Northern Rockies Adaptation Partnership: Vulnerability Assessment Summaries

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VULNERABILITY ASSESSMENT — WATER RESOURCES

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Snowpack and glaciers

Broad-scale climate change effect
Warming winter temperatures, potential shifts in precipitation (unknown direction), and increased wildfire.

Current condition, existing stressors
April 1 snow-water equivalent (SWE) has been declining throughout the region since the late-1940s. Glaciers have receded to historical lows during the 20th century. Historical trends in snowpacks have resulted from both trends in temperature and precipitation over this period. Because of the joint forcing, snowpacks at both low and high elevations have seen substantial declines. Low elevation snowpacks are robustly sensitive to temperature variations while mid-to-high-elevation snowpacks have joint sensitivity and consequently greater uncertainty.

Sensitivity to climatic variability and change
April 1 SWE, mean snow residence time (length of time snow sits in the snowpack), and center of timing of snowpack are all sensitive to both temperature and precipitation variations. Warmer (usually low elevation) snowpacks are somewhat more sensitive to temperature variations than are colder snowpacks, although both are temperature sensitive. Colder snowpacks are more sensitive to precipitation, whereas the warmest snowpacks have little sensitivity to precipitation.

Expected effects of climate change
Warming temperatures are consistent among all climate change models, but precipitation differs substantially among models. Furthermore, precipitation changes projected by global climate models have high uncertainty in mountain areas.

Places with seasonally intermittent snowpacks will likely see snow more rarely. Some mid-to-low-elevation seasonal snowpacks will likely become intermittent. Higher elevation snowpacks may or may not see substantial changes in April 1 SWE, snow residence time, or center of melt timing, depending on precipitation outcomes. In warmer locations, temperature-dependent changes are relatively robust even if precipitation increases. In colder locations, a precipitation increase within the range of projected possibilities could cancel or even overwhelm the effects of even a relatively large temperature change. Alternatively, a precipitation decrease could exacerbate projected temperature-related declines.

Glacier accumulation zones are at some of the highest elevations of the region, so may respond positively if precipitation increases. The annual dynamics of mass balance with respect to input and output suggest that the equilibrium line (demarcating places where annual snow does not completely melt each summer) will increase in elevation regardless of a precipitation increase; where that elevation falls on each glacier will influence glacier response. Most glaciers will be reduced in volume and area, and may become small enough to prevent movement. If climate at higher elevations becomes both warmer and drier, the likelihood of glaciers persisting is low.

Increasing soot from forest fires and decreased canopy cover would locally and temporarily increase glacier melt rates. The accumulation of soot over time from increasing fire occurrence could endanger glacier energy balances.

Adaptive capacity
Slight changes in snow accumulation and melt timing can be made with forest canopy modification. Effects are local and temporary, and costs to maintain conditions would be high.

Risk Assessment
Magnitude of effects: High to low, depending on elevation and winter temperature.

Likelihood of effects: High.

VULNERABILITY ASSESSMENT — WATER RESOURCES

<u>Habitat, ecosystem function, or species</u>
Streamflow

<u>Broad-scale climate change effect</u>
Warming winter and summer temperatures, potential shifts in precipitation (unknown direction), and increased wildfire.

<u>Current condition, existing stressors</u>
Annual water yield has been declining throughout the region since the late-1940s. Summer low flows have been declining in concert with declining streamflows. Some locations experiencing declining streamflows have also seen statistically significant declines in the 2-year flood (sometimes termed “bankfull”). Historical precipitation declines as well as temperature increases have both influenced streamflows across the region, affecting both total flows and seasonality of flows. Low flows have historically been more strongly affected by precipitation changes than seasonality shifts, although both are apparent.

<u>Sensitivity to climatic variability and change</u>
Most of the streams in the region depend on snowmelt for runoff, and snowpack changes integrated over the elevation range of a basin strongly dictate the streamflow response. Effects can be classed into seasonality and water yield effects. Most precipitation in the western half of the region comes in early winter and late spring, so streamflow is closely tied to snowpack changes. In the eastern half of the region, there is a greater influence from summer precipitation. Warmer locations experience more runoff in winter months and early spring, whereas colder locations experience most runoff in late spring and early summer.

Seasonality is most strongly affected by winter snowpack accumulation, which is affected by winter temperature and precipitation. Shallower snowpacks melt earlier than deeper snowpacks, and the sensitivities cited above for snowpack accumulation apply.

In the western portion of the region, midwinter flooding is common during rain-on-snow (ROS) events. ROS occurs during warm winter storms (rain instead of snow) occurring during winter months after a snowpack has accumulated. The primary effect is rapid melt rates caused by condensation of warm water vapor on the snow. Althougu these are most commonly restricted to low-mid elevations (warmer and more maritime climates), some atmospheric river related events can yield rapid melt at high elevations. These events are tied more to circulation patterns than “climatic variability,” and no trends in their occurrence have been documented. These midwinter floods are typically among the largest in the river basins where they occur.

Annual water yields are affected by annual precipitation totals (heavily influenced by winter and spring precipitation in the western part of the region) and summer evapotranspiration. Temperature is commonly used as an index for evapotranspiration, but care needs to be applied in recognizing that warm temperatures can also be caused by low moisture availability which is caused by low precipitation.

<u>Expected effects of climate change</u>
Warming temperatures will reduce snowpack accumulation and advance snowmelt timing. Despite mixed signals from precipitation and temperature changes in the historical record, future temperature changes are expected to be higher than historical temperature trends, and future

precipitation declines are expected to be less pronounced (or potentially have an increase in precipitation). Earlier streamflow center of timing is expected over much of the region and summer low flows are expected to be lower. Total yields may decrease due to increased evapotranspiration, but precipitation amounts are uncertain. Increasing precipitation could outweigh evapotranspiration effects on total water yields. Decreasing precipitation could substantially exacerbate annual water yields and low flow declines.

Midwinter flooding is expected to become more common in places where it now occurs and to occur in more locations. Because ROS-driven flood peaks tend to be much higher, flood magnitudes are expected to increase in those locations as well.

Adaptive capacity

Substantial engineering capacity exists to adapt to changes in water supply and flood-related impacts on society, however costs and further environmental impacts could be high. Slight changes in water yield and timing can be made with forest canopy modification. Effects are temporary, and costs to maintain conditions over time would be high.

Risk Assessment

Magnitude of effects: High to low across the region depending on local climate.

Likelihood of effects: High to low across the region depending on local climate.

VULNERABILITY ASSESSMENT — FISHERIES

<u>**Habitat, ecosystem function, or species**</u>

Bull trout (*Salvelinus confluentus*), primarily the interior lineage. Populations may exhibit migratory or resident life histories. Migratory fish travel long distances as subadults to more productive habitats and achieve larger sizes and greater fecundity as adults before returning to natal habitats to spawn. Fish exhibiting resident life histories remain in natal habitats and mature at smaller sizes, though often at the same age as migratory adults. Adults spawn and juveniles rear almost exclusively in streams with average summer water temperatures <12°C (54°F) and flows greater than 0.034 m^3sec^{-1} (1.2 ft^3sec^{-1}).

Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*). This taxon has a complicated lineage structure that can be roughly broken into a single lineage in the north and east that occupied and colonized river basins directly influenced by glaciation or glacial dams, and a southern and western group of several presumably older lineages in basins never directly influenced by glaciation. These fish also exhibit resident and migratory life history strategies. Spawning and juvenile rearing can occur in streams smaller (0.0057 m^3sec^{-1} [0.2 ft^3sec^{-1}]) and warmer (up to 14°C [57°F]) than those used by bull trout.

Yellowstone cutthroat trout (*O. c. bouvieri*). This taxon has an unresolved distribution, because certain lineages are found in portions of the Bonneville basin, and represent the geologically driven seesaw of connectivity between the Bonneville and upper Snake River basins. Undisputed members of this taxon are represented by a single mtDNA clade found throughout the NRAP region in the Yellowstone and Snake River basins. Life histories, and presumably spawning and juvenile habitats, are the same as for westslope cutthroat trout.

<u>**Broad-scale climate change effect**</u>

The primary climate change effects are warming air temperatures and potential changes in the amount, timing, and type (snow versus rain) of precipitation. Depending on scale and location, these will generally combine to cause warmer water temperatures, earlier snowmelt runoff, earlier declines to lower summer baseflows, and downstream contraction of perennial flow initiation from headwaters. Depending on watershed elevation, the magnitude of peak flows could increase or decrease. At high elevations where snowmelt drives the flow regime, peak flows may occur several weeks earlier and be smaller than historical averages. At mid-elevations where stream hydrographs are transitional between snow and rain, peak flows may increase and could shift much earlier if rainfall becomes the predominant form of precipitation. More extreme climatic conditions may also occur more frequently and persist over longer periods, including higher peak flows from rain-on-snow events, higher temperatures, and longer, more severe droughts.

<u>**Current condition, existing stressors**</u>

Bull trout are listed as threatened under the U.S. Endangered Species Act (ESA). Their recent historical distribution has declined because of water development and habitat degradation (particularly activities leading to water temperature increases, but also cumulative losses of in-channel habitat complexity), elimination of migratory life histories by anthropogenic barriers, harvest by anglers, and interactions with introduced non-native fishes. With respect to the latter, this involves wasted reproductive opportunities with brook trout (*Salvelinus fontinalis*), competition, and predation (in streams, perhaps with brown trout [*Salmo trutta*]; in lakes, with lake trout [*Salvelinus namaycush*]).

Both subspecies of cutthroat trout have been petitioned under the ESA, but found not warranted for listing. The distributions of both species have declined substantially (>50%) in response to the same stressors affecting bull trout, although each subspecies appears to occupy a larger proportion of its historical habitat and is often found in larger populations at higher densities. Declines in response to non-native species can be more severe than in bull trout, perhaps because bull trout favor such cold environments that non-native species invasions are limited. Brook trout have replaced cutthroat trout in many waters in the NRAP region, disproportionately so in the upper Missouri River basin. These invasions seem influenced by the distribution of low-gradient alluvial valleys that may serve as nurseries for brook trout. Introduced rainbow trout (*O. mykiss*) have introgressively hybridized with both taxa of cutthroat trout at lower elevations (in warmer waters) across their historical ranges, although this is also true in areas where westslope cutthroat trout are sympatric with native rainbow trout (Clearwater River basin in Idaho, Kootenai River basin in Idaho-Montana). Lake trout have decimated local stocks of Yellowstone cutthroat trout in Yellowstone Lake.

Sensitivity to climatic variability and change

Bull trout evolved in western North America in interior and coastal basins exhibiting a wide array of flow characteristics and natural disturbance at scales from reaches to riverscapes. Nevertheless, habitats satisfying the restrictive thermal requirements of juveniles are rare, and little evidence exists for flexibility in habitat use. The length of connected habitat needed to support a bull trout population varies with local conditions, but current estimates suggest a minimum size of ~30–50 km (20–30 mi) to achieve a probability of occupancy of 0.9, contingent on water temperature, non-native species presence, and local geomorphic characteristics. Whether migratory life histories confer greater resistance to extirpation is uncertain.

Juvenile cutthroat trout occupy a broader thermal and stream size niche than do bull trout. They also appear to persist in smaller habitat patches. Nonetheless, they still require coldwater natal habitat patches exceeding ~5–10 km (3–6 mi) to have a high probability of persistence, and this value depends on non-native species presence and geomorphic conditions.

Expected effects of climate change

Warming temperatures will cause downstream boundaries of suitable thermal habitats to retreat upstream. Both species reproduce in some of the coldest streams in this region, thus opportunities to colonize waters that are currently too cold will be limited, especially for bull trout. The initiation and permanency of perennial flow will retreat downhill, and declines in summer flow will reduce habitat volume (and fish abundance) in perennial channels. The largest habitat patches will decline in size and may fragment into smaller patches. Small habitat patches may shrink below thresholds necessary to support a population. Invasive species more tolerant of warmer temperatures—brook trout, rainbow trout, brown trout, and possibly smallmouth bass (*Micropterus dolomieu*)—will encroach further upstream and depress or replace native salmonid populations.

Less water, hostile environments, and declining connectivity (e.g., from water development) would favor resident life histories, as would greater separation between spawning and adult growth habitats. Smaller populations of both species will be more susceptible to extirpation from local environmental disturbances (such as debris torrents following fire, or larger and more frequent floods). In addition, regional weather patterns are likely to synchronize population responses and vulnerabilities; in years of extreme drought and high summer water temperatures, populations in small habitats across the area may be at risk of extirpation.

Adaptive capacity

There is little evidence within fish species of rapid evolutionary adaptation to warmer water temperatures. Collectively, the genus *Salvelinus* is restricted to coldwater habitats throughout the Northern Hemisphere, often the coldest waters occupied by any salmonid fish. Although cutthroat trout can reproduce in warmer water temperatures, they are similarly constrained evolutionarily and are more exposed to non-native species in warmer areas.

Under circumstances in which migration is feasible, whether migratory or resident life histories are favored involves how fish metabolic rates, water temperature, and stream productivity interact to influence juvenile growth and adult survival. Which life history might be more successful as climate changes is unknown.

Risk Assessment

Global climate models project relatively consistent amounts of warming by the 2040s, but more variability by the 2080s because of uncertainties associated with future greenhouse gas emissions. As a result, bull trout populations are expected to decrease at most locations and be extirpated from some by 2040. Those trends may intensify by the 2080s, but with greater uncertainties as noted above. For cutthroat trout, future declines are expected to be less severe because this species can persist in smaller habitats and reproduce in warmer reaches. The distribution of both native species may be altered by responses of non-native fishes to climate change. Changes in winter flood frequency may limit habitat gains for brook trout, but most non-native species are expected to advance their distributions upstream to track warming environments.

Magnitude of effects: Moderate for bull trout by 2040s, high by 2080s; low for cutthroat trout by 2040s, moderate by 2080s.

Likelihood of effects: High for 2040s (all taxa), moderate for 2080s.

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Alpine larch

Broad-scale climate change effect
Warming temperatures, longer growing seasons, smaller snowpacks that persist for shorter time periods, less summertime water, possible summertime droughts, and increased fire.

Current condition, existing stressors
The species is found in moist upper subalpine cove sites with abundant above- and below-ground moisture. It exists in mixed stands of whitebark pine and sometimes subalpine fir and can form extensive stands in sub-irrigated upper subalpine areas.

Sensitivity to climatic variability and change
It is very shade-intolerant and intergrades with western larch. While this species is quite sensitive to shifts in climate, it may initially increase because it may colonize upper subalpine non-forest sites more quickly than other species. However, the newly established individuals may be unable to survive to maturity as temperatures and drought increase, climates become more variable, and fires increase in the upper subalpine zones (the species is susceptible to damage from fire).

Expected effects of climate change
Growth rates in alpine larch will likely increase with increasing temperatures, and it will likely populate upper subalpine and treeline ecotones because of wind-aided seed dispersal and evergreen regenerative properties. Increased fire may reduce many stands that historically were too wet to burn. On mesic sites, an enhanced growing environment may increase competition from other more competitive, shade-tolerant conifers. A lack of whitebark pine seed caching because of depressed cone crops may favor alpine larch dominance in areas that currently lack trees (e.g., treeline, subalpine balds, meadows, glades). On xeric sites, a lack of summertime ground water may contribute to higher water stress and lower growth rates, and years with deep droughts may kill established regeneration. Alpine larch may decline in those areas with lower water availability and declining groundwater flow.

Adaptive capacity
Its specific habitat requirements may make it difficult for alpine larch to remain on the landscape over the long term. Short-term gains in alpine larch encroachment in upper subalpine and treeline glades and meadows may be lost in those years with deep drought. Effective, long-term establishment of alpine larch may depend on its ability to disperse seed to areas with sufficient moisture.

Exposure
High

Risk Assessment
Magnitude of effects: High

Likelihood of effects: High

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Cottonwood (Black cottonwood [*Populus trichocarpa*], narrowleaf cottonwood [*P. angustifolia*], and plains cottonwood [*P. deltoides*])

Broad-scale climate change effect
Warming temperatures, decreasing snowpack, and an increase in severity and frequency of wildfires.

Current condition, existing stressors
There has been a reduction in area of cottonwood due to conversion and development of floodplains. Composition and structure of cottonwood forests have been altered because of changes in stream flow regimes (e.g., dams and loss of peak flows, and diversions and thus less water in the stream channel). Structural alteration (typically simplification) of the channel through levees and bank armoring structures has likely contributed to channel widening, or channel incision and loss of floodplain interaction. Non-native trees (e.g., Russian olive and tamarisk) are present along rivers and streams in eastern Montana. Increased drought stress will likely favor these drought-tolerant species over cottonwood. Additional stressors include roads, and domestic and native ungulate browsing (particularly on young cottonwoods).

Sensitivity to climatic variability and change
Any alteration of natural flow regime (e.g., timing, magnitude and duration) will affect floodplain interaction and plant-available water. Less plant-available water results in reduced recruitment and establishment of seedlings (cottonwoods regenerate primarily by seed). With decreased stream flows and floodplain interaction (due to lower flows and/or stream incision), there will likely be a shift in streamside vegetation to upland species, along with reduced growth and regeneration, and increased mortality, of cottonwood and associated riparian species. Since cottonwoods are shade-intolerant, conifers, which establish on the drier fluvial surfaces, can grow tall enough to eventually shade out the younger cottonwoods, which affects cottonwood recruitment and long-term persistence. The size of cottonwood forests will decrease as fluvial surfaces are less frequently inundated because of flow alteration.

Expected effects of climate change
As snowpacks decline and melt earlier, there will be a shift in timing of peak flows to earlier in the season, potentially before cottonwood seed is viable for germination. This shift in timing of peak flows may result in both decreased germination and establishment of young cottonwoods. Increased demand for water (additional diversions, reservoir expansions) and increased browsing pressure (as adjacent upland vegetation senesces and desiccates earlier in the growing season) will also likely lead to a decline in cottonwood.

Adaptive capacity
Plains cottonwood may be more persistent in the future because it occurs on finer-textured soils where there is greater plant available soil water. Black and narrowleaf cottonwood typically occur in coarser substrate, which will become drier as flows are lower and recede earlier than in the past, or are attenuated due to diversions. Seedling and sapling mortality may increase in these species. Plains cottonwood regeneration occurs with episodic flooding, whereas black and narrowleaf cottonwood regenerate with 1-3 year bankfull flow return intervals; therefore plains cottonwood will likely be more adapted to irregular flows (in timing, magnitude and duration) that may occur with climate change.

Exposure
Moderate

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Douglas-fir

Broad-scale climate change effect
Increased temperatures, and increased soil moisture deficits, especially at lower elevation dry sites.

Current condition, existing stressors
An increase in forest density has put the species at risk of increased mortality from fire. Root disease is a major cause of Douglas-fir mortality in northern Idaho and western Montana.

Sensitivity to climatic variability and change
This species has a specialist adaptive strategy at low to mid elevations and generalist adaptive strategy at higher elevations, particularly on the eastside. It is sensitive to increasing temperatures and increasing soil moisture deficits which in turn will predispose Douglas-fir to other related mortality agents such as insect and disease.

Expected effects of climate change
At lower elevation, southerly aspects, ponderosa pine will be better able to cope with moisture deficits and disturbances such as fire and spruce bud worm than Douglas-fir. There will be fewer seed sources with increased area burned and cone production problems associated with spruce bud worm. There may be an increase in Douglas-fir mortality because of root disease on mesic sites. Higher elevation southerly slopes may become suitable for Douglas-fir with increasing temperatures.

Adaptive capacity
Douglas-fir has a specialist adaptive strategy at low to mid elevations, and generalist adaptive strategy at higher elevations. It is highly adaptive to a large range of moisture and temperature gradients. In moist forest settings, Douglas-fir is a relatively short-lived seral species due to the influence of two root diseases. However, with warming temperatures and a possible decrease in summer moisture, Rocky Mountain Douglas-fir may increase on mesic sites.

There is no opportunity for hybridization with the coastal Douglas-fir subspecies since distributions do not overlap.

Exposure
High

Risk Assessment
Magnitude of effects: High

Likelihood of effects: High

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Engelmann spruce

Broad-scale climate change effect
Increased disturbance frequency and severity, highly variable weather and climate, decreasing snowpacks, and lengthening growing seasons.

Current condition, existing stressors
Engelmann spruce is usually associated with fir in the Northern Rockies. It occurs as a minor to major component of many subalpine forests and only dominates in wetland or special land types. Fire exclusion has increased abundance of this species on many subalpine and upper subalpine landscapes. Many current stands have high densities, and trees may be stressed from competitive interactions, resulting in increasing susceptibility to disturbances. Increasing drought could further exacerbate competitive stress and increase mortality.

Sensitivity to climatic variability and change
The species has an intermediate adaptive strategy and intermediate phenotypic plasticity. Like fir, spruce is highly susceptible to changes in climate. It is not as an aggressive competitor and often is only a minor component of a stand. It is highly vulnerable to drought and wind. However, it can quickly regenerate on severely burned microsites, provided there are seed sources.

Expected effects of climate change
With higher temperatures and increased drought, losses of spruce in the drier portions of its range are likely, especially in those seasonal moist sites that will now be dry. It is not well-adapted to fire, and thus widespread mortality is expected in burned areas, but fire mortality may be offset by increased post-fire regeneration on mineral soil substrates. The species may increase in abundance in the upper subalpine when snowpacks become consistently lower and soil becomes drier, thereby allowing spruce to encroach into glades, meadows, and balds.

Adaptive capacity
The species has an intermediate adaptive strategy with strong opportunities to hybridize with *Picea glauca*. Hybrids may be more suited to future climates, and hybridization is another key driver in speciation.

Exposure
Low

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Grand fir

Broad-scale climate change effect
Increasing drought, longer growing seasons, increased fire and disease, and highly variable weather.

Current condition, existing stressors
Fire exclusion has allowed increased establishment of grand fir in dry and mesic sites, but increased tree densities have also stressed fir trees, contributing to increased fuel loadings, higher root rot, and greater insect damage and mortality.

Sensitivity to climatic variability and change
This species has a generalist adaptive strategy with high phenotypic plasticity. It is a late-seral, shade-tolerant species that is highly susceptible to fire. Grand fir often occurs in areas where competition and tree density is high; highly stressed trees are more susceptible to climatic fluctuations and trends.

Expected effects of climate change
On xeric sites, increased drought and longer growing seasons will exacerbate grand fir stress from competition, resulting in high mortality mainly from insects and disease. Longer fire seasons and high fuel loadings from fire exclusion will also result in reduced abundance of this species. On the mesic sites, longer growing seasons coupled with higher temperatures may increase growth rates and regeneration success, thereby increasing tree density and competition. Fire will reduce grand fir dominance at landscape and stand scales.

Adaptive capacity
The species has a generalist adaptive strategy. The only genetic differences are between races (blue and green race). Increases in disease, insects, and fire may reduce populations.

Exposure
Low

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Green ash

Broad-scale climate change effect
Warming temperatures, decreasing snowpack and an increase in severity and frequency of wildfires.

Current condition, existing stressors
Domestic and native ungulate herbivory has affected both structure and composition of these communities.

Sensitivity to climatic variability and change
Green ash has a broad ecological amplitude and can survive droughty conditions, but persists optimally in moist sites. As soil moisture declines, marginal sites may become less favorable for regeneration and survival of young trees. There is increased vegetative regeneration and decreased production of seedlings following fire. Fire often kills green ash seed on or near the soil surface, restricting seedling recruitment to surviving seed-producing trees.

Expected effects of climate change
Green ash may benefit from increased temperatures. In one study, seedling growth increased with increasing soil temperatures from 50 to 70 °F. Green ash may also respond favorably to increased fire. Both root crown and epicormic sprouts are typical following disturbances such as fire. Fire is likely very important in woody draws and riparian areas of the Great Plains. Research has suggested that, historically, low-severity fires promoted ash regeneration by thinning stands and stimulating sprouting. Browsing pressure on green ash and other associated species will likely increase with increased drought, as upland grasses and forbs desiccate and senesce earlier, or are replaced by invasive, less palatable species.

Adaptive capacity
Since green ash communities are already fire-adapted (most associated species display some fire tolerance and/or postfire sprouting ability), increased fire will likely not affect most of the moister communities. However, those communities associated with moist upland microsites (e.g., northeast facing residual snow-loaded depressions) may experience more drought stress as snowpack declines and melts sooner, and regeneration may decrease, eventually resulting in loss of those communities.

Exposure
Moderate

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: High

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Limber pine

Broad-scale climate change effect
Warming temperatures, less snowpack, variable precipitation during the growing season, potential increase in precipitation in the eastern portion of Northern Rockies.

Current condition, existing stressors
Limber pine has been reduced in abundance as a result of exotic white pine blister rust infections, native mountain pine beetle outbreaks, and continued fire exclusion. Limber pine dwarf mistletoe, combined with other stressors such as drought, can result in high mortality. Fire suppression on the east side of the Rockies has resulted in limber pine encroachment of rangelands.

Sensitivity to climatic variability and change
The species is shade-intolerant and is an early-seral to pioneer species following fire or tree removal. Limber pine has difficulty competing with other encroaching species on more productive sites. There is little to no reproduction once tree densities are below 10 trees per acre (lack of effective pollination cloud), and those seeds that are produced have increased likelihood of inbreeding. A minimum of 10 cone-bearing trees per acre is needed for dispersal by birds (i.e., corvids), as birds move to other conifer seeds when densities are below 10 trees per acre.

Expected effects of climate change
With warming temperatures, there may be increased growth; larger seed crops; increased seed dispersal into burned areas due to bird dispersal; lower seed germination; loss of ecotomycorrhizal associations; increased competition from wind-dispersed conifers; less blister rust infection, except in wave years; and higher blister rust and dwarf mistletoe infections on the eastside if precipitation increases. Suitable substrates may not exist upslope (most common occurrence on Entisols).

Adaptive capacity
Limber pine's intermediate adaptive strategy is largely driven by the timing of pollen cloud dispersal (elevational effect). Limber pine is highly adapted to populating burned areas, which are projected to increase in the future, using both wind and corvid-mediated dispersal. The species is a poor competitor on more productive sites. If future fires are larger, there will be less competition from other subalpine conifers.

Limber pine has moderate genetic variation (capacity) in blister rust resistance. A major gene resistance to blister rust has not been identified in several studies of interior populations, and warmer temperatures favor expansion of alternate host species (*Ribes, Pedicularis and Castelija)*. There is little to no opportunity for limber pine to hybridize with western white pine due to non-overlapping species distributions. Limber pine is at very high risk of loss of disjunct and isolated populations due to genetic drift, ineffective pollen cloud, and substrate availability.

<u>Exposure</u>
Moderate

<u>Risk Assessment</u>
Magnitude of effects: Low

Likelihood of effects: Low

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Lodgepole pine

Broad-scale climate change effect
Increasing temperatures, longer drought periods, and increasing fire occurrence, frequency, and severity.

Current condition, existing stressors
Advancing succession due to fire exclusion is contributing to declines in lodgepole pine in many areas. Current increases in burn areas are creating many new lodgepole pine stands, and some may become stagnated thickets. Increased drought may exacerbate stress from other factors, including competition, endemic insects and diseases, and wind. Warming temperatures may heighten bark beetle activity, resulting in more frequent and severe epidemics.

Sensitivity to climatic variability and change
Lodgepole pine has a specialist adaptive strategy, and low phenotypic plasticity. It is a shade-intolerant conifer that has a wide climatic amplitude in subalpine areas; lodgepole pine occurs on a wide variety of soil types and may be the only species to inhabit infertile and well-drained sites. It is moderately drought-tolerant. Its reproductive success depends on level of serotiny, and it is well-adapted to colonize post-burn environments. Lodgepole pine is highly susceptible to bark beetles, especially when stressed from endogenous and exogenous factors such as competition, fire damage, and drought. The species is also highly susceptible to western gall rust and *Comandra* rust.

Expected effects of climate change
Longer droughts and warmer temperatures may decrease growth and regeneration on the driest sites (lower elevation lodgepole stands). Lodgepole pine is well-adapted to increases in fire occurrence and size, depending on level of serotiny, but it may be eliminated from sites where fires reburn stands before established seedlings and saplings become reproductively mature. In mesic subalpine sites, continued fire exclusion coupled with higher productivity may heighten competitive interactions and stress more lodgepole pine, thereby increasing mortality, insect and disease vulnerability, canopy and surface fuels, and accelerating succession toward subalpine fir. Conversely, increasing fire may result in lodgepole pine expansion, even when fires are large and severe. Increasing insect (i.e., bark beetle) outbreaks may further acceleration towards non-host, shade-tolerant species. Where lodgepole pine regeneration increases, it functions as a nurse crop to facilitate establishment of other species.

Adaptive capacity
Lodgepole pine has a specialist adaptive strategy and is especially adapted to occupy post-burn landscapes that may be more common in the future. It is highly susceptible to increasing bark beetle outbreaks, especially on landscapes dominated by mature individuals. Varying levels of serotiny allow the species to both occupy new upper subalpine environments while also regenerating after fire. Its intolerance of deep droughts may reduce its capacity along the xeric edges of its current range.

Exposure
High

Risk Assessment

Magnitude of effects: Moderate

Likelihood of effects: High

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Mountain hemlock

Broad-scale climate change effect
Increased temperatures, increased area burned, and increased drought.

Current condition, existing stressors
Mountain hemlock is susceptible to frost at higher elevations.

Sensitivity to climatic variability and change
The species has an intermediate to generalist adaptive strategy and intermediate phenotypic plasticity. It is very shade-tolerant, and it can thrive in locations with *Armillaria* where other species are more susceptible. However, mountain hemlock is highly susceptible to fire damage due to thin bark and a shallow rooting habit. It is moderately susceptible to *Heterobasidion annosum* and *Phellinus weiri*. It is also susceptible to drought (top die back) in established trees, and has lower growth potential with soil moisture deficits. The seedling stage will likely be most susceptible to increasing temperatures and decreasing soil moisture.

Expected effects of climate change
Mountain hemlock may see range restriction to northerly aspects and stream bottoms. There may be sensitivity to increased area burned, with high mortality in seedlings and saplings.

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Ponderosa pine – var. *ponderosa*

Broad-scale climate change effect
Increasing temperatures, deeper and longer droughts, increasing fire severity and occurrence, longer growing seasons, and shorter dormant seasons.

Current condition, existing stressors
Grand fir and Douglas-fir compete with this species.

Sensitivity to climatic variability and change
This species has an intermediate adaptive strategy at low to mid elevations and a specialist adaptive strategy at higher elevations (above 5,000 feet). It is an early- to mid-seral species, has moderate phenotypic plasticity, little shade-tolerance, and is less adapted to drought than *Pinus ponderosa* var. *scopulorum*.

Expected effects of climate change
Increasing fires may have both beneficial and detrimental effects (high uncertainty) on the species. Dwarf mistletoe and western gull rust may decrease. There will likely be a loss of disjunct and isolated populations on edges of the species range. Suitable substrates may not exist upslope, which impedes both natural and artificial regeneration, and there is limited ecotomycorrhizae availability at higher elevations. With increasing temperatures and drought, there may an increase in pine beetles (western and mountain) outbreaks in this species.

Adaptive capacity
This species has an intermediate adaptive strategy at low to mid elevations and a specialist adaptive strategy at higher elevations (above 5,000 feet). It has moderate phenotypic plasticity and is less adapted to drought.

Exposure
Moderate

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Ponderosa pine – var. *scopulorum*

Broad-scale climate change effect
Increasing temperatures, deeper and longer droughts, increasing fire severity and occurrence, longer growing seasons, and shorter dormant seasons.

Current condition, existing stressors
There have been increasing mountain pine beetle outbreaks, advancing competition, increasing western pine shoot borer occurrence, and increases in fire severity and intensity in areas where this species occurs.

Sensitivity to climatic variability and change
Declining precipitation may cause declines in regeneration. The species is an early- to mid-seral species, has a generalist adaptive strategy, high phenotypic plasticity, and moderate to high drought tolerance.

Expected effects of climate change
There will likely be a decrease in dwarf mistletoe and western gull rust damage in this species, and an increase in competitive capacity. Effects of increased area burned are uncertain. This species is more vulnerable to loss of disjunct and isolated populations, as compared to var. *ponderosa,* and there is a high occurrence of inbreeding in disjunct, isolated populations.

Adaptive capacity
This species has a generalist adaptive strategy, high phenotypic plasticity, and is better adapted to drought than var. *ponderosa*.

Exposure
Moderate

Risk Assessment
Magnitude of effects: Low

Likelihood of effects: Low

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Quaking aspen

Broad-scale climate change effect
Warming temperatures, decreasing snowpack, and an increase in severity and frequency of wildfires.

Current condition, existing stressors
Aspen is a fire-maintained, early-seral component of a forested community. Stands are declining in number and size. Stressors include competition with and shading by conifers, typically due to fire exclusion, domestic and native ungulate herbivory, and increasing temperature coupled with declining precipitation.

Sensitivity to climatic variability and change
Aspen is most persistent on moist to wet soils; it does not tolerate extended drought. However, it is highly fire-adapted and regenerates abundantly after stand-replacing fire.

Expected effects of climate change
Aspen plant communities on warmer and drier sites could decrease in size due to water deficit. Some stands may have significant mortality with little or no regeneration (often due in large part to herbivory). Sudden aspen decline (SAD) has been associated with severe, prolonged drought, particularly in aspen stands that are on the fringe of the species' distribution (i.e., inherently warmer and drier sites than those typically considered optimal for aspen persistence). There will be fewer and smaller stands, and of those that persist, there will be increased plant stress due to increased severity of summer droughts. However, increased fire frequency will likely favor aspen regeneration by removing shading conifers. Younger stands (<40 years old) are more resilient to drought, so more frequent fires could favor aspen on moister sites. However, severe fire and reburns may kill shallow root systems and eliminate some stands in hotter and drier settings. Photosynthetic rates appear to increase more in aspen (than other tree species) with increases in atmospheric carbon; however, this may be offset by increased atmospheric ozone, which reduces growth rates and photosynthesis, and may increase susceptibility to insects and disease. There may be higher herbivory (browsing) on regenerating stands as adjacent upland vegetation senesces and desiccates earlier in the growing season. Where mountain pine beetle has caused conifer mortality (especially in lodgepole pine), suppressed aspen stands may release and regenerate once the canopy is open due to lodgepole pine mortality.

Adaptive capacity
Aspen distribution may shift upslope or to northeast (cooler, moister) aspects if drought and repeated fire causes mortality on the warmer, drier sites. Riparian aspen communities will likely persist, particularly if the sites remain moist throughout the growing season and increased fire burns the riparian zone, killing conifers. Fire will favor aspen, but prolonged drought will cause mortality. Younger aged stands (<40 years) may be more resilient to drought.

Exposure
Moderate

<u>Risk Assessment</u>
Magnitude of effects: Moderate

Likelihood of effects: High

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Subalpine fir

Broad-scale climate change effect
Increased disturbance frequency and severity, highly variable weather and climate, decreasing snowpack, and lengthening growing seasons.

Current condition, existing stressors
Fire exclusion has increased abundance of this species on many subalpine and upper subalpine landscapes. Many current stands have high densities, and trees may be stressed from competitive interactions resulting in increasing susceptibility to disturbances. Increasing drought could further exacerbate competitive stress and increase mortality.

Sensitivity to climatic variability and change
The species is highly vulnerable to subtle changes in climate. It is a shade-tolerant species that is an aggressive competitor in subalpine areas; uniquely adapted to quickly occupy gaps in subalpine forest canopies; relatively intolerant of drought; unable to mature when seasonal drought is common; not adapted to disturbance, especially fire, with high mortality even after low severity fires; and has frequent cone crops.

Expected effects of climate change
Longer growing seasons and reduced snowpacks will increase regenerative success, especially in those high-elevation areas where snow historically controlled regenerative success. Higher productivity in subalpine forests may increase regeneration and species densities, eventually resulting in high competitive stress, making these fir stands vulnerable to high mortality and therefore less resilient. Declines of the species on drier sites may result from new drought regimes, reducing regeneration success. Increases of the species on moister sites will result from increased regeneration and competitive advantages. Fir may gain in upper subalpine and timberline environments that are controlled by snow dynamics. Fir could also increase because of rust-facilitated declines in whitebark pine. Increased fire would decrease fir throughout the Northern Rockies. The future of subalpine fir will depend on both fire suppression levels and climatic responses.

Adaptive capacity
The species has a generalist adaptive strategy. Increasing fire will dramatically reduce subalpine fir populations to historical levels. Fire exclusion may foster subalpine fir encroachment into larch, lodgepole pine, and whitebark pine late-seral stands. Increasing subalpine temperatures may increase fir growth and accelerate succession toward fir-dominated stands. However, as competition increases, the warmer climates may facilitate increased mortality from insects and disease as trees become more stressed from high densities.

Exposure
High

Risk Assessment
Magnitude of effects: High

Likelihood of effects: High

VULNERABILITY ASSESSMENT — TREE SPECIES

<u>Habitat, ecosystem function, or species</u>
Western hemlock

<u>Broad-scale climate change effect</u>
Longer growing seasons, warmer temperatures, and highly variable weather.

<u>Current condition, existing stressors</u>
Western hemlock is confined to the moister portions of the Northern Rockies. It is susceptible to *Heterobasidion annosum*, and *Echinodontium tinctorium,* and has high tolerance to *Armillaria* spp.

<u>Sensitivity to climatic variability and change</u>
Provisionally, the species tends to have a generalist adaptive strategy. It has high shade tolerance; needs ample moisture (> 35”); is susceptible to spring frost; is good competitor; and is a high seed producer. Its seed viability only lasts one year in the soil bank. It is susceptible to acid rain and is ash cap dependent.

<u>Expected effects of climate change</u>
The current distribution of the species may not shift. It is vulnerable to water deficits and thus declines are possible on drier sites. Since the species is ash cap dependent, migration may be retarded on sites without ash cap soils.

<u>Adaptive capacity</u>
The species has an inferred or putative generalist adaptive strategy. It is susceptible to early frost.

<u>Exposure</u>
Moderate

<u>Risk Assessment</u>
Magnitude of effects: Moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Western larch

Broad-scale climate change effect
Increased temperature and increased drought.

Current condition, existing stressors
An increase in density has put western larch, especially large trees, at increased risk of mortality from fire. Past selective harvest and lack of fire have reduced the species distribution and density. Very large larch trees are especially rare.

Sensitivity to climatic variability and change
The species is very sensitive to changes in temperature. Spring frosts often reduce pollen and cone and seed production, which leads to sporadic seed years. Western larch regeneration is very sensitive to high temperatures, and regeneration may decrease on hotter, southerly slopes. Rising temperatures and increasing soil moisture deficits will affect potential distribution. An increasing amount of fire will likely benefit larch, as long as it is not in overly dense forests with trees of poor vigor, which would not provide adequate seed after fire.

Expected effects of climate change
With warming temperatures, western larch will likely migrate to more northerly aspects. Larger fires may facilitate larch regeneration because the larger larch trees may provide the only seed on burned areas. Also, increased drought on drier sites may exacerbate competition stress caused by invading shade-tolerant species.

Adaptive capacity
The species has an intermediate adaptive strategy. Larch is adapted to warm moist and cool moist settings and has a high adaptive capacity in these settings. Wind disperses western larch seed further than that of many associated tree species, so it can take advantage of areas newly opened from harvest or fire. Larch has few insect and disease stressors and is adapted to relatively frequent mixed-severity fire. However, western larch has a low capacity to regenerate on drier (more southerly) sites.

Exposure
High

Risk Assessment
Magnitude of effects: High

Likelihood of effects: Very high

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Western redcedar

Broad-scale climate change effect
Longer growing seasons, warmer temperatures, highly variable weather.

Current condition, existing stressors
Western redcedar is susceptible to root and butt disease but has low susceptibly to pathogens.

Sensitivity to climatic variability and change
The species has a generalist adaptive strategy and high phenotypic plasticity. The species is highly shade-tolerant, long-lived, has good seed production and good vegetative potential.

Expected effects of climate change
Western redcedar growth rates may increase with warming temperatures. Effects of increased area burned on the species are uncertain. Early warming followed by frost in the late winter/early spring may facilitate red-belt and adversely affect western redcedar. Cedar flagging may occur during drought (where entire branches are shed), which interferes with seed production. The species is ash cap dependent, which may prevent it from migrating to wetter/warmer sites.

Adaptive capacity
The species has a generalist adaptive strategy, and high phenotypic plasticity. Cold/warm cycles early in spring or winter may cause red belt.

Exposure
Moderate

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Western white pine

Broad-scale climate change effect
Warming temperatures, longer growing seasons, increased fire, and increased drought.

Current condition, existing stressors
There have been increases in *Armillaria,* and mountain pine beetle in western white pine. Needle blight is an issue with cool-wet protracted springs. Seed sources are vulnerable to fire damage. It is possible that species may not meet critical thresholds for regeneration establishment (10 trees acre^{-1}) in some areas, resulting in an ineffective pollen cloud, no seed production, and higher probability of inbreeding.

Sensitivity to climatic variability and change
The species has a generalist adaptive strategy with high phenotypic plasticity. The species has moderate shade tolerance, is early- to mid-seral, has good competitive ability and up to three years of seed viability in the soil bank.

Expected effects of climate change
Expected effects of climate change on western white pine include increased growth; increased abundance with less grand fir provided there is a seed source or planting; and less blister rust infection due to high temperatures and lower relative humidity (except for wave years). If a seed source exists, fire will increase the growing space, providing for regeneration potential. The species is dependent on ash cap on many sites, which may prevent migration to wetter/warmer sites. It will have limited ecotomycorrhizae availability at higher elevations. Suitable substrate may not exist upslope, so migration may not be expedited (most common on Andisols). Both natural and artificial regeneration may occur with drought. Pole blight may occur.

Adaptive capacity
The species has a generalist adaptive strategy and high phenotypic plasticity. Its cold hardiness may influence distribution. The species' current lack of abundance may influence its role in the moist forest ecosystem. It is especially adapted to future climates in the mesic regions of the Northern Rockies. There could be major expansions into historical ranges and the subalpine as rust-resistance increases in western white pine populations.

Exposure
Moderate

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — TREE SPECIES

Habitat, ecosystem function, or species
Whitebark pine

Broad-scale climate change effect
Warming temperatures, lower snowpacks, highly variable weather, increasing fires and increasing insect and disease outbreak frequency and severity.

Current condition, existing stressors
There is a reduced abundance of whitebark pine as a result of white pine blister rust infections, native mountain pine beetle outbreaks, and continued fire exclusion. Cold hardiness in seedlings and saplings allows survival in frost pockets and swales.

Sensitivity to climatic variability and change
The species is shade-intolerant and has an inability to compete with encroaching conifers because of low growth rates. There is little to no reproduction when tree densities are below 10 trees per acre (lack of effective pollination cloud) and there is a minimum cone-bearing tree density required for dispersal by corvids (i.e., nutcrackers).

Expected effects of climate change
On many upper subalpine sites, there may be increased growth and larger seed crops of whitebark pine. There will likely be seed dispersal into burn areas with bird-mediated dispersal, provided there are adequate seed sources. However, there will likely be lower seed germination due to warmer, drier conditions. Losses of ectomycorrhizal associations are possible. There may be a lack of suitable substrates as the species moves upslope (it is most common on Inceptisols). There may be increased competition from wind-dispersed, shade-tolerant conifers with fire exclusion. However, there may be less blister rust infection with higher temperatures and lower relative humidity, which disrupt the highly variable blister rust cycle, except in wave years. Increased fire may provide caching habitat for nutcrackers that allow decades of unfettered development in the absence of competition from fir and spruce. Losses in whitebark pine from fire may be offset by increases in growth, cone crops, and abundant regeneration in burned areas, but management actions are needed to augment natural regeneration by planting rust-resistant pine.

Adaptive capacity
The species is highly adapted to populating burned areas, which are projected to increase with climate change. If future fires are larger and more severe, there will be less competition with whitebark pine from other subalpine conifers; whitebark pine's ability to survive fire is better than its competitors. The species is moderately shade-tolerant, so it can exist in competition with limited cone crops. A delayed germination adaptation may mitigate warmer, drier conditions. It possesses moderate to high genetic variation (capacity) in adaptive traits (blister rust resistance, late winter cold hardiness and drought tolerance), as well as phenotypic plasticity to respond to climate change. Warmer temperatures favor expansion of alternate host species (*Ribes*, *Pedicularis* and *Castelija*). There is no opportunity to hybridize with another stone pine (cannot cross with western white or limber pine where species distributions overlap). The species is at high risk and loss of disjunct and isolated populations.

Exposure
High

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species
Big sagebrush (*Artemisia tridentata*) ecosystems

Broad-scale climate change effect
The expected climate change impacts on sagebrush ecosystems are multi-fold. Here, we focus on sagebrush communities dominated by big sagebrush, which constitute the bulk of extant sagebrush community types in the Northern Rockies. Increased winter temperatures will reduce winter snowpack and result in earlier spring snowmelt, changing the amount and timing of soil water recharge in big sagebrush ecosystems. In addition, higher temperatures are expected to increase evaporative demand. Collectively, these changes may result in considerably drier soils, particularly in the summer months when plants are phenologically active. However, winter precipitation is predicted to increase by 10 to 20% in the Northern Rockies, which may compensate for increasing severity and frequency of droughts. In addition, rising CO_2 levels may also offset water loss due to higher evaporative demand by increasing stomatal closure and water use efficiency. It is unclear whether increases in precipitation and water use efficiency associated with higher CO_2 will offset enhanced atmospheric demand for water associated with higher temperatures, thus big sagebrush ecosystems in the Northern Rockies may remain vulnerable to drought, despite increased winter precipitation. In addition, shifting precipitation and temperature regimes will impact big sagebrush communities indirectly through alteration of disturbance regimes and the increased spread of exotic annual grasses.

Current condition, existing stressors
The current distribution of big sagebrush ecosystems in the Northern Rockies is generally patchy throughout most of Montana with more spatially consistent big sagebrush cover in northern Wyoming. Big sagebrush ecosystems are currently limited in spatial extent in the western portions of North and South Dakota and northern Idaho. Core, contiguous regions of big sagebrush habitat are located outside the region to the south and west in the Wyoming Basins, Great Basin, and Columbia Plateau.

Big sagebrush ecosystems have declined in spatial extent in the 20^{th} century due to multiple stressors. Oil and gas development, along with urbanization and land conversion for agriculture and livestock grazing, not only lead to habitat loss, but to highly fragmented habitat patches, resulting in barriers to plant dispersal, greater sage-grouse avoidance, and the loss of obligate and facultative wildlife species. In addition to habitat destruction of big sagebrush ecosystems, several stressors can result in big sagebrush die-back and reduce its biomass and density. These include, insect pests, plant pathogens, and frost damage. Overgrazing by domestic livestock changes the structure and composition of big sagebrush ecosystems through the loss of the palatable components of the plant community (i.e., perennial grasses and forbs), along with reducing or increasing big sagebrush cover, and increasing the probability of annual exotic grass invasion (e.g., cheatgrass). Cheatgrass, in particular, has impacted the spatial distribution and habitat quality of sagebrush ecosystems throughout much of the western U.S. Cheatgrass is an annual, fire-adapted grass that produces fine, flammable fuels, resulting in a positive feedback cycle that increases fire frequency, causes big sagebrush mortality, and increases the survival and spread of cheatgrass itself.

Sensitivity to climatic variability and change

Big sagebrush has several life-history traits that make it sensitive to the direct and indirect effects of climate change. Increased drought may affect germination and survival of seedlings, as soil water content primarily controls big sagebrush seedling survival. Temperature is also important; big sagebrush seedling survival may be highest at intermediate temperature and precipitation regimes. Even after seedling establishment, drought and increased summer temperatures can impact survival and growth of adult plants, as growth is strongly positively correlated to water availability, particularly to winter precipitation and winter snow depth.

An additional concern is whether big sagebrush will be able to track shifting precipitation and temperature regimes and disperse to and colonize available habitat patches. The majority of big sagebrush seeds (50 to 60%) are not viable in the seedbank after two years, with very little viable seed in the upper soil layers. Furthermore, big sagebrush is a poor disperser and seed production is episodic. Even if big sagebrush seeds successfully disperse and germinate in response to shifting climatic regimes, probabilities of seedling establishment and adult survivorship are uncertain, as big sagebrush is a poor competitor relative to other species that will also be tracking climate change (e.g. herbaceous species).

Finally, big sagebrush is sensitive to fire and cannot re-sprout post-fire, thus recovery of big sagebrush post-disturbance comes from seed dispersal and can take a long time (50- 150 years). However, regeneration of big sagebrush post-fire is strongly linked to winter precipitation, which is expected to increase in the Northern Rockies.

Expected effects of climate change

Climate change will result in shifts in the distribution of conditions suitable to support big sagebrush and hence the spatial configuration of big sagebrush habitat. Several studies have projected that big sagebrush will move northward and up in elevation in response to increased winter temperatures and summer drought associated with climate change. While big sagebrush communities may expand northward and upslope, big sagebrush habitat is predicted to contract significantly rangewide due to increased soil moisture stress. However, range contractions are expected to be concentrated in southern latitudes and at lower elevations.

Habitat suitability for big sagebrush is projected to increase primarily in northeast and north-central Montana, and southern Canada. In contrast, habitat suitability is predicted to decrease in parts of western Montana and northwest Wyoming, primarily due to summer drought. However, expansion of big sagebrush out of unsuitable habitat and into suitable habitat is contingent on its ability to disperse to available habitat patches and compete with other species also tracking shifts in precipitation and temperature.

In addition to expansion and contractions in big sagebrush distributions, shifts in community composition and productivity are expected with climate change. Severe drought events can reduce species richness and biomass, particularly of less drought-tolerant species, such as grasses and forbs and lead to homogenization of the plant community, as only the most drought-tolerant species can survive. If drought events increase in the Northern Rockies, native herbaceous plant diversity and cover may be reduced. In contrast, in non-drought years, warming temperatures and increased levels of CO_2 may lead to increased biomass production, more frequent fires, and increases in grass biomass at the expense of fire-intolerant shrubs, such as big sagebrush.

Shifts in disturbance regimes (e.g., fire, insect damage, pathogens) associated with climate change may have large impacts on big sagebrush ecosystems in the future. Since big sagebrush is not capable of re-sprouting post-disturbance and recovery can take 50-150 years, increases in disturbance frequency and severity have the potential to reduce the spatial extent of big sagebrush ecosystems in the future, despite increases in habitat suitability and increased regeneration potential.

As discussed above, climate change may increase cheatgrass invasion, resulting in bigger, and more frequent fires. The positive feedback loop between cheatgrass and fire frequency may facilitate substantial changes in the composition and structure of big sagebrush plant and animal communities. In addition, field brome may respond positively to increased fire frequency, as it can invade shortly after fire. Expected impacts of increased cheatgrass and field brome invasion include reduction in native plant diversity and abundance, reduction in big sagebrush cover, and the loss of obligate and facultative wildlife species (e.g., greater sage-grouse).

Adaptive capacity

Big sagebrush ecosystems have some capacity to adapt to climate change. First, big sagebrush ecosystems occur over a large geographic area with differences in topography, soils, and climate. This suggests big sagebrush can withstand a relatively broad range of ecological conditions and may be more tolerant of shifting climatic conditions than species that are habitat specialists. Furthermore, the subspecies of *Artemisia tridentata* often hybridize and polyploidy is common. Hence, big sagebrush may have the capacity to undergo selection and adapt to shifting climatic regimes relatively quickly.

Although decreases in summer soil water availability may pose a threat to big sagebrush ecosystems, it would likely take very long periods of sustained drought to result in dieback of all big sagebrush biomass. In addition, although big sagebrush habitat suitability is predicted to change across space (e.g., decreasing suitability in northwestern Wyoming and across much of western Montana), big sagebrush ecosystems may still persist in “unsuitable” habitat for some time, perhaps in a degraded state.

Risk Assessment

Magnitude of effects: Climate change effects on big sagebrush ecosystems will likely be highly variable across the extent of the Northern Rockies by the end of the 21st century. In northwestern Wyoming and western Montana, the impacts of climate change will likely be low to moderate, as lower water availability due to increased temperature and evapotranspiration may result in declines in big sagebrush growth and regeneration, facilitating some habitat contraction. However, big sagebrush is predicted to expand northward into northern and eastern Montana and southern Canada, as habitat suitability increases in the coming decades. Thus, the predicted magnitude of climate change effects on big sagebrush ecosystems in much of the Northern Rockies is high because the amount of big sagebrush habitat may increase by 2100, while the extent of grasslands may decrease.

Likelihood of effects: In the coming century, some contraction in big sagebrush habitat may occur in northwest Wyoming and western Montana, particularly at lower elevations due to increased temperatures and increased evapotranspiration. If big sagebrush can successfully track changing climatic conditions, the total area covered by big sagebrush in the Northern Rockies may increase by the end of the 21st century.

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species
Dry ponderosa pine and Douglas-fir forests

Broad-scale climate change effect
Increased temperatures and increased soil moisture deficits, especially at lower elevation sites.

Current condition, existing stressors
An increase in density has put species in these forest types at increased risk of mortality from fire. Root disease is a major cause of mortality in northern Idaho and western Montana.

Sensitivity to climatic variability and change
Douglas-fir is sensitive to increasing temperatures and increasing soil moisture deficits, which predispose it to other related mortality agents, such as insects and disease. This may give ponderosa pine an advantage.

Expected effects of climate change
At lower elevation southerly aspects, ponderosa pine will likely be better able to cope with moisture deficits and disturbance such as fire and spruce bud worm. Seed sources will be limited due to fire size and cone production problems related to spruce bud worm. On mesic sites, there may be an increase in mortality from root disease. Higher elevation southerly slopes may become climate suitability for Douglas-fir, while ponderosa pine will be favored at lower elevations. Forest patch size will increase because of severe fire if density reductions are not implemented.

Adaptive capacity
Douglas-fir is highly adaptive to a large range of moisture and temperature gradients. Ponderosa pine is adapted to settings that are moisture-limited and can grow well where moisture is less limited, such as in association with grand fir. Exposure of Douglas-fir to increasing moisture deficits may increase ponderosa pine abundance. Increasing moisture deficits will give ponderosa pine the advantage on dry forest settings.

Exposure
High

Risk Assessment
Magnitude of effects: High

Likelihood of effects: High

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species
Lodgepole pine and aspen mixed conifer forests

Broad-scale climate change effect
Increasing temperatures, longer droughts, increasing fire occurrence, frequency, and severity.

Current condition, existing stressors
Many stands of this forest type are succeeding to subalpine fir-spruce due to fire exclusion. Aspen has been declining from a lack of fire and increasing drought. Healthiest areas are in wilderness.

Sensitivity to climatic variability and change
This forest type is more sensitive to management actions than climate in that continued fire exclusion will ensure their decline. This type thrives with fire and will even survive insect and disease outbreaks if fire is present on the landscape.

Expected effects of climate change
This cover type could expand in the future with increasing fires and the warming of the subalpine. Disturbances may eliminate competing conifers and facilitate serotiny-aided lodgepole pine regeneration. Aspen may decline on the drier parts of its range, but could increase and make major advances into the subalpine as fires burn competing conifers and temperatures moderate, creating favorable climates. If fires are too frequent, this cover type may be replaced by semi-permanent shrub-herb communities, but as long as fire return intervals are greater than the reproductive age, lodgepole pine and aspen should prevail. As fires increase, more areas in this type will be early seral, creating more heterogeneous landscapes with more patches of pine and fir mixed with aspen.

Adaptive capacity
This type has the capacity to withstand climate changes, and either maintain its current distribution or expand into the upper subalpine. Losses in aspen due to drought may be offset by gains in lodgepole pine, especially after fire. There may be long-term migrations of this type to higher elevation areas with increasing disturbance.

Exposure
High

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: High

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species
Mixed mesic white pine, cedar, hemlock grand fir forests

Broad-scale climate change effect
Increasing temperatures, more drought and more fires.

Current condition, existing stressors
This type is limited to the northwestern portions of the Northern Rockies, and much of this type has been harvested. Western white pine occurrence has been severely reduced by blister rust but has shown increases in some portions of this type. Unharvested stands are becoming more dense, creating conditions that favor rot, insects, and disease damage.

Sensitivity to climatic variability and change
This type includes a fire-tolerant, fast-growing, early seral species (western white pine) with a collection of late seral, shade-tolerant, and highly competitive species. Thus, this forest type may not change in distribution because fire will likely facilitate conversion to pine.

Expected effects of climate change
Western white pine may become more dominant in this type. Declines in cedar and hemlock are possible. Moisture changes are probably not limiting on these sites as much as the dependence on ash cap soils. Major gains in the type are probably not possible because of the limited distribution of ash cap soils in some areas and the decrease in moisture outside of the current type's range. Similar to other types, the distribution of seral types may be heterogeneous due to fire, but the long period of fire exclusion might foster atypical high severity fires that may burn entire landscapes, resulting in homogeneous pine stands (provided there are sufficient rust-resistance and seed sources).

Adaptive capacity
This type may have the capacity to remain intact with changing climate. It may not be able to expand due to dependence on ash cap soils. Increasing fire will favor western white pine, while fire exclusion will favor the shade-tolerant species. Drier sites may see grand fir becoming more common than cedar or hemlock.

Exposure
Low

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: Low

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species
Mountain big sagebrush (*Artemisia tridentata ssp. vaseyana*) and basin big sagebrush (*A. tridentata ssp. tridentata*) communities

Broad-scale climate change effect
Warming temperatures, decreasing snowpack and an increase in severity and frequency of wildfires.

Current condition, existing stressors
Significant acres of mountain and basin big sagebrush shrublands had been converted to agricultural lands, particularly the lower elevation basin big sagebrush, which is often interspersed with Wyoming big sagebrush. Those that remain are used for domestic livestock grazing, primarily due to the palatable herbaceous undergrowth. Those that have had chronic improper grazing typically have high bareground, low vigor of native herbaceous species and as a result, likely have non-native, invasive plant species present in varying amounts. Prolonged improper livestock grazing, native ungulate herbivory, and non-native invasive plants are the primary stressors. Loss of topsoil can occur if vegetation cover and density decline and bareground increases, primarily due to ungulate impacts (e.g., grazing and mechanical/hoof damage).

Sensitivity to climatic variability and change
Both species are killed by fire. With increased fire severity and frequency, there will be a shift in community composition to dominance by fire adapted herbaceous species or non-native invasive species. Other fire adapted shrub species may increase, particularly following fire. In addition, more spring and winter precipitation may facilitate exotic annual grasses (particularly annual bromes, [e.g., cheatgrass which germinates in the winter/early spring]) to establish and set seed earlier than the native perennial grasses, particularly in the lower elevation basin big sagebrush communities. This creates an uncharacteristic (based on fire history studies) continuous fine fuel load which can burn easily by late spring/early summer, burning sagebrush and native perennial grasses often before they have matured and set seed. In turn, other non-native invasive species (e.g., spotted knapweed, Dalmatian toadflax, butter-and-eggs, sulphur cinquefoil) respond favorably after fire and if present, will increase in both cover and density.

Expected effects of climate change
Historically the fire return intervals for both species are relatively short, (typically around 40 years) compared to Wyoming big sagebrush (>100 years). Basin big sagebrush recovers more quickly than mountain big sagebrush, but both regenerate from seeds shed from nearby unburned plants. Research studies show that mountain big sagebrush will fully recover between 30 and 40 years after fire (one SW MT study showed an average of 32 years), and basin big sagebrush will fully recover after approximately 20 years. With a warmer and drier climate, however, frequent, high severity burns (facilitated by cheatgrass --see above) may not only cause initial mortality, but these sites may not be as favorable for postfire vegetation regeneration (from sprouting, regrowth, or from seed). Since there is no viable sagebrush seed bank, if fires burn large areas and there are no live, seed-bearing sagebrush nearby, there may be a type conversion to grassland. In addition, invasive, non-native species will likely either expand into these communities after fire with a warmer, drier climate, or they will increase in abundance due to changed conditions which no longer favor the native plant community.

Adaptive capacity

Both species are not fire adapted. With warmer, drier temperatures and increased fire frequency and severity, both species may decline in both cover and density, or be eliminated under extreme conditions. Over time, especially if flashy fuels such as senesced cheatgrass, are present, more frequent fires may eliminate these species, particularly basin big sagebrush, from the community. Mountain big sagebrush, however, occurs in higher elevations, typically on more productive mesic sites. These communities are typically less invaded by non-native invasive species. Cheatgrass and other annual grasses are not as prevalent. If, however, these sites become warmer and drier, herbaceous understory composition could shift to more xeric species which are more adapted to drier, warmer conditions, and bareground may increase. As a result, invasive species, particularly cheatgrass, could expand into and establish dominance in these altered communities. It's possible that mountain big sagebrush distribution may shift to cooler and moister sites (e.g., higher elevation, and/or northeast facing snowloaded depressions). Basin big sagebrush is most productive in deep sandy soils of lower elevation ephemeral drainages and washes. With climate change, these may be the only sites where it can persist, due to more moisture and deeper soils than the surrounding landscape. Understory composition in both communities may shift to more xeric grassland species, which are more adapted to warmer and drier conditions.

Exposure

Moderate - Mountain big sagebrush, High - basin big sagebrush

Risk Assessment

Magnitude of effects: Moderate - Mountain big sagebrush, High - basin big sagebrush

Likelihood of effects: High

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species

Threetip sagebrush (*Artemisia tripartita*) and silver sagebrush (*A. cana*) communities

Broad-scale climate change effect

Warming temperatures, decreasing snowpack and an increase in severity and frequency of wildfires.

Current condition, existing stressors

Significant acres of threetip and silver sagebrush shrublands were likely converted to agricultural lands. Those that remain are used for domestic livestock grazing, due to the palatable herbaceous undergrowth. Those that have had chronic improper grazing typically have high bareground, low vigor of native herbaceous species and as a result, have non-native, invasive plant species present in varying amounts. Prolonged improper livestock grazing, native ungulate herbivory, and non-native invasive plants are the primary stressors. Loss of topsoil can occur if vegetation cover and density declines and bareground increases, primarily due to ungulate impacts (e.g., grazing and mechanical/hoof damage).

Sensitivity to climatic variability and change

Both species will sprout from the root crown following top kill (primarily fire). With increased fire severity and frequency, there may be some mortality, but overall these species will resprout. Silver sagebrush is the most successful and vigorous sprouter of all sagebrush species. Threetip is less successful as a sprouter, and its response varies based, apparently, on site characteristics. Both species occur in more mesic sites; threetip sagebrush is often associated with mountain big sagebrush communities. However, even though these species sprout, with increased fire severity and frequency (particularly in threetip communities), there may be a shift in community composition to dominance by fire adapted herbaceous species or non-native invasive species. Other fire adapted shrub species may increase, particularly following fire. In addition, more spring and winter precipitation may facilitate exotic annual grasses (particularly annual bromes, [e.g., cheatgrass which germinates in the winter/early spring]) to establish and set seed earlier than the native perennial grasses, particularly in the lower elevation communities. This creates a uncharacteristic (based on fire history studies) continuous fine fuel load which can burn easily by late spring/early summer, burning sagebrush and native grasses often before they have matured and set seed. In turn, other non-native invasive species (e.g., spotted knapweed, Dalmatian toadflax, butter-and-eggs, sulphur cinquefoil) respond favorably after fire and if present, will increase in both cover and density.

Expected effects of climate change

Historically the fire return intervals for both species are relatively short, typically less than 40 years. Research studies show that threetip will re-establish from seed between 30 and 40 years after fire. All three subspecies of silver sagebrush will sprout after fire, and, along with threetip, also typically occur on more mesic sites. With a warmer and drier climate, however, frequent, high severity burns may not only cause initial mortality, these sites may not be as favorable for postfire vegetation regeneration (from sprouting, regrowth, or from seed). Invasive species will likely either expand into these communities after fire with a warmer, drier climate, or increase in abundance due to changed conditions which no longer favor the native plant community.

Adaptive capacity

Both species are fire adapted; however silver sagebrush is more likely to sprout successfully and threetip response will vary by site. Understory composition in both communities may possibly shift to more xeric grassland species (e.g., bluebunch wheatgrass, needle-and-thread), which are more adapted to warmer and drier conditions. Both sagebrush species may shift landscape position to sites with more moisture and cooler temperature (e.g., higher elevation, lower landscape position, i.e., swales, run-on sites, and/or northeast aspect slopes).

Risk Assessment

Magnitude of effects: Moderate

Likelihood of effects: High

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species

Western grasslands (e.g., *Pseudoroegneria spicata* [bluebunch wheatgrass]*, Festuca campestris* [rough fescue] *F. idahoensis* [Idaho fescue], *Poa sandbergii* [Sandberg bluegrass], *Hesperostipa comata* [needle-and-thread], *Pascopyrum smithii* [western wheatgrass], *Koeleria cristata* [prairie junegrass], *Achnatherum nelsonii* [western needlegrass] *A. richardsonii* [Richardson's needlegrass])

Broad-scale climate change effect

Warming temperatures, decreasing snowpack, and increase in severity and frequency of wildfires.

Current condition, existing stressors

Many low elevation grasslands have been converted to agricultural lands, are used for domestic livestock grazing, and/or are subject to extensive human use and land-use conversion. Those grasslands that remain, particularly in the lower elevations, are typically highly disturbed and fragmented, and have been invaded by many non-native, invasive plant species. Prolonged improper livestock grazing, native ungulate herbivory, and non-native invasive plants are the primary stressors. Loss of topsoil can occur if vegetation cover and density decline and bareground increases, primarily due to ungulate impacts (e.g., grazing and mechanical/hoof damage).

Sensitivity to climatic variability and change

Most grassland species regrow quickly after fire. But as fires become hotter and more frequent, there is an increased risk of mortality and invasion by opportunistic non-native weed species. In addition, more spring and winter precipitation may facilitate exotic annual grasses (particularly annual bromes, [e.g., cheatgrass which germinates in the winter/early spring]) to establish and set seed earlier than the native perennial grasses. This creates an uncharacteristic (based on fire history studies) continuous fine fuel load which can burn easily by early summer, burning native perennial grasses often before they have matured and set seed. In turn, other non-native species (e.g., spotted knapweed, Dalmatian toadflax, butter-and-eggs, sulphur cinquefoil) respond favorably after fire and if present, will increase in cover and density.

Expected effects of climate change

Non-native invasive plant species will either expand into, or if already established, increase in abundance, particularly in the lower elevation grassland communities, regardless of level of disturbance, as these communities become warmer and drier. With disturbance, such as fire, the rate and magnitude of infestation will likely increase. Low elevation grasslands may shift in dominance towards more drought tolerant species. Some model output suggests that cool season (C3) grasslands will decline and that warm season (C4) grasslands will expand based solely on temperature trends. However, research indicates that elevated CO_2 favors C3 grasses and enhances biomass production, whereas warming favors C4 grasses due to increased water use efficiency. Even though C3 grasses, with few exceptions, dominate western mesic grasslands, with a warmer and drier climate C4 grasses may possibly expand westward into these grasslands. In general it is likely that with increased warming and more frequent, hotter fires, grasslands will become a more dominant landscape component as shrublands and lower montane conifer forests are burned and less able to regenerate due to increased fire frequency and unsuitable conditions. However, with fire, these grasslands will likely have more invasives species present.

Adaptive capacity

More drought-tolerant grassland species and communities (e.g., those dominated by *Pseudoroegneria spicata* [bluebunch wheatrass] and *Hesperostipa comata* [needle-and-thread]) will likely persist and possibly dominate the native grass component of these communities, since they are more adapted to warmer and drier conditions. More mesic species (e.g., *Festuca campestris* [rough fescue], *F. idahoensis* [Idaho fescue], *Pascopyrum smithii* [western wheatgrass], *Achnatherum nelsonii*, [western needlegrass], *A. richardsonii* [Richardson's needlegrass]) may shift landscape position to sites with more moisture and cooler temperatures (e.g., higher elevation and/or northeast aspect slopes, depressions).

Exposure

High

Risk Assessment

Magnitude of effects: High

Likelihood of effects: High

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species
Western larch mixed conifer forests

Broad-scale climate change effect
Increased temperatures.

Current condition, existing stressors
Larch forests have been reduced significantly in extent due to fire suppression and preferential harvest. Forest density increases have been substantial, and uncharacteristically dense forests exist in many areas. In northern Idaho, forest density (and productivity) is higher because of warm mesic climate and deep ash capped soils. Areas in northern Idaho once dominated by western larch, western white pine, and ponderosa pine are now dominated by mixed grand fir and moist site Douglas-fir forests. The spatial pattern of forest structure has been homogenized in many areas, leading to continuous fuels atypical under the historical fire regime.

Sensitivity to climatic variability and change
Larch is sensitive to changes in temperature. Regeneration is very sensitive to high temperatures. Rising temperatures and increasing soil moisture deficits will affect potential distribution and pattern of larch forests, especially on south aspects. Increasing fire will likely benefit larch.

Expected effects of climate change
Larch is highly vulnerable to increases in temperature and fires in dense forest settings. Losses of large tree structures and larch regeneration could occur, especially on south-facing slopes. Increases in soil moisture deficits could retract the range of western large to more northerly slopes with deep soils. Cone production could be positively affected with increasing temperatures, which could cause cone maturation to be earlier. Adaptation ability for cone production and seeding distance and regeneration ability may be reduced if connectivity is reduced with very large and more frequent severe fires. Simplification of within and between patch structure due to increased fire severity and size could lead to loss of diversity and loss of important wildlife habitat such as habitat for cavity nesting birds and mammals. In northern Idaho, the change in species composition of the forest to more intolerant species has resulted higher susceptibility to widespread root disease. These areas involve millions of acres on which *less* carbon sequestration is and will take place given the relatively novel species composition of today's forests. Given the likely increase in soil moisture deficits in the future, root disease effects are not likely to be reduced.

Adaptive capacity
Larch forest thrive on northerly cool aspects in the region. Distribution of larch in patches on south-facing slopes may be reduced significantly in the long run (50 years), and with loss of associated wildlife habitat.

Exposure
High

Risk Assessment
Magnitude of effects: High

Likelihood of effects: Very high

VULNERABILITY ASSESSMENT — VEGETATION TYPES

Habitat, ecosystem function, or species
Whitebark pine-spruce-fir forests

Broad-scale climate change effect
Declining snowpacks, increasing fire, and increasing temperatures.

Current condition, existing stressors
This type is probably increasing in the Northern Rockies from effective fire exclusion. Whitebark pine is successionally replaced by fir-spruce. The low elevation spruce-fir types are becoming more dense and crowded.

Sensitivity to climatic variability and change
This type might not be as sensitive as other more xeric types to direct climate change impacts because there is abundant water where it occurs, and expected increases in both regeneration and growth may increase its climate resilience. Increasing fires may cause a shift to more early-seral communities, and if whitebark pine populations were not experiencing rust outbreaks, these early-seral communities would probably be dominated by whitebark pine.

Expected effects of climate change
This type may contract in the future because of several interacting factors; whitebark pine will continue to decline due to rust and beetle outbreaks, and spruce-fir forest may decline due to increased fire and reduced soil water. This type may be replaced by lodgepole-aspen in the drier parts of the Northern Rockies. If agencies plant and conduct restoration activities, whitebark pine could make major gains in burned areas, thereby replacing spruce-fir and limiting the contraction of this type. Low elevation spruce-fir stands are probably going to move towards the western larch/mixed conifer type because of prolonged droughts and increasing temperatures, especially after fires.

Adaptive capacity
This type may have the capacity to respond favorably to changes in climate, but the depressed populations of whitebark pine coupled with increasing fire may result in short-term losses of this type. However, if rust-resistant whitebark pine is planted and restoration activities are implemented, whitebark pine can easily dominate this type, especially if fires are large and severe, and whitebark pine may be able to make advances into the timberline. Continued fire exclusion will probably aid in keeping this type somewhat static, and it may encroach on lower timberline sites if no fires are allowed.

Exposure
High

Risk Assessment
Magnitude of effects: High

Likelihood of effects: High

VULNERABILITY ASSESSMENT — VEGETATION RESOURCE CONCERNS

Habitat, ecosystem function, or species
Carbon sequestration (ecosystem service)

Broad-scale climate change effect
Increased fire, increasing drought and productivity gains and losses.

Current condition, existing stressors
Past policies of fire exclusion have created late seral landscapes that sequester little carbon. Past timber activities may have created younger stands that sequester more carbon. Increasing disturbances (e.g., fire, insects, and disease) have caused short-term losses in carbon sequestration.

Sensitivity to climatic variability and change
Carbon sequestration is very sensitive to climate change impacts on vegetation and disturbance. Rates of carbon sequestration are going to largely depend on the rate of burning in the future and the gains and losses of productivity in Northern Rockies ecosystems. Productivity gains and losses need to be evaluated at large spatial and temporal scales to understand future carbon dynamics.

Expected effects of climate change
Fire exclusion will tend to push most ecosystems into later successional stages where sequestration rates are minimal. Burning from controlled and uncontrolled wildfires and prescribed burning will cause short-term carbon losses, but the high productivity of the developing early seral stands may increase sequestration for decades. Sites that were historically dry will probably experience decreases in production and carbon sequestration in the future, while those mesic sites that experience abundant water (e.g., subalpine, upper subalpine, and timberline) may experience increases in productivity.

Adaptive capacity
All ecosystems have an inherent capability to store carbon, and the rate and capacity of carbon storage depends on plant productivity and disturbance, with the maximum levels of productivity dependent on climate while the instantaneous levels of productivity depend on successional stage or time since disturbance. Modeling studies have shown that many areas in Region 1 will actually increase in productivity and increase sequestration rate and magnitude. The delicate balance between disturbance and climate coupled with land management will dictate where sequestration will increase and where it will decrease.

Exposure
High

Risk Assessment
Magnitude of effects: High

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — VEGETATION RESOURCE CONCERNS

Habitat, ecosystem function, or species
Landscape heterogeneity

Broad-scale climate change effect
Increased disturbance frequency and extent, highly variable drought intensity and extent, and migration of species to new habitats.

Current condition, existing stressors
Ninety years of fire exclusion, coupled with past management activities (e.g., grazing), has reduced landscape heterogeneity.

Sensitivity to climatic variability and change
Landscape heterogeneity is highly susceptible to subtle shifts in climate because it is the reflection of the interaction of vegetation dynamics with disturbance regimes, topography, and land use. Small changes in climate may facilitate large changes in disturbances or vegetation dynamics, leading to new landscape mosaics.

Expected effects of climate change
Increased fire across most of the Northern Rockies may both increase and decrease landscape heterogeneity. Wildfires and wildland fire use may create patchworks of fire severity types across burned areas that will increase heterogeneity and therefore landscape resilience, but some fires may burn fire-excluded landscapes with high severity, causing atypical large patches of high plant mortality that may decrease heterogeneity. While large, severely-burned patches occurred in historical fires, the frequency and size of these patches may be different today. The highly-variable species migration rates into areas with new climates may increase heterogeneity, but the rapidly changing climate may only facilitate generalist species, thereby decreasing heterogeneity.

Adaptive capacity
Since heterogeneity is an expression of disturbance, vegetation, and climate interactions, it is dependent on other factors to determine its adaptive capacity.

Exposure
High

Risk Assessment
Magnitude of effects: Moderate

Likelihood of effects: High

VULNERABILITY ASSESSMENT — VEGETATION RESOURCE CONCERNS

Habitat, ecosystem function, or species
Timber production (ecosystem service)

Broad-scale climate change effect
Increased temperatures, increased soil moisture deficits, less available water, extended fire seasons.

Current condition, existing stressors
Composition shift causing reduced productivity is likely in the western portion of the region on root disease prone sites and in southerly exposures region wide. Risk of uncharacteristic fire severity is very high due to uncharacteristic high forest density which will reduce timber production opportunities especially in dry forest areas.

Sensitivity to climatic variability and change
Increasing temperatures will shift species composition to root disease-prone species, particularly Douglas-fir and grand fir. Higher temperatures are likely to extend fire season and to reduce forest inventory on areas suitable for timber production. Some increase in productivity may occur at mid to higher elevations; however increase in fire may reduce timber production opportunities. Sensitivity is high in northern Idaho and southerly exposures region-wide due to increasing moisture deficits and an increase in uncharacteristic disturbances such as fire and root disease.

Expected effects of climate change
There will likely be some increase in production at mid and higher elevations due to warming temperatures. This could be offset overall by losses due to root disease and increase in fire severity across the areas suitable for timber productions. Less production is anticipated in northern Idaho if current species compositions are not changed.

Adaptive capacity
Productivity could increase at higher elevation sites. Productivity in northern Idaho will likely decrease on southerly aspects due to root disease reducing productivity of alternate species, unless western larch, ponderosa pine and western white pine are aggressively restored.

Exposure
High

Risk Assessment
Magnitude of effects: Moderate to high in northern Idaho

Likelihood of effects: High in north Idaho

VULNERABILITY ASSESSMENT — VEGETATION RESOURCE CONCERNS

Ecosystem component
Bark beetle disturbances

Broad-scale climate drivers of bark beetle population outbreaks
Minimum temperatures influence winter survival, and summer/spring/fall temperatures dictate the timing of adult emergence and the number of generations that can be completed. Most bark beetles in Northern Rockies require at least 1 year to complete a generation, and at higher elevations where temperatures are cooler, 2–3 years may be required for a complete lifecycle. Precipitation indirectly affects bark beetle population success through effects on host trees. Increased precipitation can positively influence bark beetles through increased quality and quantity of phloem (the main tree tissue fed on by bark beetles), and short-term severe drought has a positive effect by weakening host tree defenses.

Landscape characteristics, ecosystem functions, and human systems affected by bark beetles
Each species of bark beetle impacts specific tree species. Mountain pine beetle (MPB) disturbances are only found in pine forests, with the exception of a few species. MPB population outbreaks can be extensive in homogenous pine forests, resulting in > 50% tree mortality across thousands of acres. In lodgepole pine ecosystems, MPB outbreaks initially reduce ecosystem carbon productivity, although as surviving and recruited stems grow, carbon productivity and live basal area recover to pre-outbreak levels within a few years or decades. Post-outbreak carbon stocks, however, will depend on pre-outbreak stand structure and composition. Post-outbreak conditions for regeneration have been found to be good for lodgepole pine and whitebark pine, although the influence of MPB outbreaks on ecosystem function of high elevation pine ecosystems is less clear. Bark beetle-killed trees can create hazardous conditions in campgrounds, near utility lines, and in the wildland urban interface.

Current status of bark beetle outbreaks within the region
All species of bark beetles affected close to 11,000,000 acres in the Northern Rockies between 2009 and 2013, although mountain pine beetle was responsible for more than 90% of the tree mortality. The number of affected acres has declined since 2011.

Sensitivity of bark beetle population outbreaks to climatic variability and change
Temperature is a main driver of bark beetle population survival and population growth. Warming minimum temperatures in recent years have resulted in increased MPB overwintering survival, particularly in Northern Rockies forests with historically severe winters. Warming temperatures other times of the year, however, also play a significant role as they influence adult emergence timing and generation time. Slight differences in temperature, even within a single tree or among trees within a stand, can result in dramatic differences in MPB generation time. Shorter generation time (i.e., 1 year to complete a lifecycle vs. 2 years) will generally result in greater population growth and subsequent tree mortality. In historic and current climate, evolved adaptations to local climate constrain MPBs capacity to successfully complete 2 generations in a single year (i.e., bivoltinism). If adult emergence occurs early in the summer a generation can be completed by the next fall, although completion of a generation over winter is constrained due to evolved thresholds for development. Other species (e.g., western pine beetle) found in the Northern Region are capable of multiple generations in a single year. Generally, several consecutive years of favorable temperatures are necessary for population growth, suggesting that high inter-annual variability that may occur with climate change may not be advantageous

to population outbreaks, although symbiotic associates may benefit. Severe short-term drought that is associated with warm temperatures can provide a pool of weakened host trees and appropriate thermal conditions for population outbreaks of multiple bark beetle species.

<u>Expected effects of climate change</u>

Climate projections for The Northern Rockies suggest temperatures will warm considerably. Although all bark beetle species that occur in the region will be affected, models and specific data for making future predictions, based on temperature, are currently only available for MPB. Using a temperature-dependent mechanistic model for MPB, the effect of future temperatures on MPB univoltine population growth relative to historic conditions was predicted. We also evaluated if thermal regimes that would promote bivoltinism would occur by initiating the model in June and testing for 2 periods of adult emergence within 375 days (i.e., 2 generations in 1 year. Effects on population growth due to stand size and structure, and drought are not included. Model output was only considered for locations where pines currently grow.

<u>Risk Assessment</u>

Likelihood of bark beetle outbreaks given temperature alone:

- Bivoltinism in MPB has historically been thermally impossible in the Northern Rockies.
- Stands at elevations < 1000 m have relatively few pines, and population growth of univoltine (i.e., 1 generation per year) populations was historically very low, most likely because it was too warm and adult emergence synchrony was disrupted. Growth rate is predicted to decline even further in current (2000-2009) and future climates relative to historic periods. However, the proportion of points at <1000 m with thermal regimes that will allow for bivoltinism (i.e., 2 generations in 1 year) is predicted to increase through 2100. The availability of pines in future climates at <1000 m, however, may be restricted.
- Pine stands at 1000-2000 m were also predicted to have lower univoltine population growth rates in current and future climates than historically, and some small proportion of stands will have increased probability of bivoltinism by 2080-2100.
- The greatest density of pine occurs at 2000-3000 m and these stands are predicted to have greater univoltine population growth rates than historic, through 2030-2050. Thermal regimes for bivoltinism are unlikely at this elevation.
- Population growth rates were historically very low in stands >3000 m until 2000-2009, and rates are predicted to increase through 2100. These stands are too cool for bivoltinism historically and in future climates.
- The Grassland subregion contains a small amount of ‘Great Plains ponderosa pine’, and historically temperatures were too warm for univoltine MPB population success. A high proportion of locations in these areas are predicted to become thermally suitable for bivoltinism.
- In the West, Central, and East subregions, univoltine population growth is predicted to decrease beginning in the 2000-2009 period, although a small proportion of locations at the lowest elevations will become thermally suitable for bivoltinism by 2080-2100.
- In the GYA univoltine population growth remains relatively high until the 2080-2100 time period with a very small proportion of locations at the lowest elevations with the potential to become bivoltine at that time.

VULNERABILITY ASSESSMENT — VEGETATION RESOURCE CONCERNS

Habitat, ecosystem function, or species

Invasive plant species (terrestrial and aquatic plants, animals, invertebrates, and pathogens). Invasive plant species include state-listed noxious weed species, along with introduced annual grasses and other species not currently listed by states. Most are herbaceous species (graminoids and forbs), but some are shrub and tree species, e.g., Russian olive and tamarisk, which occur in riparian areas.

Broad-scale climate change effect

Temperature and precipitation patterns, atmospheric CO2 concentration, indirect effects from an increase in severity and frequency of wildfires.

Current condition, existing stressors

Invasive species primarily spread into disturbed areas with sufficient bare ground and sun for germination, although some species such as spotted knapweed (*Centaurea maculosa*) and yellow toadflax (*Linaria vulgaris*) are capable of invading undisturbed plant communities. Non-forested vegetation (shrublands, grasslands) has been invaded in many areas. As fires and other disturbances increase in intensity and frequency, invasive species can occupy and potentially dominate native plant communities that were previously resistant to invasion, although numerous factors such as fire resistance of onsite species, propagule pressure, and variation in burn severity can affect establishment. Native and domestic livestock grazing and browsing of native species can reduce plant vigor and open up sites for establishment of invasive species. Silvicultural prescriptions that decrease canopy cover also increase the likelihood that invasive species may establish and increase in both cover and density.

Sensitivity to climatic variability and change

Climate change is likely to result in differing responses among invasive species, owing to differences in their ecological and life history characteristics. Bioclimatic envelope modeling indicates that climate change could result in both range expansion and contraction for five widespread and dominant invasive plants in the western U.S. Yellow starthistle (*Centaurea solstitialis*) and tamarisk (*Tamarix ramosissima*) are likely to expand, while leafy spurge (*Euphorbia esula*) is likely to contract, and cheatgrass (*Bromus tectorum*) and spotted knapweed are likely to shift in range, leading to both expansion and contraction. Invasive species are generally inherently adaptable and capable of relatively rapid genetic change, which can enhance their ability to invade new areas in response to ecosystem modifications, including short-term disturbance (fire) or long-term stressors (prolonged drought, increased temperatures, chronic improper grazing). Increased concentrations of CO2 in the atmosphere have been shown to increase the growth of weed species, which could have an influence on their invasiveness.

Expected effects of climate change

Invasive species could expand into plant communities that in the past have been considered "closed" to invasion. These may include higher elevation moist forests that are now burning more frequently and will have more bare ground for germination and a more open canopy for growth. In addition, an increase in fire frequencies in areas with fire-tolerant invasive species can lead to a self-perpetuating weed – fire cycle (e.g., the "cheatgrass – fire cycle").

Adaptive capacity

Many invasive species have long-lived seed banks and other life history strategies (e.g., prolific seed production, extensive deep rhizomes) that facilitate effective dispersal, establishment and persistence in highly variable conditions. Alteration of the competitive balance between weeds and native plant species is thus critical for enhancing the adaptive capacity of plant communities. Sustainable control of aggressive weeds is most likely going to occur only when natural, intact ecosystems are restored.

Exposure

High

Risk Assessment

Magnitude and likelihood of effects:

Invasive species component	Predicted magnitude of change	Main driver(s) of change	Likelihood of change
Area infested	Variable by species – from low to high	Changed temperature and precipitation patterns; increased atmospheric CO_2; altered fire regimes	High
Species response to habitat disturbance	High	Increased fire frequency and severity, which can increase the amount of habitat vulnerable to weed invasion	High
Changed fire regimes	High	Increased fire frequency in areas with fire-tolerant and flammable invasive species (e.g., the "cheatgrass – fire cycle")	High

VULNERABILITY ASSESSMENT — VEGETATION RESOURCE CONCERNS

Habitat, ecosystem function, or species
Wildfire regimes

Broad-scale climate change effect
Temperature and precipitation patterns, including direct effects on fire season length and live and dead fuel moistures and indirect effects on live and dead fuel amount, distribution, and type.

Landscape characteristics, ecosystem functions, and human systems affected by fire
Biome type (e.g., forest vs. grassland; woodland vs. closed-canopy forest), forest structural or seral stage (e.g., seedling, sapling, old growth, etc.), species composition (e.g., tree, shrub, herbaceous, and grassland species present), ecosystem services (e.g., wildlife habitat, carbon stores, hydrologic function), economics and social dimensions (e.g., timber, recreation, cultural resources, human health, wildland urban interface).

Current condition, existing stressors
Dry forests, shrublands, and grasslands in the region exist in a state of "fire deficit" as the result of 20th and 21st century fire exclusion. In lower elevation dry conifer forests that occur in the western portion of the region, high-frequency, low-severity fires were typical before the early 20th century. These forests historically burned frequently enough to maintain low fuel loads and an open stand structure, producing a landscape in which fire-caused mortality of mature trees was rare. The exclusion of fire from the region's fire-prone, forested biomes has increased surface and canopy fuel loads and canopy cover in forested systems, shifted the composition of mature forests toward late seral, shade-tolerant, non-fire adapted species (e.g., shift from western white pine dominated to fir-dominated forests), and hindered regeneration of fire-adapted species such as ponderosa pine, which requires exposed mineral soil for regeneration. The shrublands and grasslands that occur in the southwestern and eastern portion of the region historically experienced frequent surface fires that prevented encroachment by trees and maintained heterogeneous plant communities. Thus, fire-prone, fire-adapted ecosystems from which fires have been excluded for 100-plus years should be considered highly stressed systems that are potentially at risk for a) replacement of fire-adapted species; b) decreased heterogeneity and altered landscape composition; c) high-severity fire as the result of increased fuel loads; and d) increased tree mortality from drought, insects, and other stressors.

Sensitivity to climatic variability and change
Climate is a strong driver of wildfires, and its influence on fire regimes varies by forest type and region. For example, very dry forests in the western U.S. are typically fuel-limited, so widespread fires occur during periods of increased productivity and fuel accumulation driven by increased growing season precipitation. Conversely, in more mesic forest types, sufficient fuel is typically available to carry fire, but suitably dry conditions for fire spread occur infrequently. Regionally synchronous fires have generally occurred in the northern Rocky Mountains (Idaho and western Montana) during years with relatively warm springs and warm-dry summers.

Expected effects of climate change
Future climate projections for the Northern Rockies have dramatic implications for fire regimes. The fire season is expected to grow longer, thus allowing more fires to occur and those fires to burn for longer periods and across larger areas. Earlier onset of snow melt will reduce fuel moistures during the fire season, making a larger portion of the landscape flammable for longer periods of time.

Adaptive capacity

The adaptive capacity of a fire-prone ecosystem is strongly influenced by its degree of departure from the historical disturbance regimes under which constituent plant communities have evolved. Areas that are highly departed, such as fire-excluded ponderosa pine forests, may be rapidly and persistently altered by wildfires, especially those that burn under extreme conditions (e.g., hot and dry weather, high winds). Surface and canopy fuels accumulation, homogenous and continuous landscape fuels, and extreme weather acting in combination create the potential for high-severity, stand-replacing fire. Post-fire regeneration of forests may be slowed (e.g., decades to centuries) because of the time required for seed dispersal over large burned areal extents. In addition, the droughty, high temperature conditions associated with anthropogenic climate changes may inhibit seedling establishment and survival.

Risk Assessment

Fire regime component	Predicted magnitude of change	Main driver(s) of change	Predicted duration of change	Likelihood of change
Area burned	Increase	Increased fire season length, decreased fuel moistures, increased 'extreme' fire conditions	Until a sufficient proportion of the landscape has been exposed to fire, thus decreasing fuel loads and increasing structural and species heterogeneity	High
Fire frequency	No change	No predictable changes in lightning	No change	High
Average fire size	Increase	Increased fire season length, decreased fuel moistures, increased 'extreme' fire conditions	Until a sufficient proportion of the landscape has been exposed to fire, thus increasing the likelihood that previous fires will restrict growth of current year fires	High
Fire season length	Increase	Increased temperatures, decreased precipitation, decreased winter snowpack, decreased runoff	Until the global climate system stabilizes; predicted to increase as climate changes become more severe	High
Fire severity	Increase	Decreased fuel moistures, increased 'extreme' fire conditions	In dry forest types, until fires decrease surface fuel loads; in mesic forests, when those forests become fuel limited	Moderate

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
American pika

Broad-scale climate change effect
Loss of winter and spring snowpack due to shift from snow to rain (with consequent loss of insulation and more very-cold temperatures); increased summer temperatures; and water-balance stress (including direct physiological effects on pikas and indirect effects on pika forage [vegetation]).

Current condition, existing stressors
Pikas are well distributed across high-elevation areas in the Northern Rockies, and their elevational distribution extends lower down in the Region than in most other areas of the U.S. Many areas where pikas exist are currently protected; others experience fewer land uses than habitats in valley bottoms. Current stressors across the Northern Rockies appear to be low, especially because talus is a very undesirable habitat to develop. If rock extraction from talus slides were to happen widely, especially if the largest boulders were preferentially selected, this would likely constitute a stressor for pikas, as they tend to be associated with larger boulders on a given slope.

Sensitivity to climatic variability and change
Pikas are generally dependent both on moist and cool summer conditions and winter snow. Across paleontological timescales and from the 20th century through the present, pikas across the Great Basin have reacted to climate changes by moving upslope or becoming locally extirpated when and where the climate becomes hot and dry. Recent research in the Great Basin indicates that local extirpations and retractions are continuing across the Basin. Local changes in pika distribution have also been recorded in Utah, the southern Sierra Nevada Mountains, and the southern and central Cascade Mountains. In the Great Basin, sites of pika extirpation were generally hotter in the summer (both more-frequent acute heat, and hotter average temperature across the whole summer) and more frequently very cold in the winter (warming led to the loss of insulating snow, causing temperatures experienced by pikas to plummet) than sites where pikas persisted since the early 20th century.

Expected effects of climate change
In areas where warmer, dryer conditions cross critical thresholds, pikas are likely to experience local extirpations. Dispersal, even locally, appears to be minimal (particularly in hot, dry contexts), so recolonization in many cases is unlikely.

Adaptive capacity
All data indicate that pikas have low ability to persist in unfavorable climates. However, local microclimatic conditions, such as those associated with flowing water under talus, as well as ice caves, lava-flow tubes, and areas with thick moss, can lead to pockets of persistence.

Risk Assessment
Magnitude of effects: Low in 2030, 2050, probably moderate by 2100

Likelihood of effects: Lack of a clear understanding of the precise climatic thresholds for pika persistence and the nature of their interaction in the Region means that the locations and magnitude of these effects in the Northern Rockies are unclear. However, it is highly likely that at least some pika populations will be negatively affected, particularly during later time periods.

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Canada lynx

Broad-scale climate change effect
Loss of snowpack due to shift from snow to rain, possible effects due to changes in snow consistency

Current condition, existing stressors
Lynx are confined to limited areas in the Northern Rockies suggesting a high degree of habitat specificity. Lynx are associated with boreal forest types and are entirely dependent on snowshoe hare populations. Snowshoe hares are also sensitive due to snow dependencies that include seasonal pelage change. Lynx are listed as Threatened under the Endangered Species Act, and therefore are protected from trapping. One of the main concerns is the extremely small population sizes associated with those limited areas that currently contain lynx.

Sensitivity to climatic variability and change
Lynx are snow dependent and are morphologically adapted to travel across soft, deep snow. In Minnesota, where topographic relief is limited, lynx and bobcat partition the landscape based on the presence (or lack thereof) of lake-effect snow. The small populations in the conterminous U. S. have historically been periodically augmented by lynx from Canada, and maintaining population connectivity to Canada is central to lynx conservation. However, maintaining connectivity for lynx may become increasingly difficult as southern populations of boreal species become more isolated with climate change. This is of particular concern for lynx because the boreal forests are particularly vulnerable to climate change. Boreal forests that support lynx and snowshoe hares are structured by disturbance processes that include fire, insects, disease, wind, and human-actions; many of these disturbance factors may be altered by climate change.

Lynx diets in Montana are almost entirely (~95%) composed of snowshoe hares. Hares are also dependent on snow, exhibiting morphological adaptations similar to lynx and additionally seasonally changing their pelage from brown to white. Timing of this pelage change is critical, as hares are extremely vulnerable to predation when their coat color is a mismatch to the background. Hares, however, have low plasticity in pelage change and changes in the average snow-free period may render areas unsuitable for hares. Thus, climate change will likely affect lynx directly as well as indirectly by affecting their obligate prey.

Expected effects of climate change
Loss of snow will both shift the balance from lynx to other non-snow-adapted predators such as bobcats and coyotes and will be destructive to snowshoe hare viability.

Adaptive capacity
Lynx have little or no adaptive capacity to live in areas lacking snow. They have limited abilities to shift diets away from snowshoe hares, but other diets made up of red squirrels or microtine rodents are generally considered starvation diets and only useful as a temporary bridge until hare populations increase.

<u>Risk Assessment</u>
Magnitude of effects: Moderate by 2030, high by 2050, extreme by 2100

Likelihood of effects: High in all time periods

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Fisher

Broad-scale climate change effect
Shifting inland maritime ecosystem

Current condition, existing stressors
Fishers are patchily distributed in the Northern Rockies. They are found almost exclusively in the inland maritime ecosystem in Idaho, and in areas where it extends eastward into western Montana. While the current distribution is reduced from its historical range, the fisher was historically disjunct in the West. Genetic studies have shown, for example, that fisher populations in California have been historically separated from those in Washington State, and fishers in the southern Sierra were historically isolated from those in the Klamath. Fishers in Montana contain unique haplotypes not found elsewhere and therefore were apparently historically isolated both from large populations in northern British Columbia, and coastal populations in Washington. Thus, in the West, fishers appear to have very specific habitat associations. Common attributes for resting sites are: steep slopes, cool microclimates, dense overhead cover, a large volume of down logs, and the presence of large trees and snags. Human activities that reduce the areal extent of these structures may act as stressors.

Sensitivity to climatic variability and change
Fishers have long been thought to have specific climatic associations. For example, when compared to martens, areas in the Sierra Nevada occupied predominantly by martens were closely associated with forested areas with the deepest snow, whereas areas occupied predominantly by fishers were forested areas with low monthly snowfall. Additionally, there is direct evidence that fishers avoid deep snowpack and that deep snow can limit fisher dispersal. Fishers have also been shown to avoid dry habitat types.

Expected effects of climate change
Fishers are found in the relatively warm and wet conditions associated with the inland maritime ecosystem. Recent climate futuring of fisher habitat projected declines in habitat quality in virtually all areas where fishers currently exist, coupled with increased habitat quality in areas to the east and south. However, the old-forest structures that fishers are currently associated with require significant time to form; it is unknown whether similar climate will equate to similar habitats in the short term.

Adaptive capacity
The historical fragmentation of western fisher populations indicates that they have very specific habitat requirements, and therefore low adaptive capacity. However, in eastern North America, fishers have urbanized and have become extremely common. It is unknown whether fishers have similar adaptive capacity in the West.

Risk Assessment
Magnitude of effects: Low in 2030, moderate in 2050, probably high by 2100

Likelihood of effects: Due to the limited current distribution of fishers (indicating limited plasticity), likelihood of effects is high across all time periods.

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Flammulated owl

Broad-scale climate change effect
Disturbances leading to changes in dry forest types

Current condition, existing stressors
Flammulated owls are well distributed across the dry forest types in the Northern Rockies and across the Rocky Mountain West in general. Flammulated owls are cavity nesters and therefore associated with large diameter mature forests. They are also associated with more open forest types, but within this constraint, do not appear to be specific to any particular tree species or habitat association. Flammulated owls use both live trees and snags to nest, and have generalized insect diets. Current stressors are the loss of large diameter open forest types due to historical logging and, more recently, stand-replacing fire.

Sensitivity to climatic variability and change
Flammulated owls do not have any obvious direct sensitivities to climate change but, if increased levels of fire continue to decrease acreage of large diameter dry forests, habitats will become more limited.

Expected effects of climate change
The expected effects of climate change are not straightforward. Losses in current large diameter dry forests could be offset increased habitat qualities in what are currently more mesic forest types. However, disturbance levels that produce large acreages of primarily young forest or to shifts away from forest types and into grasslands or shrublands will most likely be detrimental to this species.

Adaptive capacity
The ability of flammulated owls to exist in many forest types (e.g., ponderosa pine, piñon pine. Douglas-fir, black oak, Jeffrey pine, white fir, and red fir), coupled with its range across much of western North America demonstrates a significant degree of habitat plasticity. However, it is associated with large diameter forests and there are, therefore, obvious limits to its plasticity.

Risk Assessment
Magnitude of effects: Largely unknown across all time periods

Likelihood of effects: Largely unknown across all time periods

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Greater sage-grouse

Broad-scale climate change effect
Climate induced changes in sagebrush habitats, disease processes, and anthropogenic activities

Current condition, existing stressors
The greater sage-grouse is considered to be a sagebrush obligate whose population has been greatly reduced when compared to historical populations; it currently occupies about half of the historical presettlement range and many monitored populations have been steadily declining in recent decades. Current stressors that have been documented in the scientific literature include: reductions in sagebrush cover (in many cases associated with agricultural conversion), exotic plants, energy exploration and extraction, grazing, changes in fire regime, climate change and in recent years, West Nile virus has also been implicated.

Sensitivity to climatic variability and change
Sage-grouse are faced with so many anthropogenic stressors, that it is difficult to separate the effects of climate change. However, studies of historical distribution and extirpation have found that populations proximal to the historical range boundary and subject to droughts were more likely to experience extirpation. This finding suggests that stressors have a greater impact on sage-grouse near to their climatic limits.

Expected effects of climate change
The expected effects of climate change are not straightforward. Both sagebrush distribution and the range limits for West Nile virus appear to be sensitive to climate change, but the projected nature of these changes varies greatly between climate models. For this species, all climate changes will interact with significant anthropogenic stressors and these interactions will be complex and hard to predict.

Adaptive capacity
The greater sage-grouse appears to have very specific habitat requirements and has shown a low degree of adaptive plasticity.

Risk Assessment
Magnitude of effects: Largely unknown across all time periods

Likelihood of effects: Largely unknown across all time periods

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Pygmy nuthatch

Broad-scale climate change effect
Disturbances leading to changes in dry forest types

Current condition, existing stressors
Pygmy nuthatches are well distributed across the dry forest types in the Northern Rockies and across the Rocky Mountain West in general. Within this area, the pygmy nuthatch is restricted to coniferous forests of the mountainous regions. It is a cavity nester and is often associated with ponderosa pine forests but, like the flammulated owl, is found in other forest types. Current stressors are the loss of dry forest types to stand replacement fires.

Sensitivity to climatic variability and change
Pygmy nuthatches do not have any clear direct sensitivities to climate change, and in several studies showed little sensitivity to disturbance (fire and thinning). However, if increased levels of fire were to convert large areas of currently dry forest to grasslands or brushlands, habitat would be lost.

Expected effects of climate change
The expected effects of climate change are not straightforward. It is possible that, even with losses of dry forests, that nuthatches could expand into higher elevation areas. However, it is most likely that disturbance levels that lead either to primarily young forests or to shifts away from forest types and into grasslands or shrublands will be detrimental to this species.

Adaptive capacity
The ability of pygmy nuthatches owls to exist in many forest types (e.g., ponderosa pine, aspen), coupled with its range across much of western North America, demonstrates a significant degree of habitat plasticity.

Risk Assessment
Magnitude of effects: Largely unknown across all time periods

Likelihood of effects: Largely unknown across all time periods

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Wolverine

Broad-scale climate change effect
Loss of spring snowpack due to shift from snow to rain

Current condition, existing stressors
Wolverines are currently well distributed across high elevation areas in the Northern Rockies. In the conterminous U.S., the population has been expanding since circa 1930, when it is likely that it was locally extirpated. Most of the areas inhabited by wolverines are protected; current levels of stress are relatively low. Montana allows very limited wolverine trapping; it is protected in other states.

Sensitivity to climatic variability and change
Wolverines den in snow, and deep persistent snow throughout the denning period is thought to be essential. Wolverines exhibit a strong, likely obligate relationship between den selection and the presence of deep, persistent snow in the late spring. The extent of persistent spring snow cover (a proxy for spring snowpack) through mid-May effectively describes den site selection and current range limits worldwide, and year-round habitat use at the southern periphery of their range. Areas identified as being associated with persistent spring snow were also strongly associated with successful dispersal and the limits of historical range.

Expected effects of climate change
Losses in spring snowpack have been occurring across the last 60 years, and further losses are anticipated by all climate projection models. Losses, when compared to current levels of snowpack, have been estimated at around 30% by mid-century and 60% by the end of the century.

Adaptive capacity
All data, including fossil records, indicate that wolverines are associated with cold snowy environments, most generally with arctic conditions. There is no evidence that wolverines can persist in areas distant from extensive areas of spring snow. Thus, adaptive capacity appears to be low.

Risk Assessment
Magnitude of effects: Low by 2030, moderate by 2050, high to extreme by 2100

Likelihood of effects: High in all time periods

Habitat, ecosystem function, or species
Ecosystems: All
Fine filter species: Canada lynx, wolverines, pika, fisher, species with seasonal pelage change

Broad-scale climate change effect
Changes in snow cover, depth, and condition (e.g., softness) are expected as temperatures and winter precipitation are predicted to increase. Depending on location and elevation, these changes are predicted to shift the balance of winter precipitation from snow to rain or, on colder sites, lead to increases in snow depth. Likely snow condition will also change on many sites with the likelihood of heavy wet snowfall increasing. These changes are very sensitive to the exact nature of warming and precipitation patterns, and therefore the locations of the various effects will be difficult to predict. However, areas close to the rain/snow threshold under current environmental conditions will be more sensitive to these changes.

Current condition, existing stressors
Current conditions may be altered from historical norms; April 1 snow water equivalent (a measure of snowpack) has declined across the Northern Rockies by 20-80% since the 1950's. However, we do not know the historical conditions with sufficient accuracy to determine whether changes in snow condition and amount have altered ecosystems and species in the Northern Rockies.

Sensitivity to climatic variability and change
Many systems and species are potentially altered by changes in snow conditions.

Ecosystems:

Grassland/shrub, dry forest, mixed mesic. All of these systems will likely be most saturated with water while snow is present and will begin to dry as soon as snow is gone. Decreased snowpack and/or snowpack that melts earlier is expected to lead to earlier onset of wildfires. Deciduous plants will break dormancy earlier, potentially leading to greater drought stress as the season progresses.

Subalpine. The same effects associated with the drier forest types will also occur in the subalpine and alpine areas. In addition, many (in many areas most) meadow and shrub areas are associated with snow. In areas with deep snow accumulation, "snow meadows" form when snow cover is deep and persistent enough to preclude conifers. Increases in snow accumulation due to increased precipitation at high elevations could lead to more expansive meadow areas. Conversely, warmer areas where precipitation shifted from snow to rain could see alpine areas become forested. Avalanches are another important alpine feature that is snow-associated. Avalanche chutes are maintained in grass/shrub conditions and provide important habitat for many species of plants and animals. In addition to the plant communities, debris piles at the base of avalanche chutes are used by both wolverines and lynx for den sites. Like alpine meadows, changes in avalanche activity are anticipated, but the direction of these changes will depend on the specific moisture/temperature regime in the area.

Riparian/special (e.g., wetlands). Any communities dependent on persistent water saturation are critically dependent on snowpack. Spring snowmelt is a climatic phenomenon that cannot be duplicated by precipitation in the form of rainfall. In many high elevation areas, 30-100 inches of liquid precipitation is held in winter snowpack. On most sites, this snowpack will melt in approximately 1 month, leading to the equivalent of a single month having 30-100 inches of precipitation. Further, this precipitation arrives optimally, at a constant rate, and enters the soil at low velocities leading to little surface erosion. Lastly, deciduous vegetation is dormant and only a small proportion of this water is lost to transpiration and interception, when compared to rain. As a result, snow melt recharge of shallow aquifers occurs to an extent that cannot be duplicated by rainfall. Because these special areas are, for the most part, dependent on flow from springs, changes in aquifer recharge associated with changes in snowpack can be expected to strongly affect these systems. Importantly, in areas which shift from snow to rain, wetlands and streams can be expected to become increasingly ephemeral.

Many species of mammals are dependent on snow. Wolverines den in snow, lynx are provided competitive advantage in soft snow, and pika require both deep snow for thermal protection during the winter and wet meadows during the summer to collect hay. All species whose pelage changes color to better blend in to a snowy background are dependent on the period of snow cover. Snowshoe hares, the primary prey for lynx, have been shown to have limited plasticity in timing of pelage change.

Expected effects of climate change

All models indicate a general loss in snowpack across all seasons. Some models do indicate midwinter increases in snowpack in higher elevation areas. However, all models indicate rather massive losses in spring snowpack. For the Northern Rockies, except for a few of the highest elevation areas, we should anticipate less snowpack, and for all areas we should anticipate earlier snowmelt, longer snow free periods, and much smaller areas that retain their snow into the late spring. Thus, we should anticipate that the primary effects will be those associated with less snow. These would include longer fire seasons in low elevation sites, fewer persistent springs leading to ephemeral streams and wetlands, and range shrinkage of all snow-dependent species such as lynx, wolverines, and snowshoe hares.

Adaptive capacity

In general, the ability to adapt to these changes is expected to be low for most of the affected systems and species.

Risk Assessment

Magnitude of effects: All of these changes are ongoing, and will continue to increase in magnitude across the period. As noted above, April 1 snow water equivalent is on average much lower today than it was 60 years ago, and this pattern is anticipated to continue. A recent analysis of snowpack, in relation to wolverine habitat, predicted that areas persistently snow covered through May 15 in the Northern Rockies would decline by ~30% by 2050 and ~60% by 2100. At smaller scales, these changes are likely to cross critical thresholds, leading to non-linear impacts on systems. For this climatic phenomenon, the threshold is the freezing point of water and the shift from snow to rain.

Likelihood of effects: These changes are already documented and, at least in terms of spring snowpack, are rather large. Further, there is nearly absolute concurrence among the climate models concerning losses in snowpack in both the fall and spring. Thus, these effects have a high likelihood of occurring across all time periods.

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Ecosystems: All, but particularly invasive, grass/shrub, dry forest, mixed mesic and all water dependent communities

Fine filter species: flammulated owl, pygmy nuthatch, and fisher

Broad-scale climate change effect
Loss of summer precipitation coupled with increased summer temperatures will lead to **drought stress** for extended periods. These changes are expected to work synergistically with decreased snowpack and earlier runoff. In aggregate, these changes are expected to lead to decreases in groundwater.

Current condition, existing stressors
Compared to the mid-20th century, we have been experiencing increases in drought stress and related conditions for the last 30 years. Our dry ecosystems have seen increased fire acreage and severity. Both dry and mesic systems have seen increased epidemic insect outbreaks. Additionally, stress related mortality has increased (e.g., aspen). Exotic invaders have increased and primarily impact our drier systems; disturbances such as fire often enable invasions. Fire suppression, coupled with removals of old, fire resistant trees, has left many of our dry forests vulnerable to extreme fire events.

Sensitivity to climatic variability and change
Nearly all of our systems are sensitive to these changes. Specifically, our dry forests are sensitive to climate variability leading to prolonged periods of drought stress. An analysis of acreage burned in the Northern Rockies shows that most of the acreage is associated with specific years in which fire occurred across the region. Similarly, most of our forests are prone to widespread insect outbreaks associated with both drought stress and warming conditions. Probably the most sensitive areas are those where small changes in water regimes (coupled with associated disturbance events) will move these areas from forests to grass/shrublands. These would include dry forest types such as ponderosa pine forests. Related to this, species dependent on older large-diameter tree species in these areas may be particularly vulnerable. In our fine filter species, these include flamulated owls and pygmy nuthatches.

Expected effects of climate change
In all models, late summer moisture deficit will increase, and soil moisture will decrease across the region. Winter precipitation is expected to increase. It is reasonable to look at the attributes of forested systems that currently experience this pattern. For example, the Sierra Nevada are characterized by heavy, warm, winter precipitation coupled with long hot droughty summers. The Sierra Nevada are extremely fire-prone because winter precipitation leads to high production of fuels and long summer droughts cause deciduous vegetation to become dormant, adding deciduous leaves to the dead fuels. Systems experience an extended fire season because systems dry early and stay dry. If model predictions are correct, we can expect these traits in many forests in the Northern Rockies. However, vegetative communities associated with Northern Rockies forests are less adapted to these conditions; many forests in the Sierra Nevada either have little or no understory vegetation, or the vegetation is made up of drought-hardy species that currently do not occur in the Northern Rockies. Thus, a shift to conditions more similar to those in the Sierra Nevada is expected to be generally destructive to extant vegetative communities, and to the species that depend on them.

Adaptive capacity

Many of the overstory species (e.g., lodgepole and ponderosa pines, Douglas-fir) are widely distributed species. Similarly, both flammulated owls and pygmy nuthatches are broadly distributed across dry forests. This might indicate some degree of adaptive potential. However, as silviculturalists have long known, the adaptive potential for the progeny of specific trees is much more limited. Particularly for Douglas-fir, seed stocks need to be carefully matched to specific climatic zones to survive to maturity. Similarly, timing of pelage change for snowshoe hares varies widely across the West, but within a specific area exhibits low plasticity. Thus, these local adaptations may preclude a high degree of plasticity for many species.

Risk Assessment

Magnitude of effects: The magnitude of the effects is huge: it affects the majority of acreage in the Northern Rockies. Because these trends are already occurring (e.g., unprecedented bark beetle outbreaks in lodgepole pine), their magnitude is expected to be high across all time periods.

Likelihood of effects: Because these trends are already occurring (e g., unprecedented bark beetle outbreaks in lodgepole pine), their likelihood is expected to be high across all time periods.

VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species
Activities where wildlife is a significant and necessary input into the recreation experience, such as hunting, fishing, and wildlife viewing (ecosystem service)

Broad-scale climate change effect
Changes in temperature and precipitation may affect suitable habitat for terrestrial and aquatic species due to changes in vegetation cover, productivity of food sources, water quantity and temperature (for aquatic species), and species interactions. Climate-related changes to disturbance regimes, including wildland fire, invasive species, and insect and disease outbreaks, may affect the amount and spatial distribution of suitable habitat.

Current condition, existing stressors
Encroaching development and habitat fragmentation

Sensitivity to climatic variability and change
Wildlife activities are sensitive to expected “catch rates,” i.e., the likelihood of catching or seeing an individual of the target species, and to the existence of highly valued target species. Hunting for terrestrial game species is sensitive to temperature during the allotted hunting season (i.e., colder temperatures preferred for dressing and pack-out of harvested animals) and the timing and amount of precipitation as snow (to reduce costs of tracking). Fishing catch rates are dependent on stream flows and temperatures to support target species. Increased water temperatures in main-stem rivers and streams limit site access due to closures.

Expected effects of climate change
Increased incidence of disturbances due to climate change is likely to be neutral or slightly beneficial for terrestrial game species populations and thus catch rates for targeted species. Potential decreases in overall vegetative productivity similarly likely have neutral effect on game species populations. Desirability of hunting during established seasons may decline as warmer weather persists later into the fall and early winter and the likelihood of snow cover decreases.

Higher temperatures will likely decrease populations of native cold-water fish species and favor increases in populations of warm-water species. Increased interannual variability in precipitation is expected to increase the incidence of low flows and stress fish populations.

Adaptive capacity
Hunting: Hunters may need to adapt by altering the timing and location of hunts; State rules on hunting season dates impose a constraint on this behavior unless states change hunting seasons based on expected climate changes.

Fishing: Anglers may adapt by choosing different species to target (e.g., shifting from cold-water to warm-water species) and choosing sites that are relatively less affected by climate change (e.g., higher-elevation secondary-stem reaches of streams). The former is less costly than the latter, although some anglers may place a high value on certain target species and have a lower willingness to target warm-water species that may thrive in place of cold-water species.

Risk Assessment
Magnitude of effects: Low (hunting, wildlife viewing); Moderate to high (fishing)
Likelihood of effects: Moderate (hunting, wildlife viewing); High (fishing)

VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species

Gathering forest products for recreational and personal uses, including foraging for food (e.g., huckleberries, mushrooms), gathering firewood, and cutting Christmas trees (ecosystem service)

Broad-scale climate change effect

Climate changes may alter species composition and vegetative cover for target species. Periods of drought may reduce productivity in the near term and reduce extent of target species in current locations in the medium to long term. Changes in disturbances (e.g., wildland fire, invasive species, insect and disease outbreaks) may place additional stress on target species and alter the availability of target species in current locations.

Current condition, existing stressors

Forest product gathering accounts for a relatively small portion of primary visit activities to Northern Rockies federal lands, although it is relatively more common as a secondary activity. A small but fervent population of enthusiasts for certain types of products supports a small-scale but steady demand for gathering as a recreational activity. Small-scale commercial gathering likely competes with recreationists for popular and high-valued products (e.g., huckleberries), although resource constraints may not be significant at current participation levels.

Sensitivity to climatic variability and change

Forest product gathering is primarily sensitive to the climatic and vegetative conditions that support the distribution and abundance of target species. Participation in forest product gathering is also akin to warm-weather recreation activities, depending on moderate temperatures for and the accessibility of sites where products are typically found.

Expected effects of climate change

Vegetative change due to warming temperatures and increased interannual variation in precipitation may alter the geographic distribution and productivity of target species. Increased incidence and severity of wildland fires may eliminate sources of forest products in some locations (e.g., berries), but in some cases fires may encourage short- or medium-term productivity for other products (e.g., mushrooms). Long-term changes in vegetation due to climate that reduces forest cover may reduce viability of forest product gathering in some areas with a high probability of vegetative transition to less productive vegetation types.

Adaptive capacity

Recreationists engaged in forest product gathering may select different gathering sites as the distribution and abundance of target species changes, although these sites may increase the costs of gathering. Those who engage in gathering as a secondary or tertiary activity may choose alternate activities to complement primary activities. Commercial products serve as an imperfect substitute for forest product gathering in some cases (e.g., Christmas trees).

Risk Assessment

Magnitude of effects: Low

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species

Participation in recreation activities that typically occur during warm weather, including hiking and walking on trails, viewing natural features, camping at developed sites, bicycling, and other non-motorized activities (ecosystem service)

Broad-scale climate change effect

Participation in these activities generally depends on the availability of snow- and ice-free sites, dry weather with non-extreme daytime temperatures, and the ability to select sites where air quality is not impaired by smoke.

Current condition, existing stressors

This broad category represents the most common recreation activities on federal lands in the Northern Rockies. Slightly more than one-third of all visits to Region 1 national forests involved one of these activities as the primary activity in which visitors participated.

Sensitivity to climatic variability and change

Sensitive to the length of appropriate season, depending on the timing of spring snow melt and availability of snow- and ice-free trails and sites, and the timing and number of days with temperatures within minimum and maximum comfortable range (which may vary with activity type and site).

Expected effects of climate change

Overall demand for warm-weather activities is expected to increase due to longer seasons. Climate change is expected to lengthen the expected season for warm-weather activities due to early availability of snow- and ice-free sites, and overall warming of spring and autumn months that increase the number warm-weather days. More common extreme summer temperatures can dampen participation during hottest weeks of the year, shift demand to cooler weeks at the beginning or end of warm-weather season, or shift demand to alternative sites that are less exposed to extreme temperatures (e.g., at higher elevations). Potential increases in likelihood of extreme wildfire activity may reduce demand for warm-weather activities in certain years due to impaired air quality from smoke or limited site access due to fire management activities.

Adaptive capacity

Adaptive capacity among recreationists is high due to the large number of potential alternative sites, ability to alter the timing of visits, and ability to alter capital investments (e.g., appropriate gear). However, some alternative sites may involve greater costs of access (due to remoteness or difficulty of terrain), and increased demand may place pressure on sites that currently have limited capacity. There may be some limits on ability to alter seasonality of visits due to the timing of scheduled academic breaks.

Risk Assessment

Magnitude of effects: Moderate

Likelihood of effects: High

VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species
Snow-based recreation activities that occur during winter, including downhill skiing, cross-country skiing, and snowmobiling (ecosystem service)

Broad-scale climate change effect
Availability of winter snow-based recreation depends on the timing and amount of precipitation as snow, and cold temperatures to support consistent snow coverage and snowmaking at developed (downhill skiing) sites.

Current condition, existing stressors
The Northern Rockies region has a large number of winter recreation sites that contain a wide range of site characteristics and attract local, national, and international visitors. Snow-based recreation is inherently sensitive to climatic variability and interannual weather patterns. For downhill ski areas, snowmaking ability can provide a buffer against low-snowfall years given water availability and appropriate temperatures.

Sensitivity to climatic variability and change
Snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation as snow.

Expected effects of climate change
Overall warming is expected to reduce expected season length and the likelihood of reliable winter recreation seasons. Some areas may become unsuitable for snow-based recreation due to warmer temperatures or increased likelihood of precipitation as rain. Higher elevation sites may not experience as large a transition to more precipitation as rain, but sites will see greater variability in season length. Warmer temperatures and increased precipitation as rain may increase availability of water in the near term during winter, but warmer temperatures may also reduce the number of days per season when snowmaking is viable.

Adaptive capacity
Snow-based recreationists have moderate capacity to adapt to changing conditions given the relatively large number of winter recreation sites in the region. For non-developed or minimally developed site activities (e.g., cross-country skiing, backcountry skiing, snowmobiling, snowshoeing), recreationists may seek higher elevation sites with higher likelihoods of viable seasons. Although developed downhill skiing sites are fixed improvements, potential adaptations include snowmaking, higher elevation development, and new run development. Changes to Northern Rockies sites relative to other regions may also be important; if other regions see greater relative effects of climate on snow-based recreation, recreationists may view Northern Rockies sites as a substitute for sites in other regions (e.g., the Southwest).

Risk Assessment
Magnitude of effects: High

Likelihood of effects: High

VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species
Water-based recreation activities that involve non-angling use of surface water bodies, including swimming, boating and floating on rivers, lakes, or reservoirs (ecosystem service)

Broad-scale climate change effect
Warming temperatures and increase in season length. Higher interannual variability in precipitation affects flows and water levels.

Current condition, existing stressors
Separate from angling, water-based activities comprise a small portion of primary recreation activity participation. Upper reaches of streams and rivers are generally not desirable for boating and floating. Lakes and reservoirs provide opportunities for both motorized and non-motorized boating and swimming, although boating may commonly be paired with fishing. Existing stressors include the occurrence of drought conditions that reduce water levels and site desirability in some years, and disturbances that can alter water quality (e.g., erosion events following wildland fires).

Sensitivity to climatic variability and change
The availability of suitable sites for non-angling water-based recreation is sensitive to reductions in water levels due to warming temperatures, increased variability in precipitation, and decreased precipitation as snow. Demand for water-based recreation is also sensitive to temperature increases as recreationists may increasingly seek out water-based activities during extreme heat and increase overall demand as the season lengthens.

Expected effects of climate change
Increasing temperatures, reduced storage of water as snowpack, and increased variability of precipitation are expected to increase the likelihood of reduced water levels and greater variation in water levels in lakes and reservoirs, which is associated with reduced site quality and suitability for certain activities. Increased demand for surface water by down-stream users may exacerbate water levels in drought years. Warmer temperatures are expected to increase the demand for water-based recreation as the viable season lengthens and people seek relief from extreme heat.

Adaptive capacity
Water-based recreationists may adapt to climate change by choosing different sites that are less susceptible to changes in water levels (e.g., by seeking out higher-elevation natural lakes) and changing the type of water-based recreation activity they engage in (e.g., from motorized boating on reservoirs to non-motorized boating on natural lakes).

Risk Assessment
Magnitude of effects: Low to moderate

Likelihood of effects: Moderate

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Introduction

Ecosystem Services are defined as the benefits that people obtain from ecosystems. A related project funded by the Region 1 Resource Information Management (RIM) Board set out to identify key and map-able ecosystem services throughout the region. Key ecosystem services were identified as those that are likely to affect a large number of people in the planning area and likely to be affected by the plan. Using the standard Millennium Ecosystem Assessment categories, the focus was on provisioning, regulating, and cultural ecosystem services. Supporting services were not considered because, while important, they are largely indirect services. The following key ecosystem services were identified in the RIM project and will be addressed in the NRAP report:

Provisioning services (services obtained from the natural environment)
1. Fresh water (quantity)
2. Building materials / wood products
3. Mining materials
4. Forage for livestock
5. Fuel (firewood, biofuels)
6. Viewsheds / air quality
7. Genetics / biodiversity (expanded to include terrestrial and aquatic habitats)

Regulating services (benefits received from the regulating forces of the natural world)
1. Water flow regulation and filtration (water quality)
2. Disturbance regulation (protection from wildfire, floods)
3. Erosion regulation
4. Carbon sequestration
5. Protecting and using cultural sites

Cultural services (nonmaterial benefits people derive from ecosystems)
1. Recreation
2. Scenery (currently listed as a provisioning service with viewsheds and air quality)
3. Exercising Native American treaty rights

Some of these ecosystem services (e.g., carbon sequestration and recreation) are addressed in previous pages. Others are addressed in the pages following. The remaining ecosystem services (e.g., forage for livestock and biodiversity) will be addressed in the final NRAP report after integrated assessment with other resource teams. However, please keep all of these ecosystem services in mind when developing adaptation strategies and tactics.

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Building materials/wood products

Broad-scale climate change effect
While temperature and precipitation may have some effect on regional vegetation, the direct impact to timber is likely to be small. More important to timber are the societal and policy changes that affect timber quotas for Northern Rockies forests. If climate significantly affects pest outbreaks or fire risk, there will be indirect impacts.

Current condition, existing stressors
Timber cut from the Northern Rockies is a provisioning ecosystem service, primarily by providing building materials for homes. Much of the timber is sent out of the region, so the most important aspect of timber in the region is its ability to provide jobs and the maintenance of a labor force capable of doing restoration work in the forests. Timber has seen large declines since the late 1980s. The region has been heavily impacted by forests pests (e.g., mountain pine beetle, Douglas-fir beetle, and white pine blister rust).

Sensitivity to climatic variability and change
The relationship between climate and pest outbreaks is still being studied. Larger fires will affect timber harvests, either by directly affecting the resource or by affecting access to the resource.

Expected effects of climate change
Increased fires may increase demand for fuels treatments, either through timber harvests or through mechanical and manual thinning that uses the same labor force and infrastructure. Increased incidence of pests and wildfire is likely.

Adaptive capacity
The regional timber industry continues to struggle, but the ability to increase or decrease capacity within the industry is there.

Risk Assessment
Magnitude of effects: Large from non-climate forces

Likelihood of effects: Likely from non-climate forces. It is unclear how climate will affect pest incidence.

Habitat, ecosystem function, or species
Cultural and heritage values (tribal belief systems, heritage tourism, culturally valuable sites)

Broad-scale climate change effect
Increased temperatures, drought, area burned, and flooding.

Current condition, existing stressors
People have inhabited the Northern Rockies region since the close of the last Pleistocene glacial period, some 14,000 years ago. Across the Northern Rockies, evidence of this distant and more recent human occupation is found throughout the incised river valleys and rugged mountains of north Idaho and western Montana; the Rocky Mountains and island mountain ranges of central Montana; and the pine-parklands and prairie grasslands of eastern Montana and western North and South Dakota. Each of these vast areas, and the national forests and grasslands they now encompass, have their own unique culture histories, representing thousands of years of human adaptations to widely variable and ever-changing environments.

The Northern Region is the ancestral homeland and aboriginal territory of the Arikara, Assiniboine, Bannock, Blackfeet, Chippewa-Cree, Coeur d'Alene, Crow, Hidatsa, Kiowa, Kutenai, Mandan, Nez Perce, Northern Cheyenne, Pend d 'Oreille, Salish, Shoshone, Sioux and other Plains, Intermountain, and Columbia Plateau American Indian tribes. Beginning in the 18th Century AD, the region was explored, then settled, by people of French, British, Irish, Scottish, Chinese, German, Scandinavian, Greek, Polish and other Old World ancestries. The region then, as today, was a diverse blend of cultural backgrounds, lifeways, and values.

The archaeological and historical evidence of these past cultural groups, interactions, and events --collectively called "cultural resources"—is extensive and varied across the Northern Rockies. This evidence comprises ancient Indian camps and villages, rock art, tool stone quarries, and travel routes; and historic military forts and battlefields, mining ruins, homesteads and ranches, logging trestles and splash dams; Civilian Conservation Corps-built recreation sites; and forest ranger stations and fire lookouts.

Cultural resources in the Northern Rockies are currently vulnerable to various natural and human agencies. Wildfire and biological processes tenaciously degrade and destroy cultural resources; particularly those either made of wood or located in erosion-prone or unstable environments. Vandalism, illegal artifact digging, arson and other depreciative human behaviors take a large toll on cultural resources. Changing population demographics and recreational use, especially in forest-urban interface and front-country settings, contribute to unauthorized cultural resource disturbance and damage. Numerous agency land management actions affect archaeological and historic sites and larger cultural landscapes each year. Cultural resource work is completed on every national forest and grassland to buffer, protect, and mitigate adverse effects to valuable cultural resources threatened by these numerous stressors, but the enormity of this task often outstrips agency resources and capacity.

Expected effects of climate change
Climate change has the potential to accelerate on-going effects to cultural resources. Warming temperatures are currently influencing the scale and severity of wildfires across the American West. Wildfire has a direct effect on cultural resources since they are broadly distributed throughout forest and grassland ecosystems. Sources of wildfire impacts are three-fold. First,

wildfires readily burn cultural resources made of wood and other combustible materials, such as ancient aboriginal pole and brush shelters and wood game drives, or historic homesteads, mining ruins, and administrative buildings. Emergency wildfire suppression tactics, including fire line construction with heavy equipment, also affect standing structures and archaeological sites buried in forest soils and duff. Finally, post-wildfire flooding and debris flows threaten cultural resources exposed on fire-charred landforms and soils.

Seasonal aridity and prolonged drought, which are expected to increase with climate change, accelerate soil deflation and erosion, and expose archaeological sites once buried in prairie or mountain soils. Wind and water roil across archaeological sites, blowing or washing away ground cover, revealing ancient artifacts and features such as cooking hearths and tool-making areas. This new ground exposure leaves artifacts highly vulnerable to artifact collecting and illegal digging. These effects are intensified in areas where livestock grazing, recreation, mining or other activity is focused and the ground is already impacted.

At the same time, a projected increase in winter precipitation, coupled with earlier and more intense spring run-off, poses another threat to cultural resources. In this context, archaeological and historic sites will be increasingly vulnerable to flooding, debris flows, down-cutting, and mass wasting of their underlying landforms. This scenario is now common in the aftermath of large-scale wildfires, especially in the dry mountains ranges of central and eastern Montana.

Perennial, high-elevation snow fields and ice patches contain ancient artifacts, the result of long-ago hunting and gathering excursions to mountain environments. Melting ice caused by climate change poses a risk to previously ice-encased and well-preserved cultural resources. For example, melting ice patches in the Beartooth Mountains of south-central Montana (Custer National Forest) have yielded ancient wood dart shafts and a rare, 1500-year old coiled basket. On one hand, melting ice patches provide unique research opportunities. On the other, the rapid rate of melting ice will preclude timely inspection of the numerous ice patches by archaeologists and newly exposed artifacts may be left to decay (or theft) without proper archaeological inspection, recording, or collection.

Cultural resources not only include places of specific archaeological, cultural or historic significance but also larger landscapes (which are typically designated as National Register of Historic Places “districts” on National Forest lands). The cultural and historical integrity of these landscapes is contingent on the component cultural resources and their surrounding environmental context. While individual species may respond differently to climate change, major shifts in vegetation regimes could potentially affect the physical and visual integrity of historic landscapes. For example, whitebark pine (*Pinus albicaulis*) is an important historical component of the Alice Creek-Lewis and Clark Pass Historic District on the Continental Divide near Helena. Whitebark pine is in danger of extinction due, in part, to climate change—warmer winter temperatures.

Cultural sites and landscapes are also recognized for their traditional and continuous relationship with descendant communities, including American Indian tribes (these places are called “traditional cultural properties” in historic preservation parlance). Some provide foods, medicinal and sacred plants, paints and other resources important to tribal peoples today. Other areas used for religious or ceremonial purposes are designated as tribal Sacred Sites under a federal executive order. Climate change effects to the environments of these specially-designated areas, particularly shifting, shrinking or disappearing vegetation resources, not only diminish the viability of these designations, but more importantly, the on-going historical and traditional use of these areas by local communities and indigenous peoples.

Adaptive capacity

Because this ecosystem service is largely about preserving the past, adaptive capacity is low.

Risk Assessment

Climate change effects on cultural resources are likely be highly variable across the Northern Rockies by the end of the 21st century. Based on current trends, wildfire poses a high risk to cultural resources. Wildfire is expected to broadly, though unevenly, affect hundreds, if not thousands, of cultural resources and cultural landscapes across the region. To some extent, wildfire effects can be mitigated through active prevention measures (for example, thinning trees around historic structures) and fire suppression and recovery tactics.

The prospect of prolonged aridity and drought caused by the projected decadal rise in global temperatures may be partly offset by increased winter precipitation across the Northern Rockies. Thus, it is difficult to quantify the long-term effects of drought, floods and extreme weather events on cultural resources over the century. In general terms, these natural processes—enhanced by climate change—are likely to pose a significant risk to cultural resources. Resource loss will be greatest in those areas prone to major hydrological events, such as at canyon mouths and along rivers and streams where both prehistoric and historic sites are typically concentrated. Experience has shown that cultural sites located in these areas are difficult to armor and protect in the face of significant flooding and debris flow events. Further, these areas are likely to be targeted by artifact collectors since newly exposed cultural materials are often strewn over a wide area in the aftermath of a hydrological event, thus invoking the need for active law enforcement.

Other potential climate change-related effects on cultural resources are more subtle and moderate. Shifting or changing vegetation regimes are likely to affect the visual integrity of some historic landscapes. Certain natural resources associated with traditional cultural landscapes, which continue to be used by tribal peoples today, may be diminished or entirely disappear. Conversely, in some settings, tribal-targeted plant resources such as huckleberry could be enhanced due to increased mountain moisture and warmer and prolonged seasonal temperatures.

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Erosion regulation

Broad-scale climate change effect
Increased rate of precipitation and changes in vegetation that may stabilize soils.

Current condition, existing stressors
General forest management practices are designed to limit erosion and soil impaction.

Soil loss has slowed on many agricultural lands because of changes in agricultural practices, but soil loss rates still exceed natural regeneration in much of the eastern part of the region. Expansion of agriculture often occurs on marginal land, where loss of soil is more likely.

Sensitivity to climatic variability and change
Erosion and landslides threaten infrastructure, water quality, and important cultural sites. Erosion may increase because of changes in precipitation patterns and runoff rates.

Expected effects of climate change
Increased flooding in the steep parts of the region will increase erosion. On the plains, where soil erosion occurs by weathering, including on farming and grazing lands, erosion will depend on changes in vegetation cover.

Adaptive capacity
Adaptive capacity is low for landslide erosion and relatively high for agricultural lands.

Risk Assessment
Magnitude of effects: Landslides and flooding have the potential for large sudden damages. Costs of soil erosion are high, but occur over long periods of time.

Likelihood of effects: Likely

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Fuel (firewood/biofuels)

Broad-scale climate change effect
While temperature and precipitation may have some effect on regional vegetation, the direct impact to firewood is likely to be small. If climate significantly affects pest outbreaks or fire risk, there will be indirect impacts to firewood. Biofuels grown as an agricultural product, particularly in the eastern plains part of the region, may be affected by changing temperatures and timing of water availability.

Current condition, existing stressors
Fuel is a provisioning ecosystem service. On the forests, firewood is the primary ecosystem service. The region has been heavily impacted by forests pests (mountain pine beetle, Douglas-fir beetle, and white pine blister rust). On the plains, biofuels from agriculture are the primary ecosystem service, and the eastern plains have seen some expansion of biofuels.

Sensitivity to climatic variability and change
The relationship between climate and pest outbreaks is still being studied. Larger fires will affect forests. Temperature and water availability will affect agricultural biofuels.

Expected effects of climate change
Increased incidence of pests and wildfire is likely. Earlier spring runoff may affect water availability for agricultural biofuels. On the other hand, climate policy may promote use of biofuels, benefiting the regional sector.

Adaptive capacity
Water storage may be possible, as well as increased efficiency of water use.

Risk Assessment
Magnitude of effects: Small for firewood, unclear for biofuels.

Likelihood of effects: Likely

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Mining materials

Broad-scale climate change effect
Climate is not likely to directly affect minerals. For several communities in the NRAP region, mineral development is an important economic driver. It is therefore included in this section for its role in adaptation in light of possible declines in other resources, as well as its potential to conflict with other ecosystem services.

Current condition, existing stressors
Oil and gas development is a provisioning ecosystem service, but its primary role in the region is as an economic driver – providing jobs and incomes. Mineral development is important throughout the region, but particularly so in the eastern part of the region. In some counties, oil and gas development represents 20 percent of total income to residents.

Sensitivity to climatic variability and change
Mineral development is not sensitive to climate change, which makes it all the more important if other economic drivers are impacted.

Expected effects of climate change
Loss of jobs in other sectors will mean jobs in minerals are more important. Non-climate drivers (national policy, prices) will be more important.

Adaptive capacity
High

Risk Assessment
Magnitude of effects: Large from non-climate forces

Likelihood of effects: Likely from non-climate forces.

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Viewsheds/clean air

Broad-scale climate change effect
Warmer summers and reduced rainfall affect fire season length. Climate change may also increase summertime organic aerosol concentration and elemental carbon.

Current condition, existing stressors
Many people like the majestic views and the clean air in the region. Limited development keeps air quality and viewsheds high. Air quality can be affected by wildfires and agricultural burning in the region. Agricultural burning is regulated, and these regulations are likely to get stricter in the future. There are currently no large cities nor are there likely to be large cities in the region that will significantly affect air quality.

Sensitivity to climatic variability and change
Air quality can decline rapidly during a fire.

Expected effects of climate change
Warmer summers and reduced rainfall increase the length of the fire season. Climate change may also increase summertime organic aerosol concentration over the western US by 40% and elemental carbon by 20% from 2000 to 2050. Smoke from fires can settle into the valleys and canyons, affecting people that live there. Health impacts can be significant.

Adaptive capacity
Use of air conditioning could increase, but otherwise, adaptive capacity is somewhat limited.

Risk Assessment
Magnitude of effects: High

Likelihood of effects: Likely

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Water quality

Broad-scale climate change effect
Water quality is likely to be affected in a number of ways by climate change. Increased number and severity of fires will deposit more sediment into the streams, lakes, and reservoirs. Increased atmospheric temperatures and loss of vegetation along the stream banks will raise the temperature of the streams. Change in vegetation may affect the landscape's ability to filter water and change the rate of flow.

Current condition, existing stressors
Many of the region's streams are already temperature impaired, and possibly sediment and nutrient impaired. Water that originates in the mountains is of high quality, and the municipal users benefit from this.

Sensitivity to climatic variability and change
Water quality is highly sensitive to variability and change, as it connects the entire landscape. Major habitats in the riparian system are likely to be affected by increased sediment and temperatures. Municipal treatment systems are designed for the high water quality typical in the region. Treatment plants and recreational users will be affected by increased sediment due to large disturbances like fire and flooding.

Expected effects of climate change
Increased stream temperatures will lead to loss of fish habitat. Increased sediment will lead to increased treatment costs. Increased frequency and severity of disturbances will lead to increased treatment costs. Increased rain rather than snow may increase runoff from agricultural fields and add pesticides and fertilizers to streams.

Adaptive capacity
Restoration along streams may stabilize temperatures. Investments in water treatment infrastructure will be needed if sediment increases substantially, or if large disturbances become more frequent.

Risk Assessment
Magnitude of effects: Large

Likelihood of effects: Likely

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Water quantity

Broad-scale climate change effect
Earlier streamflow center of timing is expected over much of the region and summer low flows are expected to be lower. Total water yields may decrease due to increased evapotranspiration, but precipitation amounts are uncertain. Changes in temperature and population growth will place slightly higher demands on water.

Current condition, existing stressors
The benefits of fresh water accrue to: in-stream use for recreational boaters, in-stream use for hydropower production, out-of-stream use for domestic and municipal consumption, out-of-stream use for agricultural production, out-of-stream use of water for industrial production, and tribal use of water under treaty rights. Decreased snowpack is already being observed in the region, most likely due to earlier than usual spring runoff. In the western part of the region, "New West" growth is increasing water demand for urban uses, though not significantly so. The new type of growth is also increasing the value of in-stream uses, with a change from working landscapes to leisure landscapes. Many of the region's river basins are over-appropriated and temporarily closed to new claims.

Sensitivity to climatic variability and change
A warming climate will change the form of precipitation from snow to rain, which will affect the timing of water availability.

Expected effects of climate change
Earlier runoff may not align with water demands, particularly in agriculture. Climate change is also expected to slightly increase demand for water for agriculture, power generation, and municipal uses.

Adaptive capacity
Storage may be a possible solution for matching the timing of water supply with water demand, though with possible impacts to other ecosystem services. Long-term projections of water demand for agricultural use would be needed to assess that sector's need for water. Increases in water efficiency are possible in the long run. Increased use of ground water and recycled water is also possible.

Risk Assessment
Magnitude of effects: Compared to the rest of the county, changes in water yield will be modest, though they will be large to locals who experience them (see RPA Assessment and Linda Joyce's detailed R1 work). Changes in timing of runoff will be significant.

Likelihood of effects: The likelihood of these effects is high.