Focal Resource: YELLOW PINE/MIXED CONIFER

CWHR Types[1]: PPN-Ponderosa pine, Jeffrey pine, Douglas fir, black oak; **JPN**-Jeffrey pine, ponderosa pine, sugar pine; **EPN**-Ponderosa pine, Jeffrey pine, white fir; **SMC**-Douglas fir, ponderosa pine, white fir, black oak and canyon live oak; **DFR**-Douglas fir, tanoak, ponderosa pine, canyon live oak; **WFR**-White fir, Douglas fir, sugar pine

General Overview of Process

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop[2]. The following document represents the vulnerability assessment results for the **YELLOW PINE/MIXED CONIFER ECOSYSTEM**, which is comprised of evaluations and comments from a participant breakout group during this workshop, peer-review comments following the workshop from at least one additional expert in the subject area, and relevant references from the literature. The aim of this synthesis is to expand understanding of resource vulnerability to changing climate conditions, and to provide a basis for developing appropriate adaptation responses. The resulting document is an initial evaluation of vulnerability based on existing information and expert input. Users are encouraged to refer to the Template for Assessing Climate Change Impacts and Management Options (TACCIMO, http://www.taccimo.sgcp.ncsu.edu/) website for the most current peer-reviewed literature on a particular resource. This synthesis is a living document that can be revised and expanded upon as new information becomes available.

Geographic Scope

The project centers on the Sierra Nevada region of California, from foothills to crests, encompassing ten national forests and two national parks. Three geographic sub-regions were identified: north, central, and south. The north sub-region includes Modoc, Lassen, and Plumas National Forests; the central sub-region includes Tahoe, Eldorado, and Stanislaus National Forests, the Lake Tahoe Basin Management Unit, and Yosemite National Park; and the south sub-region includes Humboldt-Toiyabe, Sierra, Sequoia, and Inyo National Forests, and Kings Canyon/Sequoia National Park.

Key Definitions

Vulnerability: Susceptibility of a resource to the adverse effects of climate change; a function of its sensitivity to climate and non-climate stressors, its exposure to those stressors, and its ability to cope with impacts with minimal disruption[3].

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[1] From California Wildlife Habitat Relationship (CWHR) habitat classification scheme http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp

[2] For a list of participant agencies, organizations, and universities please refer to the final report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* available online at: http://ecoadapt.org/programs/adaptation-consultations/calcc.

[3] Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

Sensitivity: A measure of whether and how a species or system is likely to be affected by a given change in climate or factors driven by climate.

Adaptive Capacity: The degree to which a species or system can change or respond to address climate impacts.

Exposure: The magnitude of the change in climate or climate driven factors that the species or system will likely experience.

Methodology

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: direct sensitivity of the system to temperature and precipitation, sensitivity of component species within the system, ecosystem sensitivity to disturbance regimes (e.g., wind, drought, flooding), sensitivity to other climate and climate-driven changes (e.g., snowpack, altered hydrology, wildfire), and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: ecosystem extent, integrity, and fragmentation; ecosystem ability to resist or recover from stressors; landscape permeability; ecosystem diversity (e.g., physical, topographical, component species, functional groups); and ecosystem value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the ecosystem and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation[4]. For more information on each of these elements of sensitivity, adaptive capacity, and exposure, including how and why they were selected, please refer to the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[5].

During the workshop, participants assigned one of three rankings (High (>70%), Moderate, or Low (<30%)) to each finer resolution element and provided a corresponding confidence score (e.g., High, Moderate, or Low) to the ranking. These individual rankings and confidence scores were then averaged (mean) to generate rankings and confidence scores for each vulnerability component (i.e., sensitivity, adaptive capacity, exposure score) (see table below). Results presented in a range (e.g. from moderate to high) reflect variability assessed by participants. Additional information on ranking and overall scoring can be found in the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[5].

Recommended Citation

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[4] Geos Institute. 2013. *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis report in support of the Vulnerability Assessment/Adaptation Strategy process.* Ashland, OR. http://ecoadapt.org/programs/adaptation-consultations/calcc.

[5] Kershner, J.M., editor. 2014. *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada.* Version 1.0. EcoAdapt, Bainbridge Island, WA. http://ecoadapt.org/programs/adaptation-consultations/calcc.

This document is available online at EcoAdapt (http://ecoadapt.org/programs/adaptation-consultations/calcc).

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Overview of Vulnerability Component Evaluations

NOTE Content reflects both group participant elicitation and additional input by an external system expert. Where rankings differed between group and system expert, rankings in the tables below reflect input of system expert. Both rankings (group and system expert) are captured in the 'Additional comments' sections on sensitivity, adaptive capacity, and exposure, below.

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	**2 Moderate**	**2 Moderate**
Direct Sensitivities – Precipitation	**2 Moderate**	**3 High**
Component Species	**1 Low to 3 High**	**3 High**
Disturbance Regimes	**2.5 Moderate–High**	**3 High**
Climate-Driven Changes	**2.5 Moderate–High**	**3 High**
Non-Climatic Stressors – Current Impact	**3 High**	**3 High**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**3 High**	**3 High**
Other Sensitivities	**None identified**	**1.5 Low-Moderate**

Overall Averaged Confidence (Sensitivity)[6]: Moderate-High

Overall Averaged Ranking (Sensitivity)[7]: Moderate–High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	**3 High**	**3 High**
Extent and Integrity – Fragmentation	**2 Moderate**	**3 High**
Resistance and Recovery	**2 Moderate**	**3 High**
Landscape Permeability	**2 Moderate**	**3 High**
System Diversity – Physical/Topographical	**3 High**	**3 High**
System Diversity – Component Species/Functional Groups	**3 High**	**3 High**
System Value	**3 High**	**3 High**
Specificity of Management Rules	**2 Moderate**	**3 High**
Other Adaptive Capacities	**1 Low**	**2 Moderate**

Overall Averaged Confidence (Adaptive Capacity)[6]: High

Overall Averaged Ranking (Adaptive Capacity)[7]: Moderate-High

EXPOSURE

Relevant Exposure Factor	Confidence
Climatic water deficit	**3 High**
Wildfire	**3 High**

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[6] 'Overall user perceived ranking' is participant group's estimation of the overall sensitivity, adaptive capacity or exposure, given their knowledge and expertise in the subject area.

[7] 'Overall averaged ranking' is the mean of the perceived rank entries provided in the respective evaluation columns.

Relevant Exposure Factor	Confidence
Snowpack	**3 High**

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**2 Moderate /2.5 Moderate–High**	**2 Moderate**
Central Sierra Nevada	**2 Moderate /2.5 Moderate–High**	**2 Moderate**
Southern Sierra Nevada	**2 Moderate**	**2 Moderate**

Overall Averaged Confidence (Exposure)[6]: Moderate

Overall Averaged Ranking (Exposure)[7]: Moderate / Moderate–High

Sensitivity

1. **Direct sensitivities to changes in temperature and precipitation.**
    a. <u>Sensitivity to temperature (means & extremes)</u>: Low (group); Moderate (external system expert)
        i. Participant confidence: High (group); Moderate (external system expert)
    b. <u>Sensitivity to precipitation (means & extremes)</u>: Low (group); Moderate (external system expert)
        i. Participant confidence: High (both)

Additional comments: The yellow pine/mixed conifer system is well studied, and persists under wide elevational range and/or climatic change. Changes in water balance and fire regimes are by far the greatest threats to the system. Long-term trends in yellow pine/mixed conifer forests are mostly driven by changes in available water (i.e. temperature *x* precipitation), as water availability drives forest health and vigor, and reduces fire activity, among other things.

References: There is substantial heterogeneity in species' sensitivity to climate (Battles et al. 2008; Scholl and Taylor 2010), however, growth and establishment of component species within the mixed conifer system are often positively associated with precipitation. For example, annual diameter increment for white fir, sugar pine and giant sequoia is positively correlated to winter precipitation on the western slope of the southern Sierra Nevada (York et al. 2010). Similarly, establishment of Jeffrey pine, sugar pine, and red fir are significantly associated with El Niño events, which cause wetter and warmer average conditions and a deep snowpack in the winter (North et al. 2005). Mixed conifer forest mortality was related to multiyear episodes of high spring and summer temperatures and low annual and seasonal precipitation in Yosemite National Park (Guarín and Taylor 2005), and conifer tree growth in the mixed forest has been shown to decline with decreases in winter precipitation and increases in summer temperature (Yeh and Wensel 2000).

<u>Temperature</u>: Of four variables tested, conifer tree growth in mixed forest was most sensitive to summer temperature (Yeh and Wensel 2000). A regional model for the southwestern U.S. indicated that ponderosa pine seedling densities were highest where average minimum May temperatures were highest (Puhlick et al. 2012).

2. **Sensitivity of component species.**
    a. <u>Sensitivity of component species to climate change</u>: Low (group); Low, Moderate, and High [*i.e. variable*] (external system expert)
        i. Participant confidence: No answer provided by workshop participants; High (external system expert)

Additional comments: The ranking provided does not consider disturbance effects on species/ habitats, for instance, the risk of fire destroying fisher and/or owl habitat.

Much of the mixed conifer forest was yellow pine forest before logging and fire suppression. Successional processes have lead to dominance by shade-tolerant species that are less drought and fire tolerant than the pine species they are supplanting. The conifer species that are better set up to survive climate warming and drought are now those that are less dominant, but beetle outbreaks will likely seriously thin their ranks.

References:
<u>Beetles and disease</u>: Dwarf mistletoe (*Arceuthobium abietinum f. sp. magnificae*), bark beetle (*Scolytus ventralis*), and annosus root disease (*Heterobasidion annosum*) are major causes of white fir mortality,

while infestations of broom rust (*Melamsporella caryophyllacearum)*, trunk rot (*Echinodontium tinctorium*), and the Douglas fir-tussock moth (*Orygia pseudotsgata)* have been shown to cause growth-loss in white fir (Laacke 1990; North et al. 2002). Exposure to pests can reduce tree vigor and increase tree susceptibility to additional pathogens and pests, potentially exacerbating the impacts of climate change. For instance, annosus root rot can increase the likelihood a tree will become infested by insects (Laacke 1990), and pest pressure can increase tree sensitivity to drought (Waring et al. 1987) and conversely, drought combined with increasing minimum temperatures, may enhance infestation of pine beetles in whitebark and limber pines (Millar et al. 2010). Attacks of bark beetle and pine beetle on Jeffrey pine and ponderosa pine have been associated with years of water shortage in the western U.S. (Grulke et al. 2009; Grulke 2010). The risk of widespread beetle-related mortality may also increase as winter temperatures warm, since prolonged periods of low temperatures result in significant overwintering mortality in some bark beetle species, but not others (Amman 1973, and Safranyik and Linton 1991 cited in Fettig et al. 2007). Moreover, pest pressure may indirectly reduce the capacity of conifers to adapt to climate change. For instance, Grulke (2010) suggests that the low ecophysiological trait variability displayed by sugar pine populations may be a result of pine blister rust experienced California-wide in the mid-1970s and 1980s.

Ponderosa pine: Warmer, drier sites are preferred by ponderosa pine (Scholl and Taylor 2010). 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). In the Placerville quadrangle of the Sierra Nevada, the western edge of the ponderosa pine forest moved an average of 7.1 km (4.4 mi) eastward and shifted about 193 m (633 ft) upward between 1934 and 1996, with the previously ponderosa-dominated areas being replaced by non-conifer species (e.g. oaks), and climate change was likely at least partially responsible for the changes (Moser et al. 2009).

Jeffrey pine: Shade intolerant Jeffrey pine lagged in response to annual climatic fluctuations, possibly because its roots tap water reserves in bedrock fissures (Hurteau et al. 2007). Despite its restricted geographic range relative to white fir and ponderosa pine in the western U.S., Jeffrey pine exhibit high variability in key ecophysiological traits, and exhibited the greatest needle and branch elongation growth in the driest site (Grulke 2010).

Sugar pine: Sugar pine populations are likely vulnerable to climate changes due to the apparent low variability of key ecophysiological traits. Sugar pine had the least variability in ecophysiological traits of four pine species (i.e. sugar pine, white fir, ponderosa pine and Jeffrey pine) studied in the western U.S. (Grulke 2010).

Giant sequoia groves: 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 (i.e. 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).

Douglas fir: Daily maximum temperature optimum for Douglas fir in western Oregon decreased with available soil water at drier sites (Beedlow et al. 2013), suggesting that vulnerability to warmer predicted summers, particularly at drier sites, could become increasingly limiting (Beedlow et al. 2013).

Modeled responses of more southern and outlying populations responded less negatively to drought conditions, which may indicate genetic adaptation to local climate (Chen et al. 2010).

White fir: White fir, red fir and mountain hemlock depends on readily available moisture during the summer growing season (Anderson 2004). White fir is found on cool, mesic slopes (Scholl and Taylor 2010). In the western Sierra Nevada, white fir often grows in clusters, in mid-slope stands, and is a strong shade-tolerant competitor, which may allow it to capitalize on available moisture, resulting in increased responsiveness to inter-annual fluctuations in precipitation (Hurteau et al. 2007).

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3. Sensitivity to changes in disturbance regimes.

- **a.** Sensitivity to disturbance regimes including: Wildfire, drought, insects, disease
- b. Sensitivity to these disturbance regimes: Low – all disturbances (group); Moderate-High (external system expert)
    - i. Participant confidence: Moderate (group); High (external system expert)

Additional comments: Yellow pine/mixed conifer forests are fairly sensitive to changes in fire regime, increased incidence of insects and disease, and increased drought, although not as sensitive as wet meadows to disturbances such as drought. Positive feedback cycles between these increasing disturbance regimes and the changes to the system they facilitate will exacerbate similar effects and trends.

References:
Wildfire: Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in Yosemite National Park (YNP) (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that "heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales" (Taylor and Scholl 2012). Burn condition heterogeneity may promote different forest understory responses in mixed conifer forests across a landscape, with lower intensity burns promoting tree regeneration, and higher intensity or more frequent burns creating shrub habitat (Lydersen and North 2012). Increases in fire will likely benefit comparatively fire-tolerant broadleaf trees on historically mixed conifer landscapes (Lenihan et al. 2008).

Since the 1980s, the Sierra Nevada has experienced an increase in large fires (>1000 acres) (>404 ha). This increase correlates to increasing temperatures and earlier snowmelt (Westerling and Bryant 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, compared to 30% in 1997-2007 (Miller et al. 2009). In parts of the southern Cascades (Taylor et al. 2008 cited in Taylor and Scholl 2012) and northern Sierra Nevada (Valliant and Stephens 2009 cited in Taylor and Scholl 2012), higher fire activity is weakly associated with El Niño (warm), while in Yosemite National Park, large fires were associated with La Niña (cool) conditions, which are characteristically drier (Taylor and Scholl 2012). 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 (Rothermel 1983). However, in Yosemite mixed conifer forests no spatial trend in fire frequency was found (Scholl and Taylor 2010).

Drought: Although mixed conifer forests in the Sierra Nevada have persisted through more severe droughts (Cook and Krusic 2004 cited in North et al. 2009) than those experienced today, the long-term effects of warming and drying are largely unknown (North et al. 2009).

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

   a. Sensitivity to climate and climate-driven changes including: Altered fire regimes, air pollution, altered hydrology (both)
   b. Sensitivity to these climate and climate-driven changes: High (group); Moderate-High (external system expert)
      i. Participant confidence: No answer provided by workshop participants; High (external system expert)

Additional comments: Although mixed conifer forests are adapted to frequent low and moderate severity fire, changes in the fire regime can lead to type conversion, resulting in the loss of flagship and keystone species. Such changes in the fire regime, combined with logging of the pine species, have already converted millions of acres of yellow pine forest to mixed conifer forest.

Decreases in precipitation will likely lead to decreased groundwater recharge, which may lead to loss of flagship giant sequoia. Snowpack changes are having major effects on trends in fire and conifer mortality. In addition, air pollution is a major stressor in the southern Sierra Nevada and effects are moving north.

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5. Sensitivity to impacts of other non-climate stressors.

   a. Sensitivity to other non-climate stressors including: Transportation and service corridors, other – fire suppression
   b. Current effects of these identified stressors on system: High (both)
      i. Participant confidence: High (both)
   c. Degree stressors increase sensitivity to climate change: High (both)
      i. Participant confidence: High (both)

Additional comments: Fire suppression and fuel loading practices lead to changes in species composition. Transportation corridors affect connectivity, potentially leading to type conversion and establishment of invasive species. Establishment of exotic grasses may subsequently facilitate changes in fire regimes. Historical livestock grazing occurred throughout the mixed conifer forest.

External system expert: The key non-climate stressor is fire suppression. Its long term and ironic implications are going to be the loss of much of the yellow pine/mixed conifer belt as climates continue to warm.

References:
Fire suppression: Fire suppression has lead to structural homogenization and changes in species composition, facilitating increased tree densities and occupation by shade-tolerant species at the expense of species like Jeffrey pine, sugar pine and western white pine (Bouldin 1999; Beaty and Taylor 2008; Scholl and Taylor 2010; Safford et al. 2012b). Fire suppression could alter species and individual growth response to climate in Sierran forests (Hurteau et al. 2007), and increase the probability of catastrophic burns by “laddering” fire into the canopy crown (Miller and Urban 2000; North et al. 2002). In Yosemite, fire suppression has reduced fire frequency from every ten years to every 378 years, causing tree densities to increase. In the early 1900s, Yosemite had an average of 160 trees/ha (~395 trees/ac) composed mostly of pine and oak; in 2003 threefold more trees were present, and were on average 20% smaller, ¼ of which were pine and oak with a ten-fold increase in white fir (Scholl and Taylor 2010).

In the Lake Tahoe Basin the greatest compositional changes during the 115-year fire-free period prior to 2008 occurred in pine-dominated stands in valley bottoms and on south aspects, shifting composition from fire-tolerant species to fire-intolerant white fir (Beaty and Taylor 2008). North et al. (2005) found that mixed-conifer species in the Teakettle forest in Sierra Nevada had distinct responses to fire, suggesting that seedling requirements and microsite preference is different between species. For instance, in the Teakettle Experimental Forest, sugar pine was found to establish 1-4 years after fire, preferentially during wet years, while white fir and incense cedar began to recruit into burned areas 13 years after fire (North et al. 2005).

[Please refer to *Question 3: Disturbance Regimes* above for further references on altered fire regimes].

Biological resource use: Since the mid-19th century, management practices have fundamentally changed the structure, biota, and ecological processes in mixed conifer and yellow pine forest (Sugihara et al. 2006, Barbour et al. 2007 cited in Safford et al. 2012b). Historical logging partially explains the loss and homogenization of yellow pine-dominated forests (Safford et al. 2012b).

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 et al. 2003). However, another study found that from Tahoe south to Sequoia, nitrogen loads that could cause impaired function were present. Nitrogen loads can cause increased invasive species, altered lichen communities and altered lake chemistry (Living Assessment 2013).

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6. Other sensitivities.

- a. Other critical sensitivities not addressed: No answer provided by workshop participants; no answer provided by external system expert
    - i. Participant confidence: Low-Moderate (group); no answer provided by external system expert
- b. Collective degree these factors increase system sensitivity to climate change: N/A

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7. Overall user ranking.

- a. Overall sensitivity of this system to climate change: Moderate (both)
    - i. Participant confidence: Moderate (both)

Additional comments: Sensitivity of the yellow pine/mixed conifer system to climate change may vary by sub-region. The northern Sierra Nevada might be ranked as High rather than Moderate, due to greater anticipated effects of altered fire regime, less snow, and longer fire season.

Adaptive Capacity

1. **System extent and integrity.**
    a. System extent throughout the Sierra Nevada (e.g., widespread to narrow distribution): High (both)
        i. Participant confidence: High (both)
    b. Level of fragmentation across the Sierra Nevada: Low (group); Moderate (external system expert)
        i. Participant confidence: High (both)

References identified by participants: Franklin and Fites-Kaufman 1996; Scholl and Taylor 2010; Collins et al. 2011. See Southern Sierra Adaptation Workshop handouts and materials[8].

External system expert: The adaptive capacity of the mixed conifer forest may be reduced through fragmentation by roads, transmission corridors, land use, resource extraction, and severe fires, which are influenced by fire suppression.

References:
Geographic extent: The mixed conifer forest covers an estimated 10% of the vegetated area in the Sierra Nevada and is the dominant community in the lower montane zone (Sierra Nevada Ecosystem Project 1996 cited in Ansley and Battles 1998). The mixed conifer forest generally occupies elevations ranging from 1300-1800 m (4265-5905 ft) but can be found at lower elevations in moist sites, and at higher elevations in the southern Sierra Nevada. However, as of 1998, less than 15% of the mixed conifer forest in the Sierra Nevada had old-growth or late-successional features, much of which is found in national parks in the southern Sierra Nevada (Franklin and Fites-Kaufmann 1996 cited in Ansley and Battles 1998).

2. **Resistance, recovery, and refugia.**
    a. Ability of system to resist or recover from impacts: Moderate (both)
        i. Participant confidence: Moderate (group); High (external system expert)
    b. Suitable microclimates within the system that could support refugial communities: These tend to occur more frequently in the southern Sierra and on north facing slopes. *External system expert:* Cool and moist canyons may be climatic refuges in the future. Higher elevation sites as well. Southern Sierra could be a major refuge, as it is much higher and snowpack will not be as affected and much of the landscape is in wilderness.

Additional comments: Logged areas have not recovered to old growth. Yellow pine/mixed conifer forests within fire suppression management areas have changed species composition. After fire or other stress, yellow pine/mixed conifer forest types have experienced type conversion to grassland or chaparral.

3. **Landscape permeability.**
    a. Degree of landscape permeability: High (group); Moderate (external system expert)
        i. Participant confidence: High (both)
    b. Potential types of barriers to dispersal that apply: Roads (highway, arterial, low volume), clear cut/logging, other – transmission corridors, land jurisdiction changes (both)

Additional comments: Potential barriers to dispersal vary depending on the time frame considered.

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[8] Southern Sierra Adaptation Workshop Information: http://climate.calcommons.org/aux/sscaw/index.htm

External system expert: Forest cover is patchy due to land use, crossed by many roads, transmission corridors, land jurisdiction changes, private logging, etc. Landscape is more or less permeable for many species but forest carnivores are having trouble dispersing/migrating.

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4. **System diversity.**
    a. Level of physical and topographic diversity: High (both)
        i. Participant confidence: High (both)
    b. Level of component species/functional group diversity: High (both)
        i. Participant confidence: High (both)
    c. Description of diversity: No answer provided by workshop participants or external system expert.
    External system expert: High diversity in all categories.

Additional comments: Some species within the system exhibit lower genetic diversity (e.g. fisher and perhaps giant sequoia), but in general the system displays high levels of diversity. Structural heterogeneity fosters resilience, and forests that experience periodic low intensity disturbance such as wind throw or low intensity fire may be better able to recover from climate-related stresses such as drought, fire and insects.

References:
Component species diversity: Grulke (2010) found that co-occurring populations of montane conifers in California varied in their potential to respond to climate change, as indicated by variability of key ecophysiological traits. Of the four species studied, white fir exhibited the highest variability, sugar pine exhibited the least, and ponderosa pine and Jeffrey pine had intermediate variability. Uphill redistribution of white fir in the Peninsular Range of southern California lends support that this species has the capacity to respond to environmental change (Grulke 2010).

Community structure: In mixed-conifer old-growth forests in the Sierra Nevada with restored fire regimes, topography and fire interact to influence forest productivity and burn intensity, creating structurally heterogeneic forests. Topography can be a strong influence on tree density and species composition (Lydersen and North 2012). "Topography can affect forest vegetation both directly, with contributing factors such as soil moisture (Scholl and Taylor 2010), soil thickness (Meyer et al. 2007), and microclimate (Abella and Denton 2009), and indirectly by differences in fire intensity (Beaty and Taylor 2001) and frequency (Taylor and Skinner 2003)" (Lydersen and North 2012).

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5. **Management potential.**
    a. Value level people ascribe to this system: High (both)
        i. Participant confidence: High (both)
    b. Specificity of rules governing management of the system: High (group); Moderate (external system expert)
        i. Participant confidence: High (both)
    c. Description of use conflicts: There are conflicts regarding restoring the overall system for resilience. For example, managing for sensitive, listed, and/or species of concern can hinder restoration actions that could reduce the system's vulnerability to climate changes. A conflict also exists between managing to allow restoration of natural fire regimes, and managing for the protection of human life and property, and other infrastructure. The removal of materials to support restoration to the system is complicated by economic constraints and the constraints of public opinion and acceptance.

External system expert: There are huge conflicts including tradeoffs among resource extraction, recreation, livestock, aesthetics, watershed protection, exurban housing expansion, and wilderness.

d. Potential for managing or alleviating climate impacts: Seed banks of tree species from different elevations could be utilized to facilitate assisted migration. Natural fire regimes could be reintroduced. Thinning of stands (especially of fire intolerant species) could reduce pressure on groundwater. However, management capacity and public opinion generally do not keep stride with changing fire regimes and fuel loading, thus the potential for managing the system in these ways to alleviate climate impacts is low.

External system expert: Theoretically, the potential for managing to alleviate climate impacts exists, especially through the use of fire and fire surrogates to reduce fire density and increase forest resilience to future drought and fire. However, political and economic realities make this very challenging. Increased planting of drought and fire tolerant species is another strategy.

Additional comments: Institutions have a low capacity to take advantage of flexibility in rules governing management, when they exist, due partially to resource constraints. In addition, although some rules include some degree of flexibility, management is also constricted by public opinion, as well as court decisions, among other factors.

References: The structural, ecological, and biological changes seen in yellow pine and mixed conifer dominated forest in the western U.S. including an increase in the area of forest dominated by shade-tolerant conifers, especially fir species (*Abies spp*.), are a product of management choices (e.g. fire suppression, logging, and grazing) since the mid-19th century (Safford et al. 2012b). To reduce catastrophic fire, retaining heterogeneity, including a mixture of species and age classes, would reduce fuel loads (Battles et al. 2008), while simultaneously increasing resilience to drought and wildfire, and providing habitat for sensitive species associated with high canopy closure and stem density (Lydersen and North 2012).

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6. Other adaptive capacity factors.

a. Additional factors affecting adaptive capacity: Invasive species; endangered species management (group); no answer provided by external system expert
    i. Participant confidence: Moderate (group); no answer provided by external system expert

b. Collective degree these factors affect the adaptive capacity of the system: Low (group); no answer provided by external system expert

Additional comments: Past practices (e.g. logging, hydraulic mining) may have negatively affected the adaptive capacity of the system. The spread of invasive species may facilitate changes in fire regimes and/or lead to type conversion, thereby decreasing adaptive capacity. As mentioned in question 5, managing for endangered species can reduce adaptive capacity, and managing forests for water quantity can influence tree species composition.

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7. Overall user ranking.

a. Overall adaptive capacity of the system: Moderate (both)
    i. Participant confidence: Moderate (group); High (external system expert)

Additional comments: The yellow pine/mixed conifer system has generally high adaptive capacity, unless it becomes exposed to a significant increase in the frequency and severity of fire, resulting in potential type conversion or significant changes in structure and landscape patterns of seral stages.

External system expert: The diversity and large land base of the system make it able to absorb a great deal of change. It is the most widely distributed forest type in the Sierra Nevada, so its resilience is key to many species in the range. Although the system does not support many locally rare species, the implications of major change would be huge.

Exposure

1. **Exposure factors[9].**
    a. Factors likely to be most relevant or important to consider for the system: Climatic water deficit, wildfire, snowpack
        i. Participant confidence: High (climatic water deficit); High (wildfire); High (snowpack)

2. **Exposure region.**
    a. Exposure by region: North – Moderate/Moderate-High; Central – Moderate/Moderate-High; South – Moderate
        i. Participant confidence: Moderate (all)

3. **Overall user ranking.**
    a. Overall exposure of the species to climate changes: Moderate
        i. Participant confidence: Moderate

References:

Distribution shifts of yellow pine/mixed conifer forests: The greatest change predicted for the forested landscape in the 21st century is the reduction of conifer-dominated forest area, which is forecast to be replaced by mixed woodland and hardwood-dominated forests (Lenihan et al. 2003; Lawler et al. *in press* cited in Purcell et al. 2012).

Please see PRBO Conservation Science (2011) for ecoregional summaries of vegetation change projected in California.

In the Sierra Nevada, deciduous forests are predicted to replace conifer dominated forests at low and middle elevations (Lenihan et al. 2008). Future increases in temperature and fire are projected to result in higher importance of broadleaf trees (especially oak species) (Lenihan et al. 2008). A drier future may present an increase in grasslands and shrublands in areas historically habited by mixed conifer forest (Lenihan et al. 2008). Results from Notaro et al.'s (2012) model indicate that potential range of white fir in the southwest U.S. will increase.

Battles et al. (2008) evaluated the impacts of climate change on the future productivity and health of a forest in the mixed-conifer region in California. Conifer tree growth declined under all climate scenarios and management regimes, with greatest reductions in white fir, incense cedar and Douglas fir relative to ponderosa pine and sugar pine (Battles et al. 2008).

Ponderosa pine, one of the two most abundant species in the southwestern U.S., is projected to decline on average by 47% in response to climate warming (Notaro 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).

Projected earlier snowmelt and runoff, and longer, drier summers in the Sierra Nevada may lead to low seedling survival, 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 by roots that

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[9] Participants were asked to identify exposure factors most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

can access deep-water reservoirs. The bedrock fissure water-holding capacity in the shallow soils may afford the Jeffrey pine some protection from annual climate variation.

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).

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).

Snow volume and timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012a). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009) and earlier timing of runoff center of mass (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Maurer et al. 2007; Young et al. 2009), as a consequence of early snowmelt events and a greater percentage of precipitation falling as rain rather than snow (Dettinger et al. 2004a, 2004b; Young et al. 2009; Null et al. 2010).

Annual snowpack in the Sierra Nevada is projected to decrease between 64-87% by late century (2060-2079) (Thorne et al. 2012; Flint et al. 2013; Geos Institute 2013). Under scenarios of 2-6˚C warming, snowpack is projected to decline 10-25% at elevations above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). Several models project greatest losses in snowmelt volume between 1750 m to 2750 m (5741 ft to 9022 ft) (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009), because snowfall is comparatively light below that elevation, and above that elevation, snowpack is projected to be largely retained. The greatest declines in snowpack are anticipated for the northern Sierra Nevada (Safford et al. 2012a), with the current patterns of snowpack retention in higher-elevation southern Sierra Nevada basins expected to continue through the end of the century (Maurer 2007).

Average fractions of total precipitation falling as rain in the Sierra Nevada can be expected to increase by approximately 10% under a scenario of 2.5˚C warming (Dettinger et al. 2004b). Snow provides an important contribution to spring and summer soil moisture in the western U.S. (Sheffield et al. 2004), and earlier snowmelt can lead to an earlier, longer dry season (Westerling et al. 2006). A shift from snowfall to rainfall is also expected to result in flashier runoff with higher flow magnitudes, and may result in less water stored within watersheds (Null et al. 2010). Further, decreases in winter precipitation combined with increases in summer temperature may produce declines in conifer tree growth in mixed conifer forest of northern California (Yeh and Wensel 2000).

Climatic water deficit: Increases in potential evapotranspiration will likely be the dominant influence in future hydrologic cycles in the Sierra Nevada, decreasing runoff even under forecasts of increased precipitation, and driving increased climatic water deficits (Thorne et al. 2012). Climatic water deficit, which combines the effects of temperature and rainfall to estimate site-specific soil moisture, is a function of actual evapotranspiration and potential evapotranspiration. In the Sierra Nevada, climatic water deficit has increased slightly (~4%) in the past 30 years compared with the 1951-1980 baseline

(Flint et al. 2013). Future downscaled water deficit projections using the Basin Characterization Model (Thorne et al. 2012; Flint et al. 2013) and IPCC A2 emissions scenario predict increased water deficits (i.e., decreased soil moisture) by up to 44% in the northern Sierra Nevada, 38% in the central Sierra Nevada, and 33% in the southern Sierra Nevada (Geos Institute 2013). The projected change in water deficit from present to future climate for Yosemite National Park is greater than that from the Little Ice Age to present, exceeding 25% increase for plots occupied by red fir, lodgepole pine, western juniper, whitebark pine, western white pine, giant sequoia and mountain hemlock (Lutz et al. 2010).

Wildfire: Both the frequency and annual area burned by wildfires in the western U.S. have increased strongly over the last several decades (Westerling et al. 2006). Increasing temperatures and earlier snowmelt in the Sierra Nevada have been correlated with an increase in large (>1000 acre or >404 ha) extent fire since the 1980s (Westerling and Bryant 2006). Between 1972-2003, years with early arrival of spring conditions accounted for 56% of wildfires and 72% of area burned in the western U.S., as opposed to 11% of wildfires and 4% of area burned in years with a late spring (Westerling et al. 2006; Geos Institute 2013). Fire severity also rose from 17% to 34% high severity (i.e. stand replacing) from 1984-2007, especially in middle elevation conifer forests (Miller et al. 2009). In Yosemite mixed conifer forests, no spatial trend in fire frequency was found (Scholl and Taylor 2010).

Fire activity within the Sierra Nevada is influenced by distinct climate patterns and diverse topography. Higher fire activity is weakly associated with El Niño (warm) conditions in parts of the southern Cascades (Taylor et al. 2008) and northern Sierra Nevada (Valliant and Stephens 2009 cited in Taylor and Scholl 2012), while in Yosemite National Park (YNP) large fires are associated with La Niña (cool) conditions, which are characteristically drier (Taylor and Scholl 2012). Some evidence suggests that fire frequency is higher on southern aspect than northern aspect slopes in mid- and upper-montane forests (Taylor 2000); however, in YNP mixed conifer forests, no spatial trend in fire frequency was found (Scholl and Taylor 2010). Burn condition heterogeneity may promote different forest understory responses in mixed conifer forests across a landscape, with lower intensity burns promoting tree regeneration, and higher intensity or more frequent burns creating shrub habitat (Lydersen and North 2012).

Large fire occurrence and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing 7-41% by 2050, and 12-74% by 2085 (Westerling et al. 2011). Models by Westerling et al. (2011) project annual area burned in the northern, central and southern Sierra Nevada to increase by 67-117%, 59-169%, and 35-88%, respectively (Geos Institute 2013). Greatest increases in area burned in the Sierra Nevada are projected to occur at mid-elevation sites along the west side of the range (Westerling et al. 2011).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013). Additional material on climate trends for the system may be found through the TACCIMO website (http://www.sgcp.ncsu.edu:8090/). Downscaled climate projections available through the Data Basin website (http://databasin.org/galleries/602b58f9bbd44dffb487a04a1c5c0f52).

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