe with climate change in the Pacific Northwest relative to the previous century (Dalton et al. 2017). Future droughts may continue to be more frequent and of longer duration (Adams et al. 2009, Dai 2011).

Various factors may lead to more severe drought conditions including lower than usual winter precipitation, winter snowpack, or summer precipitation, or higher than usual winter temperatures (Bumbaco and Mote 2010). Climate models suggest that almost 50 percent of the dryness in soil moisture between 2000 and 2018 was driven by human-induced climatic changes (Williams et al. 2020), and some models suggest a decrease in winter snowpack of up to 60 percent by 2050 under RCP8.5 across the western United States (Fyfe et al. 2017). The frequency and severity of drought events is expected to continue increasing across much of Oregon under both RCP4.5 and RCP8.5 (Gu et al. 2020) with important consequences for all resources areas in the Blue Mountains.

Seasonal drought is a natural occurrence in the Northwest, rendering many ecosystems inherently resilient to changes in water supply. Still more frequent and severe drought may challenge species adaptive capacity, alter successional pathways, and favor more drought-tolerant species (Vose et al. 2016a). Increasing temperatures and more frequent drought conditions may exacerbate the conditions that lead to wildfire, insect outbreaks, and invasive species (Halofsky and Peterson 2017). Drought may also lead to decreased growth and productivity, contribute to regeneration challenges, and broadly make the Blue Mountains national forests more vulnerable to other stressors. This could lead to altered forest composition and structure particularly at lower elevations and in the southern Blue Mountains (Vose et al. 2016b, Halofsky and Peterson 2017). Rangelands may also experience negative impacts from increasing drought as it may limit ecosystem productivity, alter nutrient cycling, increase wildfire risk, and increase susceptibility to invasive plant species (Knapp and Smith 2001, Abatzoglou and Kolden 2011, Evans and Burke 2013). More frequent and extreme drought may also significantly impact domestic and agricultural water supply, outdoor recreation, and tribal health, culture, and economies.

The figures below illustrate the deviation in average moisture index (Koch et al. 2012) for a three-year window for the Blue Mountains national forests. Differences are expressed as Z-score where values further from zero represent increasingly larger surpluses (positive scores) or deficits (negative scores) in moisture availability versus the long-term (1900–2022) average. A multi-year average is useful for characterizing drought in forest ecosystems as trees become more vulnerable to mortality over consecutive years of dry conditions. For the time-period 2000–2022, annual moisture index shows more dry years than wet with some very wet years, and summers (May–September) are even drier with more years of moderate severe drought compared to the historic record. The analysis suggests that the last two decades have been drier than the historical record since 1900.

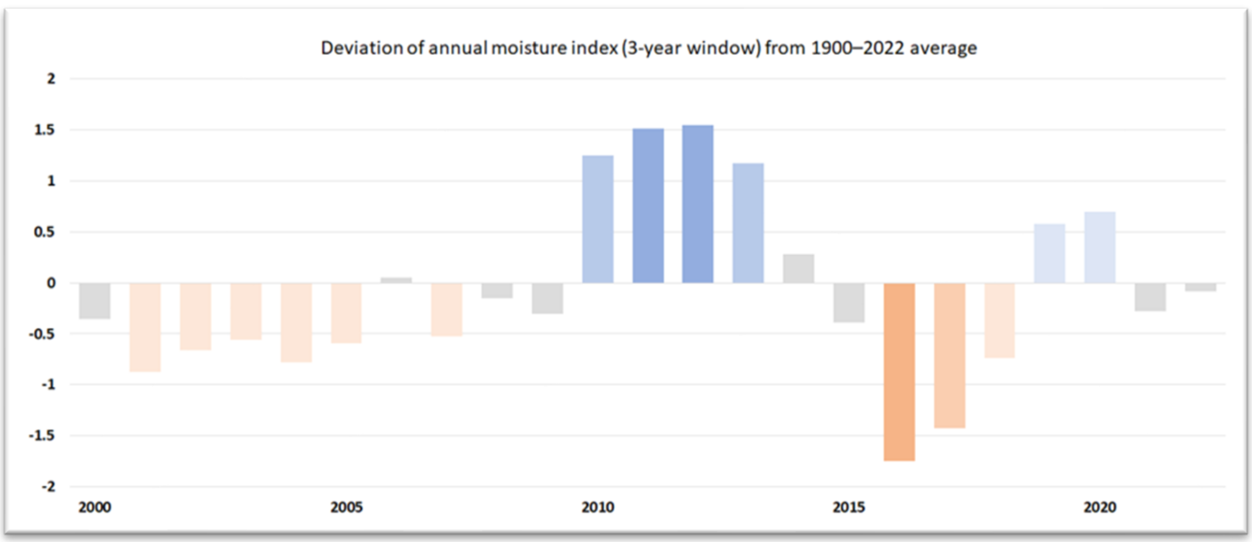

Figure 8. The deviation in annual moisture index from the 1900-2022 average for the years 2000-2022. Difference is expressed as a z-score (y-axis) where values further from zero represent larger deviations from the average, negative values indicate deficit and positive values indicate surplus (USDA Forest Service Office of Sustainability and Climate 2023, Koch et al. 2012).

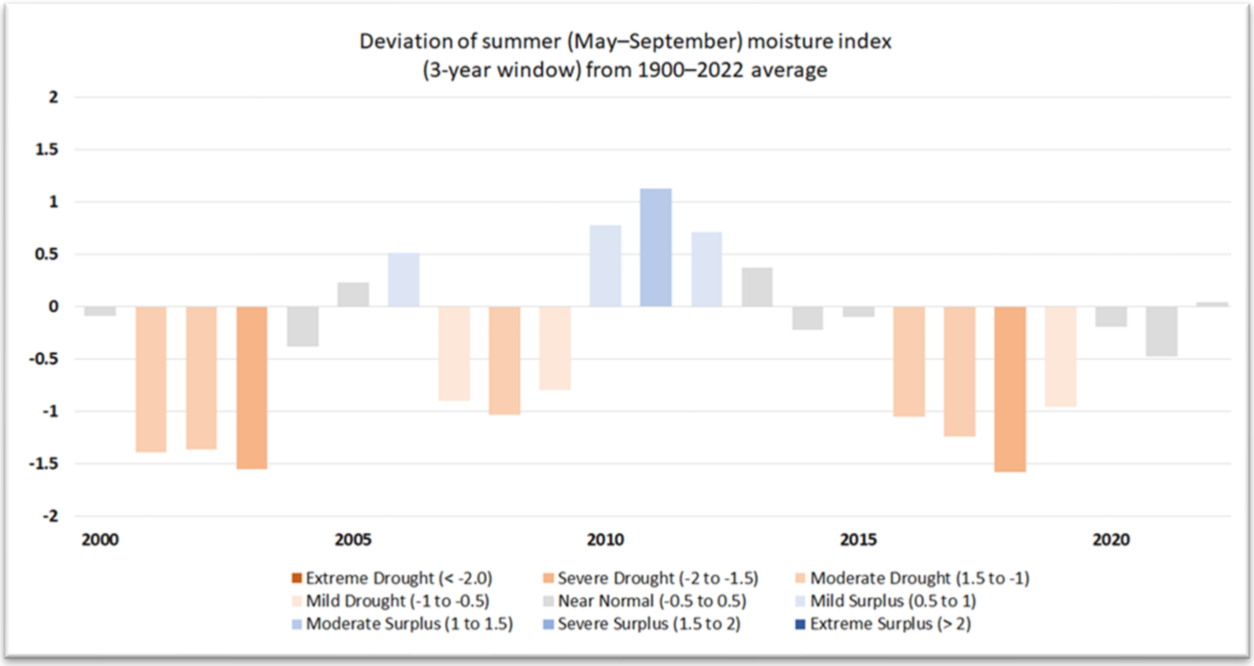

Figure 9. The deviation of summer (May-September) moisture index from the 1900-2022 average for the years 2000 to 2022. Difference is expressed as a z-score (y-axis) where values further from zero represent larger deviations from the average, negative values indicate deficit and positive values indicate surplus (USDA Forest Service Office of Sustainability and Climate 2023, Koch et al. 2012).

Drought may also affect areas across the national forests differently based on several factors, including soil type. For information on soils more vulnerable to drought, see the Soils Report.

Insects and Disease

Climate change is likely to lead to increased forest mortality from insects and disease (Adams et al. 2009, van Mantgem et al. 2009). As Halofsky and Peterson (2017) state, critical thresholds in ecosystem structure and function may be exceeded in a warmer climate.

Climate influences the geographic distribution, population dynamics, and disturbance effects of insects and diseases through either direct environmental impacts on the development and survival of insect and disease organisms, or by altering host susceptibility and defense capabilities (Peterson et al. 2014). Insect lifecycles depend on a complex interaction of temperature, moisture, and suitable hosts. For example, winter temperatures can affect survival of insects in temperate zones, while spring/summer temperatures influence insect life cycles (Bentz et al. 2010). Although outbreak dynamics differ from species to species and from forest to forest, climate change appears to be one driving factor for some of the current forest insect outbreaks in western North America.

Warmer temperatures may increase the potential for insect and disease outbreaks, particularly as a transient response in colder temperate zones where insect and pathogen vigor has historically been limited by suboptimal temperatures (Bentz et al. 2010). Higher warm-season temperatures should also increase growth rates for temperate insect herbivores, although the rate of increase will vary by species (Bale et al. 2002).

For many forest insect species (primarily beetles; notably *Ips* and *Dendroctonus* species), the influence of elevated temperatures on outbreak dynamics is most notable at higher elevations and latitudes where some beetles have shifted to completing their development in a single year, rather than two or even three years or, in some cases, have shifted to completing multiple generations per year. All else remaining constant, this decrease in generation time translates to an increasing rate of population growth. Because of effects like these, geographic distributions of insect and diseases have changed in the past in response to climate change and shifts in the north to south range distribution or into higher elevations are likely (Bentz et al. 2010). Depending on the magnitude of the temperature increase, which may vary by elevation, high elevation forests could be at greater risk to insect infestation than lower elevation forests, where warmer temperatures may disrupt the insects' seasonality. Elevated winter temperatures are associated with increased winter survival; however, it should be noted that increased winter survival does not always coincide with increased population success based on developmental timing. Each process is affected by temperature patterns occurring at different times of the year. East of the Cascades, mountain pine beetles will likely reach higher elevations, and pine trees experiencing stress from changing climatic conditions will likely be more vulnerable to infestations by beetles (Littell et al. 2009).

Climate also influences insect and disease impacts indirectly by modifying vigor and defenses in host plants (Bentz et al. 2010; Raffa et al. 2008). Climatic variability can alter stress levels and affect the susceptibility of trees to insect attacks and plant diseases. The more extreme weather fluctuations predicted by many climate models will have unpredictable effects on insects, diseases, and their host plants. Tree mortality in response to heat and drought stress is often facilitated by insects and diseases; trees weakened by prolonged drought stress have reduced defenses against the insect and disease attacks that eventually kill the tree (Kolb et al. 2016). Much of the significance of the susceptibility or hazard modeling efforts as well as the current activity levels depends on the context of what level of historic insect and disease susceptibility is considered "normal." Historically many outbreaks were likely severe, but several forest scientists have observed that uncharacteristically large insect outbreaks seem to have become more common in recent decades in many conifer forest types and they will likely continue to do so, particularly in the face of expected climate changes (Logan et al. 2003; Bentz et al. 2009, 2010; Meddens et al. 2012; Sambaraju 2012; Kolb et al. 2016; Halofsky and Peterson 2017).

Wildfire

Over the past two decades, area burned by wildfires and the area burned at high severity in the western United States has increased markedly compared to previous decades (Westerling et al. 2006, Westerling 2016), due in part to a reduction in fuel moisture driven by increased temperature. In recent decades, large fires tend to occur during hotter and drier periods or hotter and drier years and these hot and dry periods are projected to become longer and more pronounced (Halofsky et al. 2020). Climate change projections for the Blue Mountains suggest increases in summer temperatures as well as decreases in precipitation across most models (Halofsky and Peterson 2017). As such, it is likely that wildfire activity will increase with continued changes in climate (Hessburg et al. 2020).

Regional-level relationships between climate and fire differ, depending on seasonal and annual variability in climatic drivers, fire frequency and severity, and the legacy of previous-year climate in live and dead fuels (Spies et al. 2010, Veblen et al. 2000, Hessl et al. 2004). Current-year drought is typically associated with more area burned, but the effects of antecedent conditions differ owing to interactions among climatic effects (Littel 2009b). In the Pacific Northwest, direct associations exist between fire extent and current-year drought (Hessl 2004, Wright and Agee 2004, Heyerdahl et al. 2001, Heyerdahl et al. 2008, Halofsky et al. 2020). In the cold upland forest potential vegetation group and some moist upland forest potential vegetation groups where fine fuel production is not limited by climatic variability, short-term synoptic fluctuations in atmospheric conditions play an important role in forcing extreme wildfire years (Johnson and Wowchuk 1993, Gedalof et al. 2005).

Uncharacteristically severe wildfires are on the rise, especially in the dry upland forest potential vegetation group (Dennison et al. 2014). Over the past 10 years, lightning-caused fires ranged from 808 to 2,170 per year in the northwest. Human-caused fires ranged from approximately 1,078 to 2,666 fires per year in the northwest. A warmer climate will cause an increase in the frequency and extent of wildfire in most dry forest and shrubland ecosystems (Westerling et al. 2006, 2011).

Projecting future wildfire activity under changing climate is complex; however, multiple studies provide evidence for an expected increase in area burned driven by climate change (McKenzie et al. 2004; Halofsky et al. 2020). Conclusions from these studies are summarized below to provide multiple lines of evidence to indicate expected increases in wildfire activity.

- A mean temperature increase of 2° C (3.6° F) is projected to lead to area burned by wildfire increasing by a factor of 1.4 to 5 (140% to 500% increase) across western states (McKenzie et al. 2004).
- Statistical models developed by Littell et al. (2010) specifically for the Northwest suggest that area burned will increase by a factor of 3.8 in forested ecoregions including the Blue Mountains by the 2040s when compared to a 1980-2006 baseline period. This study also found that wildfire activity in the Blue Mountains ecoregion is particularly sensitive to effects of increasing temperatures (Littell et al. 2010). Updated modelling also suggests an increase in wildfire activity with climate change but suggests that fuel limitations may eventually limit these increases (Littell et al. 2018).
- A coarse resolution statistical model projects that annual area burned could increase by a factor of 5 for the period from 2010-2039 when compared to a 1961-1990 baseline in the states of Oregon and Washington (Kitzberger et al. 2017).
- Annual probability of very large fires (>5,000 hectares) may increase by a factor of 4 in 2041-2070 compared to 1971-2000 (Barbero et al. 2015).
- Davis et al. (2017) modeled changes in climatic suitability for large fires. Their models project 63 to 72 percent of Blue Mountains forests, depending on emissions scenario, may be highly suitable for large fires by the end of the century compared to just 17 percent of their area climatically suitable during the baseline period of 1971-2000. This study also suggests that mean fire return intervals will shorten by a factor of 1.7 to 1.9 (170% to 190% decrease), depending on emissions scenario, in the Blue Mountains for this time period. This study also highlights the Blue Mountains as one of

the areas with the highest suitability for large fires under future climates out of all areas in Oregon and Washington (Davis et al. 2017).
- Mechanistic vegetation modelling using the MC1 model projects that burned area will increase by around 100 percent for 2071-2090 compared to a 1971-2000 baseline in the Blue Mountains under a high emissions scenario (Rogers et al. 2011).
- Mechanistic vegetation modelling using the MC2 model also projects increases in fire activity with mean fire return intervals in the 21st century projected to be less than half what they were in the 20th century (Sheehan et al. 2015).

As summarized above, multiple lines of evidence point to increases in wildfire activity in the Blue Mountains due to climate change. Given model limitations and differences in approaches, the specific quantitative amounts of change are less important than the qualitative conclusions and the direction of change, which point to an increase in wildfire activity.

An increase in wildfire activity is not an inherently negative trend for ecosystem integrity, given the prevalence of fire-adapted forests in the Blue Mountains (see Terrestrial Ecosystems report). The extent to which these projected increases in wildfire activity associated with climate change degrade ecosystem integrity is determined by the proportion of area burned at high severity and how that reflects historical fire regimes (Halofsky et al. 2020).

Studies on climate change and fire severity suggest that area burned at high severity has increased over recent decades largely due to increases in overall area burned. However, there is some evidence that may suggest that climate change has caused an increase in the proportion of area burned at high severity (Parks and Abatzoglou 2020). Even so, fuel amounts and connectivity are the primary driver of patterns in high severity fire (Parks et al. 2018). As such, the effects of projected increases in wildfire activity on fire severity in the Blue Mountains and, by extension, on ecosystem integrity will be affected by the current conditions of forests in the area. Many forested areas in the plan area currently have characteristics, including species composition, structure, and fuel connectivity, that are not conducive to historical fire regimes for these ecosystems (Hessburg et al. 2015). Fire severity data indicates that under severe fire weather conditions, much of the Blue Mountains has the potential for high severity fire (based on Continuous Vegetation Survey (CVS) data and the forest vegetation simulator-fire/fuel extension modeling).

From analyses done for the 2018 FEIS (USDA Forest Service 2018), the current potential for high severity fire within the cold and moist upland forest potential vegetation groups exhibits the least amount of departure from historical or reference values. Even though the cold and moist upland forest potential vegetation groups show the potential for a moderate to high amount of high severity fire (32 to 55 percent of each potential vegetation group), this amount of fire is consistent with the mixed to infrequent high severity fires that historically dominated these systems. However, increased length of fire season due to climate change may bring this potential to the upper limits of the historic averages at 80 percent.

Within the dry upland forest potential vegetation group, the potential for high severity fire ranges from approximately 50 to 55 percent, which indicates a moderate to high increase in high severity fires compared to historical or reference conditions of 5 to 15 percent (USDA Forest Service 2018). This increase in potential fire severity can increase loss of key ecosystem functions, especially with the potential for longer fire seasons.

Anticipated Climate Change Effects on Cold Upland Forest

The cold upland forest potential vegetation group is a high-elevation, energy-limited forest ecosystem. Cold upland forests have relatively short growing seasons, and are dominated by subalpine fir, grand fir, Engelmann spruce, whitebark pine, and lodgepole pine in late-seral stands (see Terrestrial Ecosystems Report). Productivity is projected to increase in subalpine and alpine zones across the Pacific Northwest in response to moderate warming and elevated atmospheric carbon dioxide (Halofsky and Peterson 2017). Longer growing seasons, warmer summer temperatures, and reduced snowpack due to climate change may promote tree growth in the cold upland forest type, even moving tree line upslope in certain locations (Halofsky and Peterson 2017).

Vegetation modelling completed for the Halofsky and Peterson (2017) vulnerability assessment project states that available suitable climate for most cold upland tree species will be either moderately reduced or nonexistent in the Blue Mountains by the end of the 21st century. This is due to increased productivity allowing lower elevation species to better compete in these areas. Based on this model output, cold upland forests may be vulnerable to climate change, and high-elevation mountains (like the Wallowa Mountains and Seven Devils) may serve as refugia for subalpine species. Devine et al. (2012) considered subalpine fir, Engelmann spruce, and western white pine to be highly susceptible to climate change, although lodgepole pine has a lower susceptibility score. Although western white pine also has a high susceptibility score (Devine et al. 2012), its generalist life history (Rehfeldt et al. 1984) may confer phenotypic plasticity, allowing it to better adjust to changing environmental conditions.

Although results from experimental and observational studies are not entirely clear, multiple lines of evidence suggest climate change is likely to produce significant changes in the cold upland forests over time, including altered growth and altered tree life cycle events. Cold upland forests may be converted to high-elevation herbaceous parklands or woodlands with ponderosa pine or Douglas-fir under warmer and drier scenarios. Remnant populations may persist in the highest of elevations within the Blue Mountains (such as the Wallowa Mountains). Increased wildfire may constrain tree reestablishment in these slow-growing systems, particularly for sites without serotinous lodgepole pine as a common, pre-fire component. Increased insect and disease activity with climate change may also increase stress and mortality in these cold upland forests (Halofsky and Peterson 2017).

Anticipated Climate Change Effects on Moist Upland Forest

Moist upland forests are found at moderate to low elevations in the Blue Mountains. They are energy-limited, diverse systems consisting primarily of subalpine fir, grand fir, and Douglas-fir in late-seral stands, with lodgepole pine and western larch as common early-seral components. Douglas-fir and western white pine are common mid-seral species. They generally have cooler temperatures and higher precipitation than the lower elevation dry upland forests. There are numerous tree species of concern in this ecosystem type (see Terrestrial Ecosystems Report).

Moderate warming, along with increased atmospheric carbon dioxide, may lead to a positive response and increased productivity within some of these moist upland forests. However, in the Blue Mountains, lower elevation moist upland forests may transition to being primarily water-limited, particularly in areas without much ash or loess in soils, which enhance water holding capacity. More extreme warming and increased drought stress, particularly at lower elevations and in the southern portion of the Blue Mountains (Malheur National Forest) will likely cause decreased tree growth and forest productivity in moist upland forest. However, suitable climate habitat currently occupied by cold upland forests may offset these losses (Halofsky and Peterson 2017).

Palaeoecological and model evidence reported in the Blue Mountains Climate Change Vulnerability Assessment suggests that climate change will cause moderate to extreme loss of moist upland forests and characteristic species throughout the Blue Mountains national forests, though some model results suggest the opposite (Halofsky and Peterson 2017). Future warming with increased precipitation may lead to increased abundance of this potential vegetation group across the landscape. This outcome is somewhat supported by recent trends in response to warming in energy-limited forests (Halofsky and Peterson 2017).

Unlike cold upland forests, these forests may be able to adapt to future climate change by expanding into new available habitats (e.g., areas currently occupied by cold upland forests). Warm and very warm moist forest plant associations may be able to better adapt to warming compared to cooler plant associations within the moist upland forest potential vegetation group. However, increased summer drought stress may make these forests more vulnerable to other stressors, particularly at lower elevations and on southern sites in the Blue Mountains. Wildfire activity and insect and disease outbreaks will most likely increase with future warming and may reduce the distribution of this potential vegetation group (Halofsky and Peterson 2017).

Aspen is particularly vulnerable to a warmer climate due to compounding pressure from historical disturbance changes like fire exclusion-induced competition from conifers and grazing pressure. Warmer and drier climates could increase the risk of sudden aspen death (SAD) (Halofsky and Peterson 2017).

Anticipated Climate Change Effects on Dry Upland Forest

Dry upland forests are the most common forest type in the Blue Mountains and are dominated by ponderosa pine, Douglas-fir, or grand fir (see Terrestrial Ecosystems Report).

Dry upland forests occupy low to moderate elevations in the Blue Mountains. Dry upland forests in the Blue Mountains are water-limited, and productivity is projected to decline in a warmer climate (Latta et al. 2010). Water stress during the warm season is the primary factor limiting tree growth at low elevations common in the dry upland forest potential vegetation group. Negative water balances constrain photosynthesis, although this may be partially offset if carbon dioxide fertilization significantly increases water-use efficiency in trees. Generally, increased drought stress will likely result in decreased tree growth and forest productivity in the dry upland forests of the Blue Mountains. Areas with increased tree density due to fire exclusion may be particularly vulnerable to future climate change because of increased drought stress due to intertree competition and potential for large high severity fire. However, suitable climate habitat currently occupied by moist upland forest may offset these potential losses (Halofsky and Peterson 2017).

The Blue Mountains Climate Change Vulnerability Assessment summarizes anticipated shifts in the dry upland forests:

> *Some areas of the dry upland forest potential vegetation group may undergo undesirable changes in the face of future climate change. These forests have already experienced a long history of human land use and many are already experiencing severe and uncharacteristic wildfire and equally atypical insect and disease outbreaks that will most likely increase in the future. It is likely that the hottest and driest sites will shift to woodland or steppe vegetation. Species characteristic of hot dry [plant associations] may be better adapted to future conditions, and these species may become more common. Some models suggest that Douglas-fir and ponderosa pine may decrease in the future, although paleoecological evidence conflicts somewhat with this conclusion, suggesting that ponderosa pine was able to adapt to warmer climate by migrating north or up in elevation (Halofsky and Peterson 2017). However, the extent to which these species can adapt under current and future stressors is unclear. The overall vulnerability assessment [determined vulnerability for ponderosa pine is quite low], whereas Douglas-fir [is somewhat more vulnerable]. Given the strong paleoecological evidence regarding the persistence of ponderosa pine, coupled with its potential low vulnerability due to traits associated with drought and fire adaptation and the availability of habitat currently occupied by moist forests, it is likely that this forest type will persist and remain an important component of the landscape, although shifts in the distribution of dry upland forests and changes in relative abundance of different [plant associations] might be expected (or the formation of novel plant associations*) *(Halofsky and Peterson 2017).*

Dry upland forests may be particularly vulnerable to the effects of climate change on post-fire regeneration, particularly in areas where fires burn large patches at high severity. One study of post-fire regeneration in the Blue Mountains found that drought conditions and hotter sites (e.g., lower elevations, south-facing aspects) limited post-fire regeneration, and that Ponderosa pine generally fared better than Douglas-fir in post-fire regeneration in these areas (Boag et al. 2020).

Anticipated Climate Change Effects on Riparian Vegetation

Riparian areas and wetlands are predicted to be especially vulnerable to higher air temperatures, reduced snowpack, and altered hydrology (Dwire et al. 2018). Consequently, shifts in vegetation composition and extent are likely. Common species such as cottonwood, willow, and aspen may experience decreased establishment and growth as they have limited adaptive capacity in locations with altered streamflow and are likely to also experience increasing encroachment from conifers and eventual transition to drought-tolerant species (Halofsky and Peterson 2017). Declining winter snowpack, the main source of groundwater recharge in the Blue Mountains, may reduce areas of saturated soil and subsequently, alter plant species composition in groundwater-dependent ecosystems (Dwire et al. 2018). While there is considerable uncertainty regarding the rate of change, a change is vegetation composition is highly likely in all three ecosystems. For more information on riparian vegetation, see the Aquatic, Wetland, and Riparian Ecosystems report.

Wildlife

The anticipated climatic changes to eastern Oregon environments are likely to result in a variety of effects to wildlife populations and their habitats (Stine et al. 2014, Halofsky and Peterson 2017). Several climate change studies indicate that changes in wildlife habitats and populations have already occurred (Lawler and Mathias 2007, Root et al. 2003). A variety of responses of wildlife to changing climatic conditions have occurred or are anticipated to occur including changes in species distributions, changes in the timing of breeding and other activities, changes in pathogens and invasive species distributions, changes in survival and extinction risks, and changes in the interactions among species (Gaines et al. 2012, Stine et al. 2014).

Terrestrial and riparian species face complex challenges due to changes in their habitats. Some negative impacts to habitat include decreased snowpack, changes in water temperature, phenological mismatches between migratory wildlife and their habitats, and altered disturbance patterns. Challenges to habitat reserves can occur in ecosystems that are influenced by fire, as research has shown that wildfires greatly influenced the amount and location of old forest habitats across the landscape (Hessburg et al. 1999, 2007, 2015).

Fires increase land disturbance that can facilitate the infiltration of invasive annual grasses. This is of particular concern in the Blue Mountains, where fire frequency and severity are expected to increase as the climate warms. The loss of native ecosystems to invasive annual grasses affects many species of terrestrial fauna. Many animal species could be extirpated from the Blue Mountains as changes in vegetation patterns ripple through the ecosystems.

To aid in the assessment of the effects of climate change and forest management activities on wildlife species the Climate Change Sensitivity Database (Lawler and Case 2010) was used to determine the vulnerability of some species and the effects that climate change might have given their life history (see also the At-Risk Species Report). The vulnerability ratings for the surrogate wildlife species assessed for the previous Blue Mountains plan revisions showed 11 species (48 percent) are highly vulnerable to the effects of climate change, 10 (43 percent) have a moderate rating, and 2 (9 percent) have a low vulnerability rating (Table 3).

Table 3. Climate change vulnerability ratings for wildlife species assessed in the Blue Mountains forest plan revision

Wildlife Species	Vulnerability Rating	Specific Climate Impacts
American marten	High	Changes to habitat distribution and amount
Ash-throated Flycatcher	Medium	Changes to habitat distribution and amount
Bald eagle	Low	Changes to fish populations
Black-backed woodpecker	Medium	Changes to habitat from altered disturbance regimes
Boreal owl	High	Associated with habitat sensitive to climate change
Cassin’s finch	High	Changes to extreme temperatures and dry air
Columbia spotted frog	High	Changes to wetland and riparian habitats
Fox sparrow	Medium	Changes to habitat distribution and amount
Lark sparrow	Medium	Changes to habitat distribution and amount
Lewis’s woodpecker	Medium	Changes to habitat from altered disturbance regimes
Macgillivray’s warbler	Medium	Changes to habitat distribution and amount
Marsh wren	High	Riparian habitats high sensitivity to climate change
American (northern) goshawk	High	Changes to food supply and suitable habitat
Northern harrier	Medium	Changes in the distribution and amount of primary habitat
Peregrine falcon	Low	Generalist with high mobility
Pileated woodpecker	Medium	Changes to habitat from altered disturbance regimes
Rocky Mountain tailed-frog	High	Loss of habitat, changes to stream temperatures
Sage thrasher	Medium	Changes in the distribution and amount of primary habitat
Water vole	High	Riparian habitats high sensitivity to climate change
Western bluebird	High	Changes to habitat from altered disturbance regimes. Changes from competition with other cavity nesters.
White-headed woodpecker	Medium	Changes to habitat from altered disturbance regimes
Wilson’s snipe	High	Riparian habitats high sensitivity to climate change
Wolverine	High	Changes in persistence of spring snow used for denning

Vulnerability Ratings were derived using a combination of expert review panels, literature searches and digital databases and was developed as part of the larger Pacific Northwest Climate Change Vulnerability Assessment. Source: Lawler and Case 2010.

Populations of alpine and sub-alpine fauna are at risk of becoming increasingly fragmented and prone to extinction. Climate projections for late century (after 2050) suggest a high probability for the loss of alpine and sub-alpine ecosystems (Halofsky and Peterson 2017). Habitat isolation and restricted species movement may become prevalent. For example, breeding populations of gray-crowned rosy finches may become isolated on lingering high-elevation, boreal islands, threatening the long-term viability of the species.

Mammals

Some wildlife species, such as the wolverine (*Gulo gulo*), snowshoe hare (*Lepus americanus*), and short-tailed weasel (*Mustela erminea*), have adapted to snowy environments. The snowshoe hare, for example, is well adapted to deep snow based on its large snowshoe-like feet. A warming climate will likely put this species at a disadvantage, which may lead to cascading impacts on other wildlife because this species is a food source for many predators. Close relationships between predators and their prey (e.g., American marten (*Martes americana*) and red squirrel (*Tamiasciurus hudsonicus*)) may break apart as each species responds differently to climate changes. Native species may be further stressed by the proliferation of invasive species that thrive in warmer conditions.

The sensitivity of old forest-associated wildlife species to the effects of climate change were identified as medium for pileated woodpecker (*Dryocopus pileatus*), and high for American goshawk (formerly northern goshawk) (*Accipiter atricapillus*) and American marten (USDA Forest Service 2018). The primary effect of climate change is likely to be the loss of old forest habitats due to altered disturbance regimes (USDA Forest Service 2018).

Birds

In North America, the northern limits of many bird species are strongly associated with various climatic variables, such as winter temperature. Both the range and the abundance of birds shift on an annual basis in concert with temperature. Studies have shown that a significant number of migrating birds are arriving earlier in the year (Horton et al. 2020). Natural communities of birds may change dramatically as changes in climate and vegetation favor some species and harm others. It is difficult to predict how these changes will influence community structure or function.

The pattern in Oregon is consistent with the broader trends of North America. Ranges of some birds are moving north and increasing in elevation. The other major change is the probable shift to an earlier breeding season as the temperatures become warmer earlier in the spring. Birds associated with higher elevation wetlands dependent on snowpack may be adversely affected (North American Bird Conservation Initiative 2010). Some forest birds already of concern may be affected by summer drying. Birds in the transition zone to the Great Basin, along the southern edge of the Blue Mountains, will be particularly vulnerable to summer drying (Olson and Burnett 2009).

Bird populations are affected by a variety of climate impacts, including changes in ranges and migratory patterns. Earlier spring warming will affect breeding, as will changes in abundance of insects. Insects are particularly affected by climate dynamics since their development is closely tied to temperature. For example, an increase in temperature of 2 degrees Celsius will change the availability of insects as a food source by more than 18 days (OCCRI 2010). Birds migrating may thus be adversely affected by asynchrony; they could arrive at a time when the level of insects they feed their young has declined, passed, or not yet occurred.

Amphibians and reptiles

For amphibians and reptiles, responses to climate change will be influenced by the following primary factors: (1) variability in local environmental and habitat conditions, (2) the phenology (timing) of life-requisite activities, (3) interactions with emerging pathogens and invasive species, and (4) interactions with other environmental stressors, such as chemicals (Lind 2008). For example, in Oregon, frogs are breeding earlier in the spring and the incidence of infectious diseases among them is increasing (Oregon Climate Change Research Institute 2010). Changes in wet periods, snowpack, and flooding frequency will determine reproductive success rates and survival to metamorphosis (Oregon Climate Change Research Institute 2010). Over the long term, the frequency and duration of extreme temperature and precipitation events will likely influence the persistence of local populations, dispersal capabilities and consequently the structure of metapopulations on the landscape. Synergisms among a variety of environmental stressors adversely affect native amphibians and reptiles, and climatic change is likely to exacerbate these effects.

Amphibians and reptiles represent a great variety of species that are adapted to diverse ecosystems and environments throughout the world. In general, ecological communities are expected to move upward in both elevation and latitude (Walther et al. 2002). As with other species, montane and higher-latitude populations of amphibians and reptiles are most at risk (Root et al. 2003). Amphibians have been experiencing global population declines (Stuart et al. 2004), and similar signs of decline are emerging for reptiles (Cox et al. 2022).

Amphibian and reptile populations are sensitive to and respond strongly to changes and variability in air and water temperature, precipitation, and the hydroperiod (length of time and seasonality of water presence) of their environments (Carey and Alexander 2003). Many amphibians require aquatic habitats for egg laying and larval development as well as moist environments for post metamorphic life stages. As temperatures warm and the availability of aquatic habitats becomes more variable, amphibians are likely to experience lower rates of survival. Species associated with ephemeral waters, such as shallow ponds and intermittent streams, may be particularly vulnerable to altered precipitation patterns. Some reptile species exhibit temperature-dependent sex determination during egg incubation that could be influenced by changes and variability in global climates (Gibbons et al. 2000, Hawkes et al. 2007). Increases in frequency or intensity of wildfires could create changes that may directly affect animals during the wildfire event or degrade habitat conditions necessary for their survival post wildfire.

Amphibians typically have relatively small home ranges and low dispersal rates, although there are some exceptions. Reptiles are somewhat more mobile and have a greater ability to withstand the expected dryer and warmer conditions. However, in areas where key habitats and species ranges have already been altered and fragmented by human use and development, the physical pathways to connect animals with suitable habitats (e.g., upwards in latitude or elevation) may not exist. Although some near-term benefits of climate warming may be seen for some reptile species owing to increases in preferred temperatures and activity periods (Chamaille-Jammes et al. 2006), over the long term, expected variability and temperature extremes may be harmful to these taxa.

For amphibians and reptiles, the timing of key ecological events is influenced by environmental conditions, such as air and water temperature and precipitation patterns. Lawler et al. (2009) found amphibian ranges were thus more vulnerable to changes in precipitation than were those of birds or mammals. The timing of reproduction (breeding/egg laying), metamorphosis, dispersal, and migration may shift in response to higher temperatures and changes in rainfall (Beebee 1995). If such shifts in amphibian and reptile activities occur inconsistently with other ecological events (e.g., emergence of their insect prey), growth and survival rates would be affected.

Research on amphibian declines has documented the role of emerging pathogens and in some cases epidemic outbreaks of infections and diseases (Daszak et al. 2003). Changes in climatic regimes are likely to increase pathogen virulence and amphibian and reptile susceptibility to pathogens. Similarly, warm water invasive species (e.g., bullfrogs (*Lithobates catesbeianus*) and some fishes in the western United States) are a concern to native species and may expand their ranges given warming trends, particularly earlier warming in the spring (Bury and Whelan 1984).

Fisheries

Climate change affects the environments of aquatic species in many ways. Warming air temperatures and changing precipitation patterns are resulting in warmer stream temperatures (Bartholow 2005; Isaak et al. 2010, Isaak et al. 2012, Petersen and Kitchell 2001), altered stream hydrology (Hamlet and Lettenmaier 2007, Luce et al. 2013), and changes in the frequency, magnitude, and extent of climate-induced events such as floods, droughts, and wildfires (Holden et al. 2012, Littell et al. 2010, Luce and Holden 2009, Rieman and Isaak 2010). Lower summer flows will likely lead to warmer stream temperatures (Isaak et al. 2010, Halofsky and Peterson 2017). The areas with warm summer stream temperatures are expected to expand and the areas with cooler stream temperatures to contract (Figure 10). August stream temperatures could increase by 1.8 degrees Fahrenheit by the 2040s and 3.6 degrees Fahrenheit by the 2080s compared to a 1993–2011 baseline (Isaak et al. 2015). Decreased snowpack will shift the timing of peak flows, decrease summer low flows, and in combination with higher air temperature, increase stream temperatures. These factors all reduce the vigor of coldwater fish species.

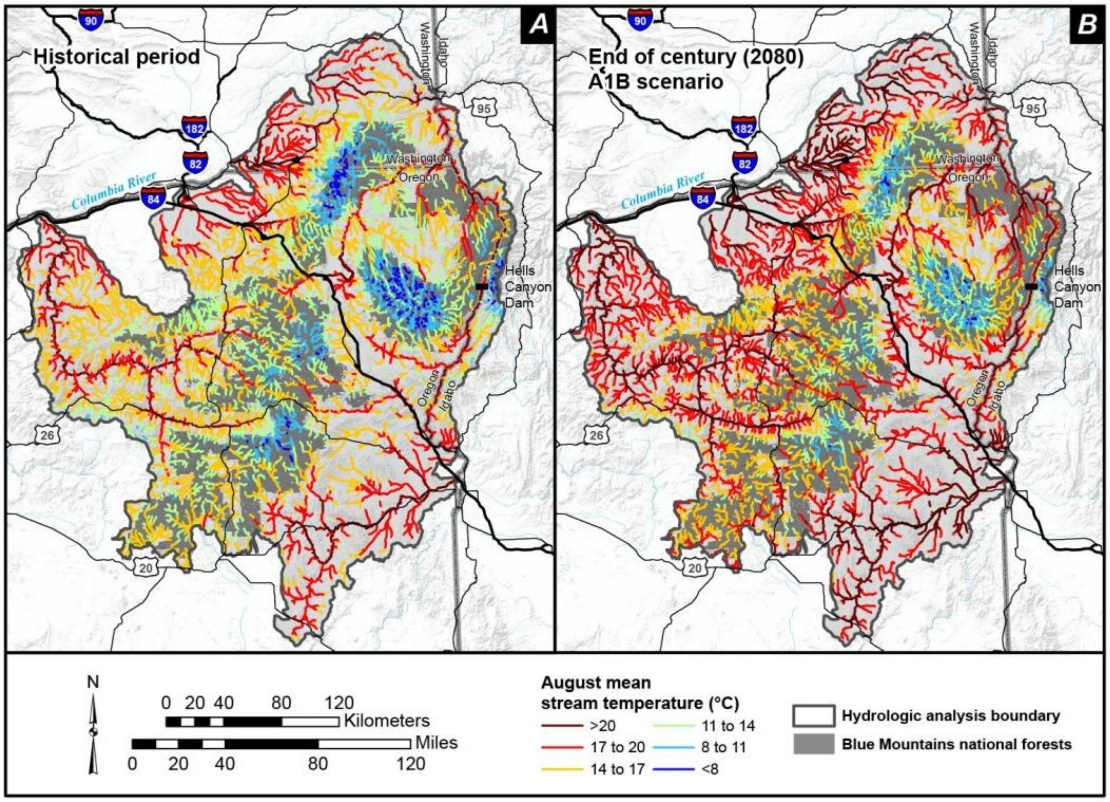

Figure 10.Summer stream temperature map for the 1980s (A) and 2080s (B) based on NorWeST scenarios and the A1B emissions trajectory (Halofsky and Peterson 2017).

The 2017 Blue Mountains Climate Change Vulnerability Assessment assessed the potential impacts of climate change on aquatic habitats for four important native aquatic species in the Blue Mountains: spring Chinook salmon (O*ncorhynchus tshwaytscha*), bull trout (*Salvelinus confluentus*), summer steelhead (*Oncorhynchus mykiss*) and interior redband trout (*Oncorhynchus mykiss gairdneri*). These species were selected due to the wide range of streams and rivers they use in the Blue Mountains, as well as concerns for their long-term viability in subbasins where their habitats are affected by land management activities (such as timber production, livestock grazing, construction, and management of the road network in particular).

Although habitats for the selected species overlap in places, each species uses a unique set of aquatic habitats in the Blue Mountains national forests and their associated subbasins, depending on their life stage, season of the year, and available habitat conditions. These species have a diverse array of life history strategies, including anadromy (steelhead and spring Chinook salmon), fluvial and adfluvial movements (bull trout), and residency (bull trout and redband trout).

Fall spawning species, such as salmon and bull trout, whose eggs overwinter in streambed gravels, are likely to be impacted by increased winter flooding and greater movement of streambed gravels and cobbles during winter rain-on-snow events (Halofsky and Peterson 2017). Steelhead and redband trout are spring spawners; their spawning activity typically occurs as winter and spring flood flows are declining. Their eggs are less likely to be damaged than the eggs of fall-spawning salmon and bull trout.

Some subbasins that are currently snow-dominated (spring snowmelt) systems, are expected to shift to transitory snow dominated (winter rain-on-snow) systems, as climate change progresses. In this scenario, spring Chinook salmon and bull trout spawning habitats would be most at risk. Other subbasins may experience limited change in timing of runoff and fish populations would be less affected by shifts in timing of runoff. Other subbasins may shift to winter rain-dominated systems from their current transitory snow dominated regimes. Steelhead are likely to experience challenges like those faced by salmon of similar ages. However, due to seasonal differences in timing of migratory movement, spawning and egg residence periods in natal gravels relative to stream flows and water temperatures, different species are likely to experience climate change in somewhat different ways (Mote 2003a).

Most researchers expect bull trout to be the least resilient to climate change of any of the surrogate species, in that they are likely heavily impacted by warmer waters which would constrict their habitat by warmer water encroaching further upstream, and further constricted by greater declines in stream flow on the colder ends of their habitat, high in the watersheds, due to earlier loss of snowpack. The Blue Mountains Climate Vulnerability Assessment for bull trout found that bull trout will be affected in the Blue Mountains by changes in stream flow and water temperature (Halofsky and Peterson 2017). Lack of connectivity within and between subbasins may be more impactive to bull trout in the Blue Mountains than to the other species. Bull trout, with their dependence on cold water, are expected to be severely affected; losses of habitat in the Columbia River Basin are estimated at 22 to 92 percent (Independent Scientific Advisory Board 2007, Oregon Climate Change Research Institute 2010). The practical implication is that some sensitive fish populations are likely to become extirpated.

Fall-spawning bull trout will likely see their year-round spawning and rearing habitats shrink as well, particularly on the lower end of the current range as water temperatures increase. Migration corridors may become inhospitable earlier in the spring, triggering upstream movement from wintering areas more quickly as spring runoff levels drop. Bull trout may find their habitat shrinking on the upper end of current use areas. In some stream reaches, riffles will become shallower and perhaps intermittent (Sando and Blasch 2015).

Fish populations have been adapting by shifting their phenology and migration dates (Crozier et al. 2008, 2011; Keefer et al. 2008), using cold water refugia during thermally stressful periods (Keefer et al. 2009; Torgersen et al. 1999, 2012), and shifting spatial distributions within river networks (Comte et al. 2013, Eby et al. 2014). These changes are adding additional stressors to many fish populations, but many populations are also likely to have sufficient resilience and habitat diversity to make the necessary adjustments.

However, abundance and distribution of spring Chinook salmon, redband trout, steelhead, and especially bull trout will be greatly reduced, although effects will differ by location as a function of both stream temperature and competition from nonnative fish species.

Streams located high in watersheds that historically provided some of the best habitat may no longer be accessible to migratory fishes if snowpack is reduced, thus limiting available rearing areas and access to thermal refugia in summer. Even moderate climate induced changes may significantly increase the risk of extirpating local populations of Chinook salmon (Crozier et al. 2008).

In addition to direct impacts to water precipitation, climate change is expected to cause indirect impacts to hydrology. For example, anticipated increases in wildfire will add sediment to streams, increase peak flows and channel scouring, and raise stream temperature by removing vegetation.

Sensitive Botanical Resources

Species occupying the alpine fellfields and subalpine parkland habitat group are most at risk from climate change, as this habitat has been and will continue to decline in the next century. Species dependent on snow melt basins or other moist micro sites (*Carex vernacula*, *C. micropoda*, *Lomatium erythrocarpum*, and *Saxifraga adscendens* ssp. *oregonensis*) are also at risk, as these habitats may decline first. Species or habitats dependent on snowmelt runoff, such as various riparian ecosystems like the cottonwood habitat group, may decline in abundance. Cottonwoods depend on period flooding and sediment deposition for seedling germination (Mahoney and Rood 1998). With reduced peak spring streamflow, cottonwood seedlings may not have proper conditions to germinate on floodplains. Where germination has been successful, reduced late summer discharge may not provide sufficient moisture for seedlings to survive through the first growing season and establish (Halofsky and Peterson 2017). Cottonwood, willow, and aspen may be replaced by upland vegetation in some areas (Halofsky and Peterson 2017). Many other species within the plan area are endemic to small ranges or comprise disjunct populations beyond the species' contiguous range, regardless of their habitat group. These species are at risk of local extirpation due to factors cited earlier.

Whitebark Pine

Whitebark pine *(Pinus albicaulis),* a slow-growing high-elevation species characteristic of alpine environments, is vulnerable to interactions between climate change and disturbance (Halofsky and Peterson 2017). Though whitebark pine is relatively rare in the Blue Mountains, the species maintains disproportionate importance as a food source for other species such as Clark's nutcracker (*Nucifraga columbiana*). Whitebark pine populations are declining in the Blue Mountains and model projections predict major to complete loss of the species by 2100 (Halofsky and Peterson 2017). Much of this loss may be attributed to white pine blister rust, mountain pine beetle, and altered fire frequency than may have been historically experienced (Ward et al. 2006). The direct impacts of climate change on whitebark pine may vary based on geography. While a longer growing season may increase whitebark pine growth in an energy-limited environment, warmer temperatures may simultaneously contribute to greater mortality from mountain pine beetle as their range expands. Impacts of increased wildfire frequency may be variable with potential benefits for wetter sites and drawbacks in drier habitats (Halofsky and Peterson 2017).

Co-Stressor: Invasive Species

The likelihood of forests, woodlands, and shrublands being invaded by nonnative annual grasses in a warmer climate will increase because of more disturbance, effects of warming on species distributions, enhanced competitiveness of nonnative plants from elevated carbon dioxide, and increased stress to native species (Halofsky and Peterson 2017). Warming alone may increase the risk of nonnative plants, because many invasive species have range limits set by cold temperatures. This tends to limit their establishment in forests, particularly the higher elevation and continental western forests.

A species distribution model that assumed lower (summer) precipitation in the future projected expansion of cheatgrass (*Bromus tectorum*) in a warmer climate. Because of the fire and invasive grass cycle, changes in future fire regimes are important climate considerations for nonnative annual grasses. More area burned, more frequent large wildfires, larger extent of high-severity fire, longer wildfire durations, and longer wildfire seasons are expected in the future, thus increasing the invasion risk of nonnative annual grass species.

Of particular concern in the Blue Mountains is the recent increase in North Africa grass (*Ventenata dubia*) and its apparent ability to inhabit forest communities previously uninvaded by cheatgrass and other invasive grasses (Tortorelli et al. 2020). *Ventenata* has already invaded around eight percent of the Blue Mountains ecoregion, primarily in open areas and forest scablands sparsely vegetated by other species that historically served as natural fire breaks, but now contain a highly flammable invasive grass, exacerbating the risk of wildfire (Tortorelli et al. 2023). Interactions between climate change, invasive species, and disturbance regimes, as exemplified by *Ventenata dubia*, threaten forest resilience in the Blue Mountains.

In shrubland and grassland systems, increased area burned will likely lead to increased mortality of shrub species and native grasses, and increased abundance of nonnative species, annual grasses in particular (Halofsky and Peterson 2017).

Anticipated Climate Change Effects on Economic and Social Well-being

Climate change is expected to cause higher temperatures, decreased snowpack, earlier snowmelt, and increased vulnerability to disturbance (Halofsky and Peterson 2017). The ecological and socioeconomic systems in the Blue Mountains area are vulnerable to the effects of climate change. Municipal water supply, recreation opportunities, forage for livestock, and forest product availability may be reduced due to climate change (Halofsky and Peterson 2017). Extreme heat waves and other weather events associated with climate change will also adversely affect human health and wellbeing in communities around the Blue Mountains national forests (Dalton and Fleischman 2021).

Anticipated Climate Change Effects on Water Resources

Decreasing snowpack and declining summer flows due to climate change are projected to alter the timing and availability of water supply, affecting municipal and public uses downstream from, and in, national forests. See the Watershed Report for more information on trends in water use.

It will also affect other forest resources including livestock grazing, wildlife, recreation, firefighting, road maintenance, instream fishery flows, and hydrological resources. Projected declines in summer low flows and loss in water availability aligns with the period of peak demand (e.g., for irrigation and power supply) (Halofsky and Peterson 2017).

Pronounced changes in snow and streamflow are expected to occur in headwater basins of the Wallowa Mountains, especially in high-elevation radial drainages out of the Eagle Cap Wilderness, with large changes occurring in the more northerly sections of the Umatilla and Wallowa-Whitman National Forests along the Oregon-Washington border. Models project that the Burnt, Powder, Upper Grande Ronde, Silver, Silvies, Upper John Day, Wallowa, and Willow subbasins are at highest risk for summer water shortages associated with low streamflows by 2080 (Figure 11) (Halofsky and Peterson 2017). Mid-elevation areas where snow is currently not persistent (northern Blue Mountains, margins of Wallowa, Elkhorn, Greenhorn, and Strawberry Mountains) may become largely snow-free in the future.

Several basins in the Blue Mountains in which irrigation water use is already high are more likely to be subject to water shortages soon. Increased temperatures make extended, multi-year droughts more likely. The Third Oregon Climate Assessment (Dalton et al. 2017) suggests that 2015, the warmest and one of the driest years on record, may represent “normal” conditions by mid-century in the Pacific Northwest.

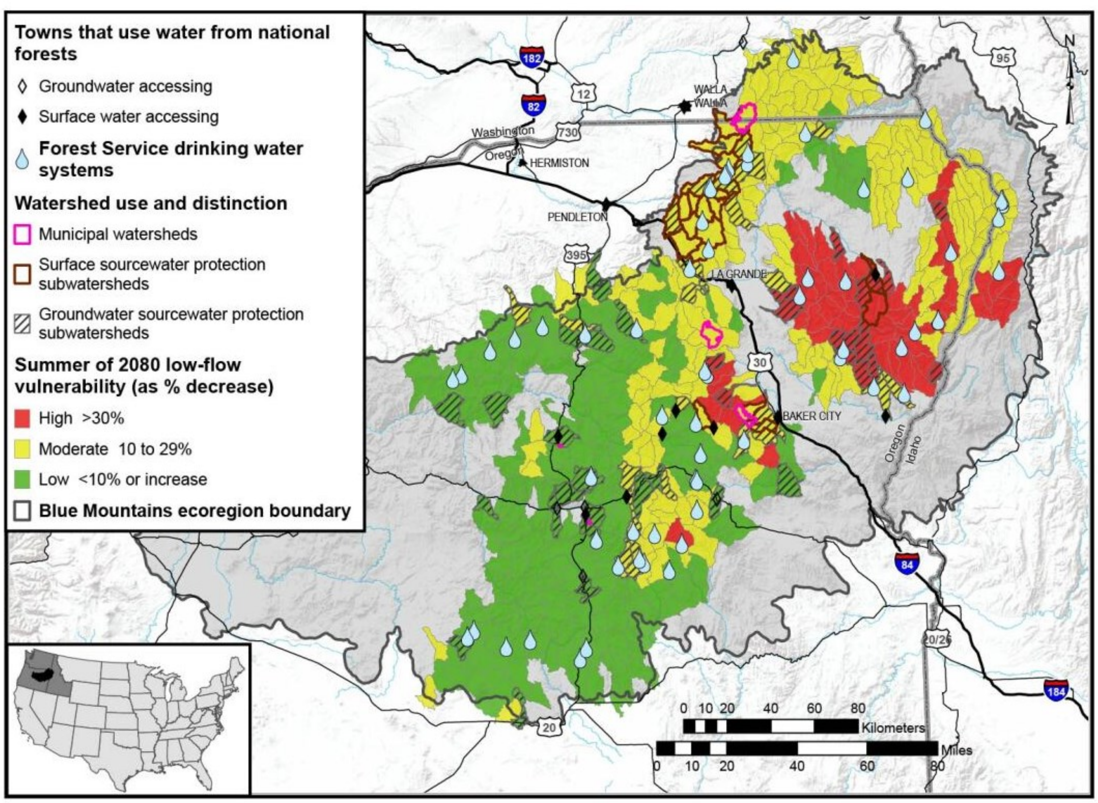

Figure 11. Projections of risk of summer water shortage associated with low streamflows in summer for 2080. Projections were calculated using flow data from the Variable Infiltration Capacity model, based on

historical data for 1915–2006 and summer flow simulated for a global climate model ensemble for the A1B emission scenario (from Wenger et al. 2010). The Burnt, Powder, Upper Grande Ronde, Silver, Silvies, Upper John Day, Wallowa, and Willow Creek watersheds are at highest risk of summer water shortage. (Halofsky and Peterson 2017)

Anticipated Climate Change Effects on Rangeland

Rangelands are of particular regional importance in the Blue Mountains (see the Rangeland Report). Climate change, primarily through increases in temperature and carbon dioxide, and changes in precipitation, will likely result in shifts in species composition and distribution in rangeland communities. Climatic changes have resulted and will continue to result in earlier initiation of the growing season, longer growing season length, earlier plant senescence, mismatches among climate characteristics and plant and animal phenology, and increased risk of drought and fire disturbance. In fact, rangeland systems in general may be an early indicator of climate change due to the dominance of grasses and forbs and, hence, their relatively higher sensitivity to annual climate variability compared to forestlands (Halofsky and Peterson 2017).

General increases in precipitation could result in expansion of woody species and shifts from grasslands to shrublands, or from grasslands and shrublands to woodlands and forests. Conversely, decreases in effective precipitation could cause declines in vegetation productivity and shifts from forests, woodlands, and shrublands to grasslands and deserts (Halofsky and Peterson 2017). In a warmer, drier climate for the Blue Mountains, vegetation types comprising rangelands are likely to increase on the landscape (Halofsky and Peterson 2017). Species found in different rangeland types will respond individualistically. Given enough water for growth, elevated carbon dioxide has the potential to increase rangeland plant productivity through increases in water-use efficiency. Native cool season species are positively affected by higher carbon dioxide levels, but so are some nonnative invasive plant species, such as cheatgrass, red brome, and others (Chambers and Pellant 2008, Halofsky and Peterson 2017).

Some species have the potential to migrate upslope with increases in temperature. However, habitat fragmentation and barriers to migration may impede many species from migrating to more suitable habitats in the north. Some native rangeland species may be displaced where climate change favors invasive species (Halofsky and Peterson 2017).

Rangelands will likely be affected by increasing amounts of wildfire but may still have fewer disturbances than occurred either historically (e.g., natural fire, Native American fire, wild ungulate grazing) or through Euro-American activities. Ecosystem disturbances can accelerate both loss of native species and invasion of exotics (Sala et al. 2000).

Changes in rangeland composition, structure, and productivity could have consequences for livestock grazing, including changes to the annual timing of grazing (e.g., earlier on- and/or off-dates), and reduced overall AUMs where forage production declines.

Although an ecosystem’s sensitivity to grazing pressure and threshold for degradation changes with bioclimatic setting, resulting in lower sustainability in very dry and very humid ecosystems (Asner et al. 2004), the future bioclimatic setting within the project area is highly uncertain. It is very likely that as future average temperatures increase, snowpack will be reduced, snow melt, run-off and peak flows will occur earlier in the year (Ryan and Archer 2008). In addition, with increased atmospheric carbon, primary production is expected to increase particularly on semi-arid rangelands (Derner and Schuman 2007).

Anticipated Climate Change Effects on Infrastructure, Recreation, and Access

Climate change is expected to have an impact on recreation opportunities, infrastructure, and access. "Increased magnitude of peak stream flows will likely damage roads near perennial streams, ranging from minor erosion to complete loss of the road prism, thus affecting public safety, access for resource management, water quality, and aquatic habitat." (Halofsky and Peterson 2017). Some roads that are currently located adjacent to streams are likely to be at increased risk from flood damage as the hydrologic regime changes in response to climate warming (Halofsky and Peterson 2017) (Figure 12). Bridges, culverts, campgrounds, trails, and national forest facilities near streams and floodplains will be especially vulnerable. Roads and trails on steep slopes may also be at risk due to increased chances of landslides and washouts.

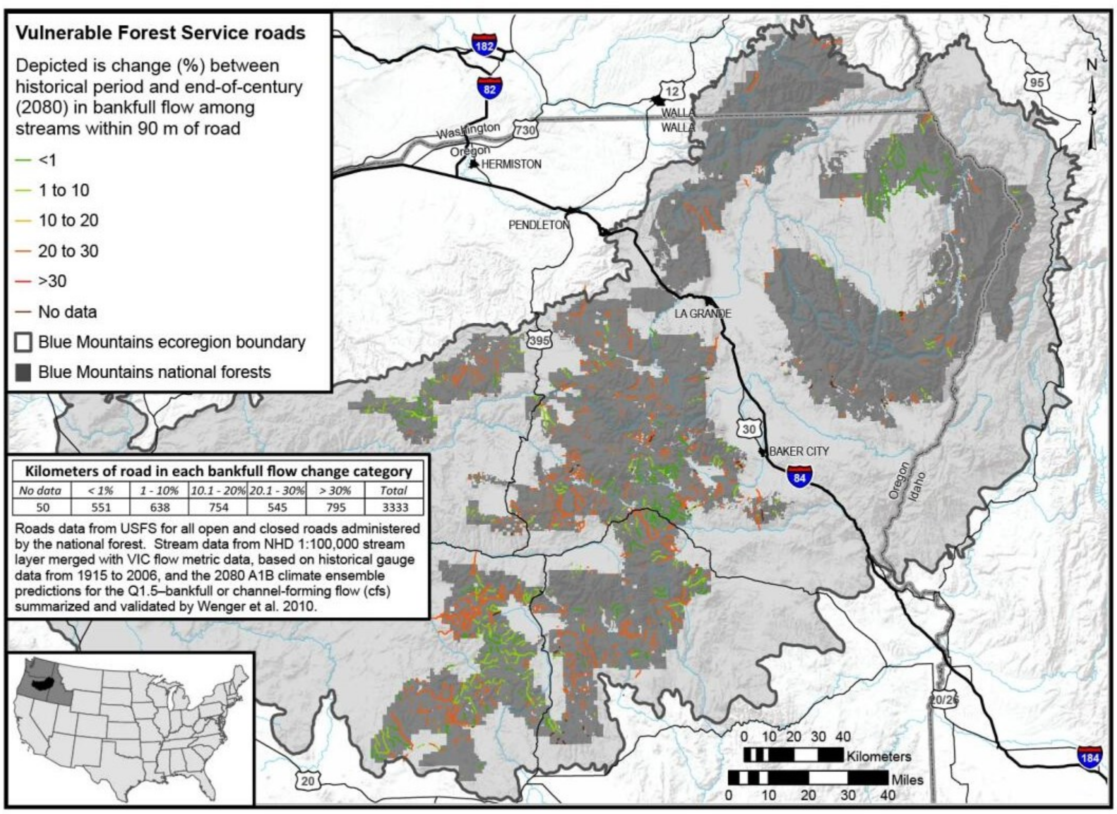

Figure 12. Projected percentage change in bankfull flow in 2080 for roads within 90 m of a major river or stream. Bankfull flow refers to the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain. Projections were calculated using flow data from the Variable Infiltration Capacity model, based on historical data for 1915-2006 and the Q1.5-bankfull or channel-forming flow simulated for a global climate model ensemble for the A1B emission scenario (from Wenger et al. 2010). Note that not all vulnerable roads are represented; some roads also interrupt smaller intermittent streams and vice versa. (Halofsky and Peterson 2017)

National forest recreation opportunities that rely on water access, like swimming or boating, may contract with lowering water flows or experience greater interannual variation. Overall, participation in water-based recreation is expected to increase with warmer temperatures leading to a longer season and residents looking to escape the heat (Miller et al. 2022). Water quality for recreation may also vary with these record highs and lows. Current infrastructure may or may not be able to accommodate the increase in demand. Visitor demand may also increase for water-based recreation with predicted temperature rise in summer (White et al. 2023). The combination of this overall decreased average water availability and increased user demand is expected to put increased pressure on already-popular water-based sites and will likely add pressure to sites that have not yet experienced much use.

National forest recreation opportunities that rely on snow, such as skiing and snowmobiling, are likely to contract as winter snow levels are expected to decline in amount, distribution, and timing. Demand may continue to increase in the short and medium term for snow-based activities (White et al. 2023) potentially concentrating use to areas that still reliably contain snow.

National forest recreation opportunities that rely on wildlife, such as wildlife viewing, fishing, and hunting, may shift in available opportunity and location as wildlife populations change and respond to changes in vegetation assemblages and location (Miller et al. 2022).

National forest recreation opportunities that rely on snow-free access like general hiking, camping, sight-seeing, horseback riding, biking, OHV use, and picnicking may expand their seasonal accessibility in terms of location and seasonal duration (Scott et al. 2007), though perhaps not reliably year to year in timing. Both summer and shoulder season access expansion may be affected by interannual variability in storms with heavy precipitation and/or lightning that ignites wildfires. Wildfires result in the presence of smoke in the short-term and may create hazard trees in the medium- and long-term. Large disturbance events damage roads, other access infrastructure, and may make certain areas unsafe, leaving interannual access unpredictable. Popularity of high elevation recreation sites may increase during summer months as lower elevation sites become less suitable for warm weather activities and visitors seek to escape lower elevation heat waves (Manley and Egoh 2022). This may be countered in some years by decreases in visitation due to smoke from increased fire activity (Sage and Nickerson 2017, Richardson et al. 2012).

National forest recreation opportunities that rely on scenic values may be reduced with increased likelihood of impacts to forest and other vegetation from wildfire and insect and disease mortality. However, the effects on recreationist behavior to disturbance-driven landscape change may be diverse and variable over time (Englin et al. 2001, Sánchez et al. 2016).

At developed facilities, there may be increasing demand for shade structures as temperatures increase and as forest disturbance decreases tree cover through wildfire, drought, or insect and disease mortality.

Anticipated Climate Change Effects on Fire Risk, Safety, and Community Well-being

Drought and disease are expected to increase the intensity and extent of wildfire (Halofsky and Peterson 2017). Fires adjacent to communities in the Blue Mountains may adversely affect private property and human health. Climate change is expected to exacerbate these threats and reduce well-being in communities near the forests by worsening air quality, displacing individuals, and disrupting services, particularly for vulnerable or underserved populations. Wildfire may also affect the supply of goods and services from the Blue Mountains national forests. For example, wildfire is expected to displace outdoor recreation users and is likely to impact associated employment and labor.

Smoke/air quality

Climate change will continue to affect air quality, primarily through changes in fire regimes. A warmer climate, reductions in snowpack, changes in the timing of snowmelt, early declines in soil moisture, changes in the timing and length of the growing season, and increased drought have already led to more frequent fires, more severe fires, earlier initiation of the fire season, and a longer fire season in the western United States relative to historical levels (Westerling et al. 2006). With these changes, the contribution of fire to regional haze and reduced visibility is expected to increase in some areas (McKenzie et al. 2006). Most sources of greenhouse gas emissions are point source; however, large stand-replacing fires on National Forest System lands can be a major source of greenhouse gas emissions and particulates. Increased wildfire activity can result in increases in particulate emissions, carbon monoxide, carbon dioxide, ammonia, and other pollutants from National Forest System lands. Changes in atmospheric circulation may lead to longer durations and more frequent periods of stagnant air, contributing to localized increases in adverse effects from criteria pollutants, such as ozone, particulate matter, and nitrogen oxides (Jacob and Winner 2009). Increases in wildfire activity and the increased soil respiration due to higher temperatures can potentially release large amounts of mercury to the atmosphere (Wiedinmyer and Friedli 2007).

Anticipated Climate Change Effects on Timber and Non-Timber Forest Products

Forest products including timber are an important ecosystem service provided by forests in the Blue Mountains. Production of wood products in the U.S are projected to steadily increase over the next half-century with the Pacific coast region’s contribution remaining steady, being responsible for 3 percent of global production by 2070 (Johnston et al 2023). All three forests of the Blue Mountains contribute to the supply of wood products, including sawtimber and non-sawtimber that provides jobs and supports local economies (USDA Forest Service 2019). Climate-driven changes in forest vegetation will have implications for local and regional socioeconomic conditions, affecting industries and communities that are dependent on timber and nontimber forest products. Further, potential changes to species spatial distribution, age class, and quality could affect ease of access and market desirability of harvested wood products. Changes in technology and global markets will couple with climate change impacts to cause uncertainty in the value of timber resources in the future.

As stated in the vegetation section, uncertainty exists about how climate change will affect species distribution, forest productivity, and ecological disturbance in the Blue Mountains. How these factors play out on the landscape will determine impacts to timber and forest products in the Blue Mountains. A future climate with increasing temperatures and sufficient moisture coupled with a potential fertilization effect from increasing atmospheric concentrations of CO_2 could lead to gains in vegetation productivity, and higher levels of timber production. However, water limitations with increasing temperatures may limit or negate this increased productivity, potentially reducing the amount of merchantable timber and other harvested forest products. The direct climatic effects may matter less than the indirect effects of changes to disturbance regimes (Kirilenko and Sedjo 2007). Increased frequency or severity of drought-induced disturbances, such as insect outbreaks (Hicke et al. 2006) and wildfire (McKenzie et al. 2004), are anticipated to cause widespread tree mortality. These disturbances may mean less availability in green timber with more opportunity coming from dead materials through salvage and biomass sales (Halofsky and Peterson 2022). Operations may also be affected as suitable weather windows may decease with more extreme heat and fire danger during the summer and loss of snowpack for oversnow work in the winter. Increased hazards and storm damage to roads could hamper operations, increasing timelines and costs.

Non-timber forest products (NTFPs) are harvested by a variety of user groups for cultural, subsistence, recreational, craft, and commercial purposes (Hansis et al. 2001). Disturbances like drought, wildfire, and insect outbreaks are affecting habitat quality and access to valued NTFPs in the region (Chamberlain et al. 2018). As climate change affects vegetation in the Blue Mountains, the availability of and access to NTFPs will also change, and people who benefit from them will be affected by these changes. Each plant species that provides these products will respond individually to climate change, affecting the quantity, quality, and seasonality of plant materials. Uncertainty in magnitude and rates of change and change in spatial patterns will be difficult to discern given interannual variation (Halofsky and Peterson 2022). In many cases, desired qualities, spatial distribution, and abundance of NTFP species are associated with a particular forest seral stage, time since disturbance, or severity of the disturbance. Ascertaining the temporal and spatial periodicity of NTFPs based on disturbance history and habitat integrity could become increasingly challenging. Some NTFP's suitable habitat is anticipated to remain stable, but the range for many species is likely to shift as environmental conditions change (Fettig et al. 2013). The capacity of NTFP harvesters to anticipate when and where NTFPs will occur across the landscape in response to climate associated disturbances remains unclear (Chamberlain et al. 2018).

Anticipated Climate Change Effects on Soils

Climate change effects on soils in the West are not well known, but changes in the amount and timing of precipitation, wind, snowpack, stream flow, and the frequency and severity of floods, fires, and droughts have important implications for soil carbon sequestration, soil water retention, and erosion (Halofsky and Peterson 2017).

Elevated carbon dioxide increases carbon supply below-ground through increased plant biomass, stimulated root growth, and root secretions in soils (Pendall et al. 2004, Ainsworth and Rogers 2007, and Ainsworth and Long 2005). Soil organic matter exerts a strong influence on nutrient balance and can also influence soil water holding capacity and populations of soil organisms (Carney et al. 2007). Any gains of soil carbon will occur faster in grassed environments compared to forested environments.

“Organic matter decomposition is a critical factor in assessing the possible impacts of future climate change on soil carbon pools” (Jurgensen et al. 2005). These impacts have the potential to moderate one another relative to carbon emissions to the atmosphere (Kirschbaum 2000), but the effect is sensitive to changes in average temperature and changes in temperature variation (O’Donnell et al. 2011). Indirect effects of warming temperatures and other climate changes on soil moisture availability and nutrient supply may alter soil and plant processes in unexpected ways (Pendall et al. 2004).

Increasingly warm temperatures and associated changes in rainfall patterns, increased evaporative stress, and declines in snowpack are expected to cause a decline in soil moisture availability and possibly result in decreased soil organic matter content. Reduced soil moisture availability may in turn result in increased drought stress, making forests more susceptible to mortality from insect infestations and large severe fires. East of the Cascade Range (i.e., the Blue Mountains), soil moisture decline and increased drought stress on forests is projected to increase over time (Halofsky and Peterson 2017). Increased plant growth driven by increased temperatures and carbon dioxide could also increase demands on available soil moisture. Soil texture, organic matter content, and depth is important to soil water holding capacity, and hence to an ecosystem’s vulnerability to drought.

Soil erosion rates are expected to change in response to changes in climate for a variety of reasons, including the erosive power of rainfall. If rainfall or precipitation event intensities increase in the Blue Mountains, erosion will also increase.

Observed and anticipated increases in fire frequency and severity in the Blue Mountains due to climate change also have implications for soils. High severity burns lead to higher rates of soil loss from erosion, greater duff reduction, loss in soil nutrients, and soil heating (McNabb and Swanson 1990, Hungerford et al. 1991).

Ability of ecosystems in the plan area to adapt to change

Adaptation is defined as an adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects (USDA Forest Service 2022). The definition of adaptation is broad, especially when taking into account that adaptation can mean resistance to change from historic range of variability; adjustments to enhance the resilience of ecosystems to stressors while maintaining ecosystem functionality; or transitions to new ecosystem types and novel assemblages (Swanston et al. 2016).

Whether the ecosystems in the area can adapt to change “adequately” depends almost entirely on what the national forests of the Blues Mountains see as acceptable change. This degree of change or range of acceptable conditions has not yet been defined. Therefore, it is difficult to say whether the ecosystems can adapt adequately.

All ecosystems in the plan area are expected to see impacts from climate change. Some resources and ecosystems are more vulnerable than others – some may have local persistence threatened even if large human efforts to moderate the negative effects of climate change were to occur. Some may persist on the landscape if movement is facilitated to keep pace with the changes. Some may see range or opportunity expansion without management intervention.

Ecosystem adaptability could be measured against many goals or desired conditions. Adaptation to climate change may include forested types that persist as forest rather than convert to other vegetation types after severe disturbance; animal species that retain viable populations despite climate-induced habitat degradation; watersheds that retain erosion control, adequate water supply, and fish habitat despite floods, fires, insect epidemics, or spread of exotic plant species (Peterson et al. 2011). All of these are dependent on complex factors and cannot be predicted with certainty. However, as noted in specific sections in this report, there are usually some species or systems that are more likely to have resilience or ability to adapt than others. For example, wildlife species qualities that confer higher adaptability include being a habitat or food source generalist.

Currently, the resilience of most systems, even those like forests that contain tree species with wide ecological amplitudes that are considered more likely to be adaptable to climatic changes (Halofsky and Peterson 2017), is fairly low because of the current condition and health of their relative ecosystems (see the Terrestrial Ecosystems and Aquatic, Wetland, and Riparian Ecosystems Reports).

Uncertainty

The degree and rate of apparent climatic changes depends on the pathway of global greenhouse gas emissions growth or reduction and on annual stochasticity; weather conditions and environmental conditions in individual years is difficult to predict. This uncertainty in exact timing and degree of effects is another important aspect of the current condition related to climate change as a stressor. GCM outputs vary due to different assumptions built into different models, and the complex interactions of earth systems lead to uncertainty in future climate effects, especially over longer time horizons (Lee et al. 2021).

Climate change is relatively gradual in the near term, and the magnitude of ecological responses in 10 to 20 years is anticipated to be relatively small compared to those anticipated in 50 to 100 years. However, while the average change may be gradual, it is often the more extreme circumstances and not the average degree of change that will likely be the reason for most of the effects (Halofsky and Peterson 2017). Over a few decades or more, climatic warming will likely increase and begin to dominate other natural climatic drivers.

Because the future climate may differ considerably from what has been observed in the past, it is difficult to project vegetative response accurately for specific locations and time periods.

Uncertainties also exist about species' response to climate stressors in terms of individuals' and populations' responses to gradual changes and climate-mediated events, dispersal rate and ability, and other markers of vulnerability. There are uncertainties about the effectiveness of management goals and treatments in maintaining ecosystem assemblages and function in the face of uncertain climate effects and species responses.

Information Needs

There are several information needs that would improve estimation of climatic changes and their magnitudes as well as certainty.

Information specific to the Blue Mountains will help with understanding how models and estimations relevant to western North America downscale to this ecoregion, including information on precipitation amounts, timing, and variability, streamflow, and snowpack.

Vegetation change model improvements could be done by incorporating biotic interactions and species' phenotypic plasticities (the range of traits that can be expressed by their particular genotypes) (Halofsky and Peterson 2017).

Information on ecosystem changes in species composition and overall function in response to changes in climate will be useful.

Continued monitoring of climate, snowpack, hydrology, and other resources will be important to help clarify the uncertainties mentioned above. Monitoring combined with research that develops appropriate metrics and ecologically meaningful thresholds would help define forest management direction in an adaptive capacity.

Project and permitted activity effectiveness monitoring will allow managers to adapt future treatments, standards, and guidelines in response to unexpected responses of affected ecosystem components and function.

Key Findings

- Temperatures in the Pacific Northwest are expected to increase by 2.4 to 3.1 °C (4.3 to 5.6 ° F) by 2050 and 3.2 to 6.3 °C (5.8 to 11.3 ° F) by 2100 from 1950-1999 temperatures.
- Precipitation trends in future are not clear, but reductions in snowpack, changes in timing of peak streamflow and decreased summer flow, increases in extreme hydrologic events, increases in drought, and higher evaporative demand pressure on soils are predicted.
- Climate change is anticipated to make conditions for severe fire, increased severe fire patch size relative to natural conditions, and extreme fire behavior more common and is anticipated to increase the threats of uncharacteristic tree mortality from insects and disease.
- All terrestrial ecosystem biomes will be affected by climate change with varying levels of vulnerability. Generally, higher elevation ecosystems and ecosystems more limited in distribution will be more vulnerable.
- Ecological disturbance, including wildfire and insect outbreaks, will be the primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees.
- Riparian areas will be vulnerable to climate change. Reduced groundwater discharge to groundwater-dependent ecosystems will reduce areas of saturated soil, convert perennial springs to ephemeral springs, eliminate some ephemeral springs, and alter local aquatic flora and fauna.

- Effects on rangelands are uncertain. Rangeland area may expand, though some area may be likely to convert to shrubland with higher vegetative productivity. The response of individual rangeland species will be variable. Species composition may shift with invasive annual grass spread and changing fire regimes.
- Many wildlife species populations will be negatively affected by climate change, including coldwater fish species. Wildlife that specializes in particular habitats, like American marten, boreal owl, marsh wren, water vole, American (northern) goshawk, wolverine, and others, are highly vulnerable to climate change effects.
- Various resources will be affected by low summer water flows, including livestock grazing, wildlife, recreation, firefighting, road integrity, and instream fishery flows.
- Decreasing snowpack and declining summer flows will alter timing and availability of water supply, affecting municipal and public uses downstream from and in national forests.
- Recreation users may be affected by low summer water flows, changes in snowpack for winter recreation, and access limitations due to the anticipated effects of extreme hydrologic events, wildfire, and drought-based tree mortality on roads and infrastructure.
- Increased magnitude of peak streamflows will damage roads near streams, ranging from minor erosion to complete loss of the road prism, thus affecting public safety, access for resource management, water quality, and aquatic habitat. Bridges, campgrounds, and national forest facilities near streams and floodplains will be especially vulnerable, reducing access.

Glossary and Acronyms[1]

Adaptation - Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects. Climate change adaptation includes initiatives and measures to reduce the vulnerability of natural and human systems to actual or expected climate change effects. Adaptation strategies include (1) building resistance to climate related stressors; (2) increasing ecosystem resilience by minimizing the severity of climate change impacts, reducing vulnerabilities, and/or increasing the adaptive capacity of ecosystem elements; and (3) facilitating ecological transitions in response to changing environmental conditions.

Global Climate Model or General Circulation Model (GCM) - models used to predict future climate projections based on various GHG emissions scenarios. There are over 20 GCMs available with different parameters, assumptions, physical processes represented, interactions amongst those processes, and other aspects.

Greenhouse gas (GHG) - Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.

Representative Concentration Pathway (RCP) - a future GHG emissions (atmospheric concentration) scenario used as an input for GCMs. representing a scenario (4.5) in which greenhouse gases are significantly reduced by year 2100 and one (8.5) in which global greenhouse gas emissions continue at similar rates to earlier in the 21st century through the end of 2100.

Refugia - Areas that remain relatively buffered from contemporary climate change over time and enable the persistence of valued physical, ecological, and sociocultural resources.

Resilience - The capability to anticipate, prepare for, respond to, and recover from significant multihazard threats with minimum damage to social well-being, the economy, and the environment. In the context of ecosystems, the Forest Service defines resilience as the ability of an ecosystem and its component parts to absorb or recover from the effects of disturbances through preservation, restoration, or improvement of its essential structures and functions and redundancy of ecological patterns across the landscape.

Vulnerability – The degree to which physical, biological, and socioeconomic systems are susceptible to and unable to cope with the adverse impacts of climate change.

[1] Definitions are combined from USDA Forest Service 2022, Janowiak et al. 2017, and Halofsky and Peterson 2017

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