



CalVeg types included:

**PPN**-Ponderosa Pin, Jeffrey pine, Douglas fir; **JPN**-Jeffrey pine, ponderosa pine, sugar pine; **EPN**-Ponderosa pine, Jeffrey pine, white fir; **SMC**-Douglas fir, ponderosa pine, white fir; **DFR**-Douglas fir, tanoak, ponderosa pine; **WFR**-White fir, Douglas fir, sugar pine;

## Sensitivity Assessment

### 1. Direct sensitivities to changes in temperature and precipitation

- Temperature
  - Means and extremes
    - Historical
      - In Yosemite National Park, from 1941-2002 at elevations from 1300 to 2000 m, mean monthly temperature ranged from 2°C in January to 18°C in July (Scholl and Taylor, 2010). Mean annual temperatures across California have increased by 1-2.5°F over the last century with the predominance of the warming signal occurring during nighttime (Hayhoe et al., 2004).
    - Future
      - Over the next century, average temperatures are expected to increase by 2-4°F in winter and 4-8°F in the summer. Models indicate that there may be less warming along the southwest coast but more warming to the north and northeast (Hayhoe et al., 2004). In a 2011 paper by Das et al., the Northern and Southern parts of the western slope of the Sierra Nevada with an average elevation of 1360 m were modeled; temperatures were forecasted to increase between 0.5°C and 1°C by 2049; 2°C and 3°C by 2099. Patterns across the north and south were roughly uniform.
  - System's sensitivity, composition and response to temperature
    - Four, downscaled climate models were applied to the Blodgett Forest in El Dorado county. All the models predicted a reduced conifer growth rate in the coming century due to increased summer temperatures. Depending on emissions scenarios, stem volume increment decreases ranged from 5% to 25% (Battles et al., 2008).
- Precipitation
  - Means and extremes
    - Historical
      - In Yosemite National Park, from 1941-2002 at elevations from 1300 to 200 m, annual mean precipitation was 109.1 cm with 86% of it falling between November to April as snow (Scholl and Taylor, 2010). In the North, mean annual precipitation is 160 cm;



78% falls between November and March, 25% as snow (Battles et al, 2008). In general, precipitation in the Sierra Nevada has increased over the past century although a higher proportion is falling in the form of rain rather than snow (Hayhoe et al, 2004).

- Future
  - It is unclear how precipitation will change in the future. Das et al. (2011) used models to explore changes in the Northern and Southern parts of the western slope of the Sierra Nevada with an average elevation of 1360 m and found that some models predicted overall drying while others projected a 10% increase in precipitation by 2049. By 2099, precipitation patterns ranged from near historical normal to an 8% reduction. Patterns across the north and south were roughly uniform.
- System's sensitivity, composition and response to precipitation
  - The establishment of Jeffrey pine, sugar pine, and red fir are significantly associated with El Nino events, which cause wetter and warmer average conditions and a deep snowpack in the winter (North et al., 2005).

## 2. Sensitivity of component species

- Dominant species
  - Conifer tree growth in the mixed forest has been shown to decline with decreases in winter precipitation and increases in summer temperature. Summer temperature and winter precipitation explained 67% of the observed growth variations in sugar pine and ponderosa; 74% in white fir, Douglas fir, and incense cedar. Of four variables tested, tree growth was most sensitive to summer temperature (Yeh and Wensel, 2000).
  - Trees have varying sensitivities to climate change. Based upon forecasting models, tree growth in the mixed forest will be most reduced in white fir, incense cedar and Douglas fir relative to ponderosa pine and sugar pine. No projected climate scenarios and mortality models produced dramatic increases in white fir mortality (Battles et al., 2008)
- Ecosystem engineers
- Keystone species

## 3. Sensitivity to changes in disturbance regimes

- Wildfire
  - Historically, fire activity was correlated with positive phases of the Pacific North America Pattern (PNA) and during warm periods (Taylor, 2011). Since the 1980s, the Sierra Nevada has experienced an increase in large fires (>1,000 ac). This increase is correlated to increasing temperatures and earlier snowmelt (Westerling 2006). Fire severity has also risen from 1984-2007, especially in the middle elevation conifer forests. In 1984, fires burned an average of 17% high



(stand replacing) severity but in 1997-2007 the average was 30% (Miller, 2009). Fire frequency is usually higher on south-facing relative to north-facing slopes (Taylor, 2000); and at mid to upper slope positions due to higher winds, lower canopy cover, and fuel characteristics relative to lower slope (Rothermel 1983). Models suggest that the increase in fuel and temperature (to dry the fuel out) may increase both the severity and frequency of fire. This could cause vegetation conversion and a corresponding decrease in old growth forest (Lenihan 2008). Strong fires promote shrubs and seedlings but can limit the survival of small trees. To reduce catastrophic fire, retain a mixture of species and ages in the mixed-conifer forest or reduce tree stand densities to reduce fuel loads (Battle, 2008).

- In Yosemite mixed conifer forests, there was no spatial trend in fire frequency; it was not correlated between warmer drier sites vs. cooler moister sites, long-needled pines vs. short-needled pines, nor elevation or slope aspect (Scholl et al., 2010).
- Sugar pine establishes itself 1-4 years after a fire and prefers to do so in wet years. White fir and incense cedar recruit into burned areas 13 years after the fire. Fire in California is more probable during La Nina years which can cause drought and drier than average conditions (North, 2005).
- Disease
  - Pine pitch canker could expand from the coastal areas into the middle elevation Sierra Nevada due to milder winter minimum temperatures.
  - Heterobasidion root disease infests about 1.4 million acres of ponderosa pine and Jeffrey pines and 600,000 acres of true fir. It decays wood at the base and in the roots of trees (Living Assessment, 2013)
  - Dwarf mistletoe is widespread in the Sierra Nevada and can cause growth loss and reduction. Commonly it weakens the tree enough to allow a bark beetle infestation, leading to death. (Living Assessment, 2013). The interaction of dwarf mistletoe and bark beetles are responsible for 40-60% of the pine mortality in southern California.
  - White pine blister rust attacks sugar pine in northern California.
- Flooding
  - Under most climate scenarios, runoff and potential flooding in the winter and early spring is expected to be higher than historical norms due to earlier snowmelt coupled with enhanced rainfall. The higher elevation the river, the more flood prone it will be due to its greater reliance on snowmelt (Miller, 2003).
  - In a 2011 (Das) study, the Northern and Southern parts of the western slope of the Sierra Nevada with an average elevation of 1360 m were modeled to assess future flood regimes. Flood frequency is expected to increase. This increase may be caused by an increase in the size of storms, increase in storm frequency and due to wetter, more water logged soils, as a result of increased precipitation falling as rain rather than snow; this reduces the ability of the surface soils to absorb rainfall.



- Insects
  - A 2006 model estimated 1.4 million acres were susceptible to high levels of mortality due to insects and disease, where susceptible is defined as the expectation that 25% or more of the standing tree volume would die over the next 15 years. Lodgepole and ponderosa pine are attacked by the mountain pine beetle; the western pine beetle attacks ponderosa pine; and, the Jeffrey pine beetle attacks Jeffrey pine. In the past five years, over 1.3 million acres of forested land in the Sierra Nevada have experienced some tree mortality due to bark beetles. Conifers tend to be more stressed and hence, more vulnerable to insect infestation, when annual precipitation is less than 80% of normal (Living Assessment, 2013).
  - A diverse forest may limit the spread of pathogens and insects.
- Wind
  - In Yosemite, from 1948 to 2005, westerly winds have weakened, causing cooler temperatures on the east slope. This trend may explain the increased warming trend on west slopes relative to east slopes and why spring melt occurs earlier on west slopes (Lundquist, 2007).
- Drought
  - There is evidence that severe, long-term droughts occurred for roughly 200 years prior to 1100 A.D. and again for 150 years around 1350 A.D. Lake levels in the middle and high elevations fell as much as 70 ft. below modern day levels, riverbeds dried, and marshes desiccated. Trees could be found growing at sites that today, are too wet to support woody growth (Stine, 2002).
  - Old-growth forests, in middle elevation forests (3,300-6,700 ft) have experienced higher mortality rates relative to higher elevation forests (>6,700 ft); mortality patterns were correlated to regional warming and drought (Van Mantgem, 2009)

#### 4. Sensitivity to other types of climate and climate-driven changes

- Altered hydrology
  - Over the past 50 years, spring snowpack in the Sierra Nevada has decreased by 70-120% although there is a high degree of spatial heterogeneity; snowpack in the southern portion of the Sierra Nevada has increased. The reduction in snowpack will likely be greater at lower elevations in northern Sierra than in the higher elevations in the southern Sierra. Annual snowpack in the Sierra Nevada could decrease by 20-90% due to future climate change (Safford, 2010).
  - Earlier timing of snowmelt will cause earlier peak runoff and reduce spring and summer streamflow. By 2099, as much as 5.6 km<sup>3</sup> volume of water could enter streams before April 1 relative to historic norms; this is a 20% change in historic annual flow volume (Knowles, 2004). Timing of peak streamflow is expected to occur earlier due to warmer temperatures melting snow earlier however, total annual volume of streamflow is not expected to change as much.
- Altered fire regimes
  - A fire exclusion policy was instated in the beginning of the early 20<sup>th</sup> century. Reduced fire frequency increased forest density and shifted the forest



composition to less fire tolerant species and more shade tolerant species. In general, historical fire suppression has promoted more shade tolerant species to occupy the dense understory of the forest canopy at the expense of species like Jeffrey pine and western white pine (Bouldin, 1999). Prior to European fire management, large scale fires coincided during periods with a summer drought and large-scale sources of variability like La Nina. The absence of fire has allowed fuel loads to build on forest floors and tree densities to increase (Taylor, 2011).

- In Yosemite, fire suppression has reduced fire frequency from every ten years to every 378 years. This has caused tree densities to increase. In the early 1900s, Yosemite had an average of 160 trees/ha composed mostly of pine and oak; in 2003 there were threefold more trees that were on average 20% smaller, ¼ of which were pine and oak with a ten-fold increase in white fir (Scholl, 2010). In the 1970s, both Yosemite and Sequoia National Parks began to allow managed wildfire on some of their lands.
- Evapotranspiration and soil moisture
  - Higher summer temperatures could increase evapotranspiration rates and decrease the amount of moisture stored in the soils. This could cause a shorter growing season due to lack of moisture.
- Extreme precipitation and temperature
  - In general, most models predict that the frequency of extreme precipitation will increase. Estimates range from an increase of 11-40% by 2049 and 18-55% by 2099 (Das, 2011).
- Water temperature
  - Along the entire western slope of the Sierra Nevada at elevations ranging from 1500-2500 m, climate warming is projected to warm stream temperatures approximately 1.6 °C for every 2 °C rise in average annual air temperature. Stream temperatures warmed the most during spring. Between wet and dry years, stream temperatures reach similar maxima but, warm water conditions (greater than 18 °C) persisted for 1-2 months during wet years and increased to 3-4 months during dry years. Streams in the central to north portion of the Sierra Nevada appear to be more susceptible to increases in the average annual number of weeks stream temperatures exceed 21 °C; the watersheds of the southern Sierra Nevada appear to be less vulnerable to changes in thermal regimes (Null, 2012).
- Storm frequency and intensity

## 5. Sensitivity to impacts of other non-climate-related threats

- Residential and commercial development
- Agriculture and aquaculture
  - Historical livestock grazing occurred throughout the mixed conifer forest.
- Energy production and mining
  - The gold rush began in 1849 and saw an influx of miners in to the Sierra Nevada region. Hydraulic mining altered stream channels, caused erosion, and began



timber harvest for supplies. Roughly 680 million cubic yards of hydraulic waste was washed into California rivers.

- Transportation and service corridors
- Biological resource use
  - From 1860-1950, extensive logging of the ponderosa pine and sugar pine occurred.
  - Historical logging partially explains the loss of yellow pine-dominated forest, an increase in the forest dominated by shade tolerant species, and a loss of blue oak woodland (Safford, 2010).
- Altered interspecific interactions
- Human intrusions and disturbance
- Natural system modification
- Invasive and other problem species
  - In general, due to the relative isolation of higher elevation forests, there is not a high proportion of invasive species.
- Pollution and poisons
  - Excess nitrogen and ozone cause physiological disturbances to trees in highly polluted areas such as stands in the San Bernadino Mountains. Air pollution effects in the Sierra Nevada appear to be reduced but ozone injury has been seen in the southern and western edge (Fenn 2003). However, another study found that nitrogen critical load from Tahoe south to Sequoia had nitrogen loads that could cause impaired function. Nitrogen loads can cause increased invasive species, altered lichen communities and altered lake chemistry (Living Assessment, 2013).
- Geological events

## 6. Other Sensitivities

- Management

## Adaptive Capacity

### 1. Extent and Characteristics

- Geographic extent in California
  - The mixed conifer forest generally occupies elevations ranging from 1300-1800 m. The mixed conifer forest covers an estimated 10% of the vegetated area in the Sierra Nevada and is the dominate community in the lower montane zone. As of 1998, less than 15% of the mixed conifer forest had old-growth tree stands; most of the remaining stands are found in parks in the southern Sierra Nevada (Ansley, 1998).
  - It has been projected that woody forests could migrate to higher elevations as warmer temperatures make these areas more habitable. Forests may expand to



the north and to higher elevations if the future is warmer and wetter. A deciduous forest was predicted to replace the conifer dominated forest at low and middle elevations. A drier future may present an increase in grasslands and shrublands in areas historically habited by mixed conifer forest (Lenihan, 2008).

## 2. Landscape Permeability

- Barriers to dispersal or fragmentation

## 3. System Diversity

- Diversity of component species
  - Warmer, drier sites are preferred by ponderosa pine and black oak; white fir is commonly found on cool, mesic north-facing slopes (Scholl et al., 2010).
  - White fir, incense cedar, and sugar pine occur in mid-slope areas. Jeffrey pine is found in shallow soils on ridgetops; the bedrock fissure water-holding capacity in the shallow soils may afford the Jeffrey pine some protection from annual climate variation. White fir growth most closely follows trends in climate. (Hurteau 2007)
  - “Pollen of white and red fir (*Abies concolor* and *A. magnifica*) and mountain hemlock suggests that during the early Holocene these species were only minor components of the Sierra Nevada forests. However, by approximately 6,000 years ago, each of these species increased in abundance, perhaps largely in response to changing climate and higher soil moisture levels (Anderson and Smith1994). Because each of the tree species that increased during the late Holocene depends upon readily available soil moisture during the summer growing season, it has been suggested elsewhere (Anderson 1990) that either a reduction in the length of the summer dry season, an increase in precipitation during the winter months (as snow, lasting longer into the spring), a reduction in temperature causing reduced evaporation, or some combination of these processes would have favored the above-mentioned conifers.” (Anderson, 2002)
- Community Structure
  - Forests that experience periodic, low intensity disturbance such as wind throw or low intensity fire, may be more able to recover from climate related stresses such as drought, fire and insects. Structural heterogeneity fosters resilience.
  - Medium and large size tree populations tend to be more strongly influenced by topography; mesic sites support greater tree densities and more fire-intolerant species while ridges provide the lowest productivity. Topography can be a strong influence on tree density and species composition (Lydersen, 2011).

## Exposure

The biggest predicted change in the forested landscape in the 21<sup>st</sup> century is the reduction of



conifer-dominated forest area, which is forecast to be replaced by mixed woodland and hardwood-dominated forests (Purcell et al. 2012). In the Sierra Nevada, the sierra mixed conifer/white fir/ Jeffrey pine vegetation type is projected to decrease (by 12 to 32%), while increases to 2070 are projected for blue oak/foothill pine, and ponderosa pine/Klamath mixed conifer (Gardali et al. 2011). In contrast, results from Notaro et al.'s (2012) model indicate that potential range of white fir in the southwest US will increase. In the western Sierra Nevada, white fir is often growing in clusters of trees, topographically in mid-slope stands, and is a strong shade-tolerant competitor, which may be allowing it to capitalize on available moisture, resulting in increased responsiveness to inter-annual fluctuations in precipitation (Hurteau et al. 2007). However, according to Safford et al. (2012), both the loss of yellow pine-dominated forest and the increase in the area of forest dominated by shade-tolerant conifers, especially fir species (*Abies spp.*) seem to be a product of management choices rather than climate change.

In western North America, the simulated patterns of change in potential ranges often have large distances occurring between a species' current distribution and simulated areas of future potential habitat, for example for Douglas fir (Shafer et al. 2001). Under future climate scenarios Douglas fir in the northern Sierras is projected to move from the west to the east of the mountains (Shafer et al. 2001). Comparisons of Forest Service vegetation inventories and maps show changes in the distribution of many Sierra Nevada vegetation types during the 80 years following the 1930s (Safford et al 2012). However, according to Safford et al. (2012), both the loss of yellow pine-dominated forest and the increase in the area of forest dominated by shade-tolerant conifers, especially fir species (*Abies spp.*) seem to be a product of management choices rather than climate change.

Species range modeling based on IPCC scenarios suggest that climate will be sufficiently different in Washington by 2060s to put Douglas fir at increasing risk (Littell et al. 2010).

Annual diameter increment for white fir and sugar pine is positively correlated to winter precipitation in the western slope of the southern Sierra Nevada (York et al. 2010). Between 1930s and 1990s, large diameter tree density in Yosemite National Park declined 24%. Jeffrey pine, sugar pine and ponderosa pine experienced disproportionately larger decreases in large-diameter tree densities in lower-elevation portions of their range (Lutz et al. 2009). Battles et al. (2008) evaluated the impacts of climate change on the productivity and health of a forest in the mixed-conifer region in California. Conifer tree growth declined under all climate scenarios and management regimes (Battles et al. 2008). Under the most extreme climate changes, modeled productivity, as measured by stem volume increment in mature stands, decreased by 19% by 2100 (Battles et al. 2008). The reductions in growth under each scenario also resulted in moderate increases in susceptibility to non-catastrophic (i.e., non fire) causes of mortality in white fir (*Abies concolor*).

Alternatively, Coops et al. (2011) suggest that drought-adapted Northwest species such as ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) may find the reduced frost and potentially longer growing season associated with climatic warming advantageous. On the other hand, St. Clair and Howe (2007) suggest that increased temperatures throughout the fall, winter and spring may extend the growing season in a way that lowers the fitness of current populations. At the genetic level, a tradeoff exists between





adaptation to cold and annual growth. If natural selection of genetic traits occurs in response to rare, extreme events, which may occur in mature stands, the ecological consequences are likely to be more severe (St. Clair and Howe 2007). According to their analysis, gene flow among climatically diverse populations of coastal Douglas fir (*Pseudotsuga menziesii*) would need to occur across very large differences in elevation (450-1130m) or latitude (1.8-4.91) to contribute alleles from populations that are well adapted to future climates (St. Clair and Howe 2007).

Temperature and water are currently limiting Douglas fir in western Oregon and for the interior variety (Chen et al. 2010, Beedlow et al. 2013). Daily maximum temperature optimum for Douglas fir in western Oregon decreased with plant available soil water at drier sites (Beedlow et al. 2013), suggesting that vulnerability to hotter summers predicted by climate change models, particularly on Douglas fir at drier sites could become increasingly limiting (Beedlow et al. 2013). While climate change impacts on Douglas fir productivity could be negative over much of its range, climatic growth limitations may be unique in high elevation Douglas fir populations in British Columbia, resulting in increased productivity in these environments (Griesbauer and Green 2010). At high elevation margins of its range, Douglas fir growth appears to be more limited by annual and winter temperatures and snowfall, and future warmer temperatures, less snow accumulation, and earlier snowmelt may increase Douglas fir productivity in these environments (Griesbauer and Green 2010). Modeled responses of more southern and outlying populations responded less negatively to drought conditions, which indicates genetic adaptation to local climate (Chen et al. 2010). Projection of growth under 18 climate change scenarios suggest the populations of the inland variety of Douglas fir with greatest vulnerability at higher latitudes and elevations (Chen et al. 2010). For the coastal variety of Douglas fir, Chen et al. (2010) found no consistent positive or negative impacts of climate change impacts on the observed chronology samples, suggesting that impacts are likely to be overall neutral for the coastal Douglas fir variety and interior populations of the 'inland rain forest' ecosystem (Chen et al. 2010).

White fir exhibited the greatest variability in key ecophysiological traits, as well as dynamic stomatal responses to changes in both needle xylem water potential and leaf to air vapor pressure deficit, across a large latitudinal gradient. Documentation of uphill redistribution of white fir in the Peninsular Range of southern California supports the capacity of this species to respond to environmental change (Grulke 2010). In contrast, Jeffrey pine exhibits high susceptibility to drought despite its significant variability in key physiological traits, as well as high needle elongation growth at the margins of its latitudinal and elevational limits (Grulke 2010).

### Fire

In the Southwest, the largest fires in ponderosa pine forests were associated with current-year drought after several years of above average precipitation, suggesting that higher average precipitation may actually increase the number of large fires (Strom and Fule 2007). This effect of climate change on fire regimes may indirectly hasten vegetation shifts more than the direct effects of climate change itself on vegetation. In contrast, in mixed conifer forests of Yosemite National Park, mortality was related to multiyear episodes of high spring and summer



temperatures and low annual and seasonal precipitation, whose effects have been most extensive for pinyon pine and ponderosa pine forests in the southwestern US (Millar et al. 2012).

In a study by Miller et al. (2009), forest types among the most affected by increasing fire severity in the Sierra Nevada and southern Cascade mountains were those which form the majority of the National Forest land-base, and those that support most of the remaining habitat for a suite of old forest obligate carnivores and raptors. Additionally, burn areas offer sites for invasive species such as cheatgrass (*Bromus tectorum*) to colonize, and increased fire size and frequency may decrease the habitat available to late successional species. Old ponderosa pine forests, already rare, may become further imperiled (Strom and Fule 2007). In the southwestern US, undisturbed stands of ponderosa pine are carbon sinks, and stands recovering from wildfires may be sources of carbon to the atmosphere for decades after the fire (Dore et al. 2008). Keeling and Sala (2012) suggest that even without increases in fire activity across the mountain west, winter drought and low soil moisture recharge may put physiological stress on trees that could increase damage to trees from fires or reduce resilience to the effects of fire.

In three climatically distinct conifer forest types in Oregon, fuel treatments were effective in reducing combustion in wildfire. However, even in the mature, fire suppressed ponderosa pine forest, protecting one unit of carbon from wildfire combustion came at the cost of removing three units of carbon in treatment. Conventional fuel-reduction treatments that remove fine canopy fuels (i.e. leaves and twigs) usually remove more carbon from a forest stand than would a wildfire burning in an untreated stand (Campbell et al. 2012).

In the Lake Tahoe Basin, the 115-year fire free period prior to 2008, the greatest compositional changes occurred in pine-dominated stands in valley bottoms and on south aspects, shifting species away from fire tolerant species such as Jeffrey pine and sugar pine to an increase of fire intolerant white fir (Beaty and Taylor 2008).

Pre-fire suppression conditions in California old-growth mixed-conifer stands were low density, with a large proportion of large-diameter shade intolerant and fire-tolerant pines and oak. At the time of fire-regime disruption, Yosemite National Park mixed-conifer forests had on average 160 trees/ha with a mean size .52 cm dbh and a mean basal area of 29.2 m<sup>2</sup>/ha. In 2003, after more than 100 years of fire suppression, threefold more trees were present, twofold more basal area, and the mean size of a tree was 20% smaller. There was also a strong shift in forest composition; only a quarter of the trees in 2003 were pine or oak and there was a nearly 10-fold increase in the density of white fir (Scholl and Taylor 2010).

### Pests

Losses attributed to armillaria root disease (*Armillaria solidipes*) are greatest in relatively dry Mediterranean or continental climates (Sturrock et al. 2011). The incidence of armillaria root disease is likely to increase as temperatures increase and precipitation decreases, causing Douglas fir, a major host in the interior northwestern US, to become more vulnerable (Klopfenstein et al. 2009, Chmura et al. 2011, Sturrock et al. 2011). Greater stand densities, as a



result of fire suppression and climate change, may also increase mortality from armillaria root disease in northwestern US (Chmura et al. 2011).

### **Ponderosa pine** (*Pinus ponderosa*)

Ponderosa pine, one of the two most abundant species in the southwestern US, is projected to decline on average by 47% in response to climate warming (Notaro et al. 2012). Ponderosa pine growth is strongly limited by summer soil moisture in drier eastside Cascade and westside Rockies locations (Fagre et al. 2003), and earlier springtime drying of soils could result in reduced or delayed germination and increased seed mortality (Puhlick et al. 2012). In addition, changes in fire regimes may threaten old ponderosa pine forests, already rare (Strom and Fule 2007).

However, simulations run by Tingley et al. (2001) suggest that increasing CO<sub>2</sub> will increase ponderosa pine growth in the western US, even if there is seasonal drought. A regional model for the southwestern US indicated that ponderosa pine seedling densities were highest where average minimum May temperatures were highest (Puhlick et al 2012). Warmer temperatures predicted by climate models may promote seedling germination earlier in the season and result in longer growth periods for shoot and root development, reducing the susceptibility of young seedlings to frost heaving and drought conditions (Puhlick et al 2012). In addition, increased atmospheric CO<sub>2</sub> may offset the negative impact of current and increasing tropospheric O<sub>3</sub> on tree growth. Sites with mesic conditions have inherently high O<sub>3</sub> sensitivity (Tingley et al. 2001).

Nevertheless, ponderosa pine has experienced increased mortality at its southern limit in the Peninsular Range in California, due to syncopated stressors, drought and outbreaks of mountain pine beetle (*Dendroctonus ponderosae*) and western pine beetle (*Dendroctonus brevicomis*) at the western end of the San Bernadino Mountains (Grukke 2010).

Climate change was likely at least partially responsible for the changes in ponderosa pine forest between 1934 and 1996 in the Sierra Nevada (Placerville quadrangle) (Moser et al. 2009). The western edge of the forest moved an average of 7.1km eastward and shifted upward about 193 meters, with the previously ponderosa-dominated areas being replaced by non-conifer species (e.g., oaks) (Moser et al. 2009).

### **Jeffrey pine** (*Pinus jeffreyi*)

The primary actor limiting lower elevation establishment of Jeffrey pine appears to be available soil moisture in eastern California. Projected earlier snowmelt and runoff, and longer drier, summers in the Sierra Nevada may lead to low seedling survival, the contraction of the regional distribution of Jeffrey pine, and an upslope migration of the forest-shrubland (Alpert and Loik 2013). However, a study by Hubbert et al. (2001) suggests Jeffrey pine in the Sierra Nevada might be buffered from variation in annual precipitation abundance, because its roots can access deep water reservoirs.

**Sugar pine (*Pinus lambertiana*)**

Sugar pine populations are likely vulnerable to climate changes due to the apparent low variability of key traits. Of the four pine species (sugar pine, white fir, ponderosa pine and Jeffrey pine) studied in the western US, sugar pine had the least variability in physiological traits, and the lowest gross photosynthetic rate and percentage foliar nitrogen of young needle age-classes, especially at San Jacinto State Park and Sequoia National Park (Grulke 2010). This limited variability may be due to selective pressure by pine blister rust experienced in California during the mid 1970s to 1980s.

**Giant sequoia groves (*Sequoiadendron giganteum*)**

A significant and positive correlation between winter precipitation and diameter growth was documented for all subsets of giant sequoia, regardless of canopy status or location (gap adjacent or reference). Conversely, no correlation was found between growth and summer temperature (York et al. 2010). Extreme positive growth anomaly years in mid-elevation giant sequoias in the central and southern Sierra Nevada are characterized by wet winters with temperatures near the mean and average or somewhat cool summers, while negative growth anomaly years are characterized by warm dry winters and somewhat warm summers (Garfin 1998). Soil moisture is a primary factor in the restriction of grove boundaries to their present locations (York et al 2010), and future climate scenarios forecast increased water deficit for giant sequoia (Lutz et al. 2010).

Animals

Specialist species in terms of habitat and diet on the Olympic peninsula in Washington, such as northern spotted owl, American marten, and northern flying squirrel, were ranked highly sensitive to climate change (Halofsky et al. 2011).

**Pacific fisher (*Martes pennanti*)**

Because oaks, especially California black oaks are a key component of fisher habitat in Sierra Nevada, predicted shifts of conifer dominated forest types to mixed woodland and hardwood forest types may benefit fishers (Purcell et al. 2012). However, martens and fishers will be highly sensitive to climate change, and will likely experience the largest climate impacts at the southernmost Sierra Nevada (Purcell et al. 2012). A study found that macroclimate conditions closely correlated with Pacific fisher presence in California. Climate conditions are likely to change greatly over the next century, resulting in a possibly pronounced loss of suitable habitat for fishers. The fisher is associated with dense forest cover in both the Klamath/Shasta region and southern Sierra Nevada (Davis et al. 2007), and is associated with areas of low or intermediate snowfall in which topographic breaks change snowfall amounts over small areas (Krohn et al. 1997). As these factors are closely related to fisher rest site and home range use in



the southern Sierra Nevada, the expectation is for an overall decrease in the availability of fisher habitat (Purcell et al. 2012).

In addition, decreases in the density of large conifer and hardwood trees and canopy cover are projected as fire severity increases. Large, severe wildfires pose a potentially large risk to the remaining fisher populations in the southern Sierra Nevada. Models by Scheller et al. (2011) projected that the ability of fuel treatments to preserve fisher habitat will vary by elevation, with the best results at higher elevations (Scheller et al. 2011). Treatments were under more severe fire regimes, and in proximity to high-quality habitat (>0.5 fisher occurrence probability) provided the greatest benefit to fishers. Under a heightened fire regime simulation, fuel treatments in marginal fisher habitat also benefited fishers as fires spread more readily between high and low quality habitat (Scheller et al. 2011).

Predator-prey relationships may play important role in fisher abundance. In British Columbia, fishers have been found to increase their activity with ambient temperature, perhaps because prey activity is greatest during warmer temperatures (Weir and Corbould 2007). Increased overlap and competition between fishers and marten is expected to likely benefit fishers (Purcell et al. 2012).

### **Marten** (*Martes americana*)

In the Sierra Nevada, a shift in distribution to higher elevations would drive martens toward the limit of forested habitats, which would limit their distribution and lead to decreases in population size. In fact, the marten range in the California Cascades may already be demonstrating such effects (Purcell et al. 2012). While martens have been documented to use boulder fields, talus slopes and rock slides in areas with reduced forest cover, they still may not provide for year-round habitat needs (Purcell et al. 2012). Furthermore, because the marten requires thermal cover provided by snow in subalpine and montane habitats during winter, reduced snowpack could expose the marten to lethally cold temperatures (Halofsky et al. 2011)

Climate change may also reduce the connectivity of dispersal habitat for the marten and fisher (Cushman et al. 2012), as it is projected to do under climate scenarios in northwestern Montana and the Idaho panhandle (Wasserman et al. 2012). The resultant patchiness is predicted to genetically isolate the marten, reducing genetic allelic richness and expected heterozygosity (Wasserman et al. 2012). Inbreeding depression has been strongly linked to extinction risk and the loss of allelic diversity reduces evolutionary potential. In addition, dramatic reduction of habitat area will likely be accompanied by large decreases in local population size, increasing likelihood of local extinction (Wasserman et al. 2012).

### **Flying squirrel**

No information found

### **California spotted owl** (*Strix occidentalis occidentalis*)



Despite being federally and/or state listed as threatened and endangered in California, the northern spotted owl is not on the climate change vulnerability list (Gardali et al. 2012).

Negative effects of wet weather on reproduction of California spotted owls during the spring nesting season have been modeled and observed in California (Franklin et al. 2000, North et al. 2000, LaHaye et al. 2004, Peery et al. 2012, Roberts and North 2012). In terms of energetic costs, owls have their highest daily energy expenditures during the breeding season in spring (Franklin et al. 2000). Precipitation during breeding season may decrease hunting efficiency, prey activity, and prey populations (Franklin et al. 2000). Extreme conditions during the early nesting period may exacerbate an energetic stress on an individual by decreasing its time to starvation. In addition, Franklin et al. (2000) surmise that increased precipitation in northwestern California during late breeding season may directly affect survival of young outs before they fledge (Franklin et al. 2000) through energy loss (LaHaye et al. 2004).

Modeled warm temperatures and low precipitation scenarios also appear to have a negative influence on both forecasted mean adult fecundity and survival of spotted owl in Arizona and New Mexico, leading to rapidly declining populations over the next century (Peery et al. 2012). Because some prey species decline during drought months, there may be an indirect link between short-term drought during the previous year and poor reproduction (LaHaye et al. 2004). Contrasting models forecast reproductive output in spotted owls in Southern California is likely to respond favorably to predicted climate warming, thereby reducing extinction risk in these populations (Peery et al. 2012)

A model of wildfire risk to northern spotted owl in central Oregon displayed non-linear decreases in the probability of habitat loss with increasing fuel treatment area (Ager et al. 2007). Results from previous studies of impacts of wildfires on spotted owls have been equivocal. In some cases, large stand-replacing fires appeared to have a negative impact on owl occupancy (see: Gaines et al. 1997), although it is unclear whether these birds moved or were killed (Bond et al. 2002). Other reports suggest that low-to-moderate severity fires did not adversely impact spotted owls (Bond et al. 2002).

Physiological and behavioral observations indicated that California spotted owls are relatively intolerant of high temperatures (Weathers et al. 2001). At temperatures above 34.2°C, resting metabolic rate increased 1.48 times faster than predicted allometrically, and behavioral responses to heat stress (increased breathing rate, ptiloerection, gaping, and wing drooping) occurred at relatively modest temperatures 30-34°C (Weathers et al. 2001).

### **Black-backed woodpecker (*Picoides arcticus*)**

Climate change to impact black-backed woodpecker primarily through altered fire regimes. If studies indicating an increased frequency and size of high-severity fires in California are correct, the black-backed woodpecker is likely to benefit, provided that sufficient amounts of post fire forests are retained. However, predicted shifts in vegetative communities, with reduced vegetation leading to reduced frequency and intensity wildfires, the black-backed woodpecker would be adversely impacted (Bond et al. 2012).



Not accounting for changes in fire regimes, modeled shifts in distribution in California due to climate change predict range contractions across the Sierra Nevada and southern Cascades, especially in the northern portion of its range in California, where the species is most common. In the models, the variables most influencing distribution were annual mean temperature and precipitation, as well as vegetation (Bond et al. 2012)

If the black-backed woodpecker shifts its range upslope, as numerous birds have already responded in the Sierra Nevada, even if the overall extent of habitat in California is reduced, substantial areas of coniferous forests are likely available for colonization at higher elevations, except in the northern Sierra Nevada, where elevations are lower (Bond et al. 2012).

Bond et al. (2012) indicate that throughout its North American range, winter distribution of the black-backed woodpecker has shifted 100 miles north and over 130 miles inland over the last 40 years.

### **Northern Goshawk (*Accipiter gentilis*)**

A study in northern Nevada indicated that climatic factors such as cold temperatures, high snowpack and rain may play a major role in determining the number of goshawk pairs breeding annually (Bechard et al. 2006). Warm dry springs are significantly related to goshawk breeding, while periods of cold and above average precipitation prevent goshawks from initiating breeding. Colder, wetter springs may also increase mortality through chilling of eggs and nestlings. Moreover, cold weather may affect foraging behavior of males, causing poor food provisioning to pre-egg laying females, preempting egg-laying entirely (Bechard et al. 2006).



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