Focal Resource: ALPINE/SUBALPINE SYSTEMS

CWHR Types[1]: SCN-Engelmann spruce (*Picea englemannii*), subalpine fir (*Abies lasciocarpa*), mountain hemlock (*Tsuga mertensiana*)

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 **ALPINE/SUBALPINE 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].

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.

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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.

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

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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.

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Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Direct Sensitivities – Temperature	**3 High**	**3 High**
Direct Sensitivities – Precipitation	**3 High**	**2 Moderate**
Component Species	**3 High**	**2 Moderate**
Disturbance Regimes	**3 High**	**2 Moderate**
Climate-Driven Changes	**3 High**	**2 Moderate**
Non-Climatic Stressors – Current Impact	**1 Low**	**2 Moderate**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**2 Moderate**	**No answer provided by participants**
Other Sensitivities	**3 High**	**2 Moderate**

Overall Averaged Confidence (Sensitivity)[6]: Moderate

Overall Averaged Ranking (Sensitivity)[7]: High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	**2 Moderate**	**3 High**
Extent and Integrity – Fragmentation	**2 Moderate (subalpine)** **1 High (alpine)**	**3 High**
Resistance and Recovery	**1 Low**	**3 High**
Landscape Permeability	**1.5 Low-Moderate**	**1 Low**
System Diversity – Physical/Topographical	**1.5 Low-Moderate**	**2.5 Moderate-High**
System Diversity – Component Species/Functional Groups	**No answer provided by participants**	**No answer provided by participants**
System Value	**3 High**	**2.5 Moderate-High**
Specificity of Management Rules	**3 High**	**3 High**
Other Adaptive Capacities	**No answer provided by participants**	**No answer provided by participants**

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

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

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	**2 Moderate**
Precipitation	**2 Moderate**
Dominant vegetation type	**1.5 Low-Moderate**

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[6] Overall confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure, respectively.

[7] Overall sensitivity, adaptive capacity, and exposure are an average of the sensitivity, adaptive capacity, or exposure evaluation columns above, respectively.

Relevant Exposure Factor	Confidence
Climatic water deficit	**1 Low**
Wildfire	**1 Low**
Snowpack	**2 Moderate**
Runoff	**1.5 Low-Moderate**
Timing of flows	**1.5 Low-Moderate**
Other – precipitation type	**1 Low**

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**Moderate-High**	**3 High**
Central Sierra Nevada	**Moderate**	**3 High**
Southern Sierra Nevada	**Moderate**	**3 High**

Overall Averaged Confidence (Exposure)[6]: High

Overall Averaged Ranking (Exposure)[7]: Moderate

Sensitivity

1. **Direct sensitivities to changes in temperature and precipitation.**
    a. Sensitivity to temperature (means & extremes): High
        i. Participant confidence: High
    b. Sensitivity to precipitation (means & extremes): High
        i. Participant confidence: Moderate

Additional comments: The alpine/subalpine systems are sensitive to the type and timing of precipitation, more than the amount of precipitation. Currently, the subalpine zone is considered fairly protected. The confidence ratings of high and moderate are a result of participant discussion, as well as existing science and literature.

References:
Temperature: Over the past century, high elevation forests have seen pronounced increases in temperature. In the Central Sierra Nevada, daily minimum temperature has increased by 1.2˚C since 1929-34 (Dolanc et al. 2013). From 1910-20, average minimum temperature was 3.8˚C; in 1990-2000, average minimum temperature increased to 7.5˚C in upper elevation forests of the central Sierra Nevada (Millar et al. 2004). A positive relationship exists between temperature in the Sierra Nevada and ring-width growth of treeline bristlecone pine (Salzer et al. 2009), branch growth of whitebark pine and lodgepole pine, and establishment of western white pine (Millar et al. 2004).

Precipitation: Some studies indicate that responses of high elevation forests may be largely dictated by water supply (Lloyd and Graumlich 1997; Fites-Kaufman et al. 2007), and evidence suggests that warming, plus higher precipitation in some cases, may have improved growing conditions for some tree species in the subalpine zone since the 1930s (Bouldin 1999; Dolanc et al. 2013). Precipitation averages from 750-1250 mm (30-50 in) per year, most of which falls as snow (Fites-Kaufman et al. 2007). In the Central Sierra Nevada, precipitation has increased by 15-48% since 1929-34, resulting in less stressful conditions (Dolanc et al. 2013). From 1910-20, precipitation averaged 417 mm (16.4 in); in 1990-2000, average precipitation increased to 632 mm (24.9 in) in upper elevation forests of the central Sierra Nevada (Millar et al. 2004).

Although steady or increased precipitation and warming temperatures have led to less stressful conditions for recruitment and survival of small trees, these changes may also contribute to increased mortality of large subalpine trees (Dolanc et al. 2013). For example, whitebark pine experienced significant mortality from 2007-2010 in Sierra Nevada subalpine sites (mean elevation 2993 m)(9820 ft) that were warmer and drier relative to species distribution (Millar et al. 2004).

In addition, rising temperatures between 1987-2007 indicates 73% of 'Köppen' alpine tundra classification in the western United States now exceeds the 10°C (50˚F) temperature threshold for this habitat classification during in the warmest month (Diaz and Eischeid 2007). Our understanding of limiting factors such as temperature means and extremes, and moisture availability in species establishment and survival in alpine habitats remains poor (Graham et al. 2012).

Topographic features (such as slope or aspect) can affect evaporative demands of the forest, influencing forest types found at the same elevation (Fites-Kaufman et al. 2007).

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2. **Sensitivity of component species.**
    a. Sensitivity of component species to climate change: High
        i. Participant confidence: Moderate

Additional comments: Overall, subalpine and alpine species are highly sensitive to changes in temperature and precipitation, although many species have been tolerant of climate fluctuations during the late Holocene. For example, limber pine is more tolerant of drier and steeper landscapes, and both whitebark pine and limber pine likely exhibit lower sensitivity to drought stress in less dense and short-statured (e.g., krummholtz) stands. A critical research question in the higher elevation southern Sierra Nevada is whether edaphic (i.e., soil) or other limitations (e.g., dispersal potential) will preclude effective migration of subalpine tree species upslope.

<u>References identified by participants:</u> Eric Beever (USGS, pika research); Grinnell resurvey project (UC Berkeley).

References: For the foxtail pine, lodgepole pine, and western white pine, maximum growth occurs with high winter precipitation and warm summers but there is substantial species to species variation (Fites-Kaufman et al. 2007).

From the early 1930s to the 1990s, young mountain hemlock increased their density and basal area but large western white pine populations decreased; whitebark pine density increased and had more young trees. Similarly, lodgepole pine appears to be responding favorably to warming trends and increased precipitation. Lodgepole pine, western white pine, and mountain hemlock all show decreased mortality (Bouldin 1999).

The comparative stasis of foxtail pine (*Pinus balfouriana*) in Sequoia National Park during the last 100-200 years indicates that there are steep gradients of vulnerability to climate change at treeline in the Sierra Nevada (Lloyd and Graumlich 1997).

<u>Foxtail Pine:</u> A study by Lloyd and Graumlich (1997) found that historic records of foxtail pines (*Pinus balfouriana*) in Sequoia National Park exhibited a lack of population sensitivity to paleoclimate summer temperatures and winter precipitation in treeline forests during the last 1000 years. Foxtail pine recruitment displayed less variability than mortality, and while rates of recruitment and changes in treeline stand density were inversely correlated with summer temperature, mortality rates were uncorrelated with precipitation and temperature. The inverse correlation of temperature and recruitment may indicate an important role for water balance in regulating population growth (Lloyd and Graumlich 1997).

Life history characteristics which reduce moisture and nutrient requirement (Bunn et al. 2005) and moderate densities of adult trees, which are able to moderate their microclimate, may provide resistance to climate change, while trees in marginal locations do not experience the full protective influence of this buffering (Lloyd and Graumlich 1997). Foxtail pines in drier regions of the cold and dry eastern crest of Sequoia National Park may lose the ability to grow in warm temperatures if insufficient water leads to drought stress (Bunn et al. 2005).

The downslope expansion of foxtail pine is correlated with the distribution of shade-tolerant conifers, which are in turn correlated with habitat heterogeneity (i.e., boulder cover and ultramafic substrates). This implies that although climate change may be the driving force behind expansions, within the Klamath Mountains, downslope expansion can be facilitated by habitat heterogeneity (Eckert and Eckert 2007).

<u>Western White Pine</u>: Millar et al. 2004 found that in the Sierra Nevada, response of colonization rate of western white pine (*Pinus monticola*) into formerly persistent snowfields below treeline to warming and climate variability throughout the 20th century were directional and ongoing, from minimal to significant establishment.

Mountain Hemlock: The temperature driven change in the mountain hemlock (*Tsuga mertensiana*) forest in the last 150 years suggests that predicted warming (Houghton et al. 1992 cited in Taylor 1995) will have a significant effect on these forests in Lassen Volcanic Park and elsewhere in the Pacific Northwest. During that period, near treeline mountain hemlock forests have increased in density, warming triggered population expansion, and initial recruitment peaked during a warm mesic period. Recruitment response is spatially variable, however, because high precipitation (i.e., high snowpack) retards recruitment on mesic flats with late lying snow and promotes it on xeric sites (Taylor 1995).

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3. Sensitivity to changes in disturbance regimes.

   a. Sensitivity to disturbance regimes including: Wildfire, drought, disease, wind, insects, other – ecosystem species shifted

   b. Sensitivity to these disturbance regimes: High

      i. Participant confidence: Moderate

Additional comments: The alpine/subalpine system is relatively moderate in its sensitivity to these (above mentioned) disturbance regimes. However, high sensitivity to disturbance regimes applies especially to high-elevation white pines (whitebark pine, limber pine, foxtail pine, bristlecone pine, western white pine), and the subalpine system will become highly sensitive if fire increases. Wildfire is expected to have the greatest impact in denser stands and at lower elevations adjacent to relatively productive upper montane forests, where fuel loading is higher and spatially contiguous. Subalpine forests are most sensitive to disease (e.g., white pine blister rust) and insect outbreaks (especially mountain pine beetle), especially in denser and more productive stands dominated by whitebark pine or other high-elevation white pines. Range of the parasite dwarf mistletoe is thought to be currently limited by climate, but climate change may extend its range to higher elevations and further north as temperatures warm and the growing season lengthens.

References identified by participants: NCAR Artic/Alpine Research Lab; Betty Willard; Michelle Slaton, Inyo NF; U.C. Research Lab in White Mountains; Ecologists: Hugh Stafford (USFS), Sarah Sawyer (USFS); Insects: (Sheri Smith) Forest Self Protection Team.

References:
Wildfire: Historically, forest fires were relatively rare in alpine and subalpine vegetation, and did not play as strong a role in structuring these ecosystems as they did in lower elevation systems (Van de Water and Safford 2011; Safford and Van de Water 2013). However, with earlier snowmelt and warmer temperatures, models and current trends suggest that fire may become a more significant ecological disturbance in high elevation forests through the 21st century (Fites-Kaufman et al. 2007; Mallek et al. 2013), especially if climate warming leads to densification of bristlecone stands (Dolanc et al. 2013). Historical fires were often not severe enough to be stand-replacing (Caprio and Narog 2008).

Fire frequency increases with earlier snowmelt and warmer temperatures (Fites-Kaufman et al. 2007). Since the late Holocene, forest fires at high elevations seem to be driven by the intensification of ENSO; warmer temperatures may cause a greater number of extreme convective storms, including enhanced occurrence of lightning strikes (Hallett and Anderson 2010).

Disease: Native fungal diseases include annosus root disease, armillaria root disease and black-stain root disease. Annosus root disease may be spreading more easily to the more dense forests that have been created by fire suppression (Slaughter and Rizzo 1999, Rizzo and Slaughter 2001 cited in Fites-Kaufman et al. 2007). White pine blister rust was introduced from Asia; it attacks five-needled pine species but the sugar pine is particularly susceptible (van Mantgem et al. 2004 cited in Fites-Kaufman et al. 2007).

Insects: The most significant ongoing mortality episode in subalpine forests of western North America is occurring in whitebark pine (Millar et al. 2012) with mortality trends increasing since 1998 (Gibson et al. 2008 cited in Millar et al. 2012). Despite low levels of mountain pine beetle mortality reported from 1998-2005 (Gibson et al. 2008 cited in Millar et al. 2012), a major mortality event in eastern California occurred from 2007-2010 (Millar et al. 2012). Events occurred in monotypic, closed-canopy, relatively young stands located on the eastern edge of escarpments on north/northeast aspects with slopes >40% at elevations between 2740-2840 m (8990-9318 ft). Infestation of bark beetles is enhanced by increasing minimum temperatures combined with drought (Millar et al. 2012).

Wind: Winds can be high in the alpine and sub-alpine and can limit plant growth by battering plants or through enhanced evapotranspiration. Trees in the subalpine and alpine region can develop twisted or bent forms due to the high winds (Fites-Kaufman et al. 2007).

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

- a. Sensitivity to climate and climate-driven changes including: Altered hydrology, evapotranspiration and soil moisture, extreme temperature
- b. Sensitivity to these climate and climate-driven changes: High
    - i. Participant confidence: Moderate

Additional comments: Air pollution impacts are negligible over near to mid-term future, but this stressor is worth monitoring in the long-term. Other climate-related disturbances that may impact subalpine forests include avalanche, extreme wind events, and altered hydrologic patterns. For example, earlier runoff and snowmelt will lead to increased climatic water deficit for subalpine trees, resulting in increased climate exposure of subalpine forests.

References identified by participants: Information from NPS Southern Sierra Adaptation Workshop 2013[8].

References:

Altered fire regimes: At elevations above 2500 m (8202 ft), the fire-return interval before the mid-1800s could be 200 years or greater (Skinner and Chang 1996, Caprio and Lineback 2002, and van Wagtendonk and Fites-Kaufman 2006 cited in Fites-Kaufman et al. 2007). Because fire has historically been relatively rare at higher elevations, the fire management and suppression strategy implemented in the early 1900s did not impact high altitude forests as much as it did its lower elevation counterparts (Fites-Kaufman et al. 2007; Miller et al. 2009).

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 (Safford et al. 2012). Avalanches on steep, north-facing slopes can disturb vegetation (Fites-Kaufman et al. 2007).

Further, warmer temperatures are causing the spring thaw to occur earlier in the year; in 2002 it occurred 5-30 days earlier than in 1948. Peak streamflow occurred 5-15 days earlier in 2002 relative to 1948; March flows were higher by 5-20% but June flows were mostly lower (Safford et al. 2012).

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

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

a. Sensitivity to other non-climate stressors including: Commercial development, human intrusions and disturbance, other – outdoor recreation.
b. Current effects of these identified stressors on system: Low
    i. Participant confidence: Moderate
c. Degree stressors increase sensitivity to climate change: Moderate
    i. Participant confidence: No answer provided by breakout group

Additional comments: The potential exists for increased incidence of invasive species, especially cheatgrass, at higher elevations.

There is little commercial or residential development at these high elevations. Primary commercial development in high-elevation areas is related to ski area development, but the overall footprint of these developments is limited in extent. The stressors from development and outdoor recreation are currently considered low due to limited accessibility at high elevation. The participants' confidence is moderate for these stressors.

References identified by participants: Trent Proctor - Region 5 Air Pollution Specialist; possibly Forest Health Protection Group; California Air Resource Board - Mary Nichols; Nate Stephenson - (USGS) Sequoia and Kings Canyon Field Station.

References:
Pollution and poisons: Ozone and nitrogen levels are relatively low at high elevations and do not appear to harm the ecosystem (Fenn et al. 2003).

Insects: Mountain pine beetle and whitebark pine beetle infestations have resulted in major mortality events for subalpine species, such as whitebark pine and limber pine in recent decades in western North America (Logan and Powell 2001, Logan et al. 2010 cited in Millar et al. 2012). In whitebark pine forests, significant ongoing mortality is also caused by white pine blister rust (*Cronartium ribicola* A. Dietr.) (Tomback and Achuff 2010 cited in Millar et al. 2012). Rising minimum temperatures, combined with drought, contribute to bark beetle infestations in the Sierra Nevada (Millar et al. 2007 cited in Millar et al. 2012), and can aggravate climate-driven mortality.

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6. Other sensitivities.

a. Other critical sensitivities not addressed: Soils
    i. Participant confidence: Moderate
b. Collective degree these factors increase system sensitivity to climate change: High

Additional comments: The alpine zone is sensitive due to its isolation. Connectivity among isolated mountain peaks is required to allow migration as ecosystem components attempt to move to more hospitable habitats in response to climate shifts. The sensitivity of the alpine system is in part related to the soil belt, limited soil productivity, and the time required for cryogenic soil evolution.

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7. Overall user ranking.

a. Overall sensitivity of this system to climate change: High
    i. Participant confidence: Moderate

Additional comments: The alpine/subalpine system is highly susceptible to climate change because it occurs within a small band, and has limited opportunity for system expansion.

Adaptive Capacity

1. **System extent and integrity.**
    a. System extent throughout the Sierra Nevada (e.g., widespread to narrow distribution): Moderate
        i. Participant confidence: High
    b. Level of fragmentation across the Sierra Nevada: Alpine – High; Subalpine - Moderate
        i. Participant confidence: High

Additional comments: Total acreage of alpine/subalpine ecosystems is small and getting smaller. The subalpine runs continuously south of Tahoe, but is somewhat more disconnected north of Tahoe. The alpine system appears much more fragmented than subalpine. Portions of the southern Sierra Nevada have consistent but limited alpine zones, and a fairly continuous subalpine zone. North of Tahoe the alpine zone is relatively sporadic and fragmented.

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2. **Resistance, recovery, and refugia.**
    a. Ability of system to resist or recover from impacts: Low
        i. Participant confidence: High
    b. Suitable microclimates within the system that could support refugial communities: Because the alpine and subalpine systems may require up to 300 years to recover, the particpants' assessed the recovery rating as low. In the alpine/subalpine system there is very little connectivity and soil mass. Topography would also impact the system's ability to resist or recover from impacts. Some of the narrow, deep canyons, and riparian areas will be more resilient. The north / northeast facing slopes are considered more biologically diverse and provide a dense microclimate for diversity and will remain cooler and retain more snowpack as climate changes. However, precipitation and snowpack vary depending on rain shadow, slope orientation, tree cover, and elevation.

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3. **Landscape permeability.**
    a. Degree of landscape permeability: Low-moderate
        i. Participant confidence: Low
    b. Potential types of barriers to dispersal that apply: Geologic features

Additional comments: The alpine system has low landscape permeability, while the subalpine system has moderate landscape permeability. However, narrow and deep canyons may provide cool, wet refugia. The alpine zone has very few existing developments and little development potential, while the subalpine is more vulnerable to development impact. The alpine system is very fragile once disturbed, due in part to the shallow soil layer and slow growing plants. The isolated nature of mountaintops, particularly in the north, represent barriers to alpine species dispersal. Species that have elevational migrations (like bighorn sheep) may experience dispersal barriers from development in lower elevation ecosystems.

References: Many species in the subalpine and alpine area have limited room to vertically migrate because they are already located at the higher elevations of the Sierra Nevada. The area available to occupy decreases with elevation. Because of this, models have predicted a 70-95% loss in alpine/subalpine forest relative to 1961-1990 stands (Hayhoe et al. 2004).

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4. **System diversity.**
    a. Level of physical and topographic diversity: Low

        i. Participant confidence: Moderate-High

b. <u>Level of component species/functional group diversity</u>: No answer provided by breakout group
    i. Participant confidence: No answer provided by breakout group
c. <u>Description of diversity</u>: No answer provided by breakout group

Additional comments: Physical and topographic diversity is low for alpine zones, and moderate for subalpine zones. There is diversity in topographic features running south of Tahoe, somewhat consistent with granite along the crest, and eastern slopes are more granitic. Participants believe that differences exist in faunal diversity between the Sierra Nevada and the southern Cascades, as well as between the east and west slopes of the Sierra Nevada. However, there is consistency in species in the alpine zones in both the southern and northern parts of the state.

References:
<u>Community structure</u>: In general, many species in the alpine and subalpine are experiencing enhanced growth. Since 1929-34, 6 of 8 tree species increased small tree densities at both the upper and lower boundaries of subalpine; tree composition was the same (Dolanc et al. 2013). Trees are colonizing historically subalpine meadows (Millar et al. 2004). Trees are also increasingly occupying formerly persistent snowfields since the 1900s with pulses correlated to Pacific Decadal Oscillation (PDO) and minimum temperature (Millar et al. 2004). High elevation ecosystems experience harsh conditions and suitable growing conditions only exist for an average of 6-9 weeks a year (Fites-Kaufman et al. 2007). Most plants are very slow growing but long lived; plants in this zone can remain reproductively active for decades to centuries. There is a strong decline in the forest turnover with increasing elevation (Fites-Kaufman et al. 2007).

The limber pine appears to be more drought-hardy and may have higher genetic diversity, allowing for adaptation to drought conditions relative to the whitebark pine. The whitebark pine does not appear to have the adaptive genetic diversity for drought and warmth (Millar et al. 2010). Despite cooling since the 1940s, mountain hemlock populations have continued to expand, suggesting that tree patches provide microclimatic amelioration and cause recruitment despite unfavorable climatic conditions(Taylor 1995).

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5. **Management potential.**
    a. <u>Value level people ascribe to this system</u>: High
        i. Participant confidence: Moderate-high
    b. <u>Specificity of rules governing management of the system</u>: High
        i. Participant confidence: High
    c. <u>Description of use conflicts</u>: Both alpine and subalpine zones are largely covered by protected area designations such as wilderness, national park, or national forest roadless areas. However, options for active management are very limited due to the various environmental rules and geologic constraints. A potential management option includes reducing non-climate stressors, particularly those originating outside of the protected areas. Other options include taking action to address invasive species and address wildfire management. Limiting and channeling visitor use impacts within protected areas is also an option.
    d. <u>Potential for managing or alleviating climate impacts</u>: See above

Additional comments: There may be a need to increase artificial snowpack in light of future projected climate temperatures in the Sierra. Other adaptive capacity options may include developing connectivity routes for species migration.

References identified by participants: Aplet and Gallo 2012.

6. **Other adaptive capacity factors.**
   a. Additional factors affecting adaptive capacity: Artificial snowpack (see above)
      i. Participant confidence: No answer provided by breakout group
   b. Collective degree these factors affect the adaptive capacity of the system: No answer provided by breakout group

7. **Overall user ranking.**
   a. Overall adaptive capacity of the system: Low
      i. Participant confidence: Moderate

Additional comments: For alpine zone the capacity is low. For subalpine zone, the capacity is low to moderate.

Exposure

1. **Exposure factors[9].**
    a. Factors likely to be most relevant or important to consider for the system: Temperature, precipitation, dominant vegetation type, climatic water deficit, wildfire, snowpack, runoff, timing of flows, other – type of precipitation
        i. Participant confidence: Moderate (temperature), moderate (precipitation), low-moderate (dominant vegetation type), low (climatic water deficit), low (wildfire), moderate (snowpack), low-moderate (runoff), low-moderate (timing of flows), low (other – type of precipitation)

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

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

References:

Vegetation changes: Models of climate change in the Sierra Nevada predict uphill migration (Van de Ven et al. 2007) and restricted distribution of alpine/subalpine plant communities (Lenihan et al. 2006; Van de Ven et al. 2007,). In the three scenarios modeled by Lenihan et al. (2006) to the end of the century, alpine/subalpine forest experienced significant declines in extent, particularly under the warmest conditions. Similarly, Lenihan et al. (2003) and Hayhoe et al. (2004) project declines in alpine and subalpine habitat extent by 75-90% by the end of the century. Scenarios with longer and warmer growing seasons resulted in replacement of alpine/subalpine forest at high elevations with other vegetation types. For example, some models predict advancement of shrubland into alpine/subalpine habitats (Lenihan et al. 2003). Van de Ven et al. (2007) modeled predicted distributions of 14 alpine and subalpine species in the (arid) White and Inyo Mountains to an increased temperature of 6°C, in 1°C increments. All species are predicted to shift upslope and decrease their ranges due to this shift. Some shifted from south to north facing slopes, and previously continuous habitat became fragmented. At an increase of 3°C, 2 species became extinct, and the new ranges of the remaining species areas were 68% or less of current areas. At an increase of 6°C, 10 out of 14 species disappeared from the study area, and the remaining 4 shrank to 1% of their current ranges.

Millar et al. (2006) found that Medieval climatic conditions were similar to those projected for 2070-2099 in Whitewing Mountain and San Joaquin, Mono County, but produced a significant increase in subalpine forest extent and diversity, in contrast to the estimated 75-90% reduction of subalpine forest projected based on vegetation-climate projections.

Although warming at high elevations is commonly assumed to exert primary effect by causing altitudinal shifts in treeline, complex changes in spatial distribution, productivity, and type conversions below treeline may be more important, at least in the early decades of the 21st century (Millar et al. 2004). A warming-induced rise in treeline elevation is likely to involve landscape-scale increases in biomass, productivity, and carbon pools as a result of increases in forested area and density (Lloyd & Graumlich

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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.

1997). However, the paleoecological record indicates that future warming is unlikely to cause an expansion of subalpine forests if it is accompanied by a reduction in water supply (Lloyd & Graumlich 1997).

Moreover, data on alpine microclimate traits suggest that models predicting upslope movements of species under increasing temperatures may not be entirely realistic, and that sufficient microclimate heterogeneity may slow such migration. Graham et al. (2012) built upon work by Scherrer and Körner (2011) which revealed large and persistent microhabitat temperature variations over mesoscale alpine landscape, mimicking temperature gradients of several hundred meters of elevation, suggesting that alpine plants may find appropriate thermal niches for establishment and survival without elevational shifts. Graham et al. (2012) found that alpine fellfield topographic variability in the White Mountains creates thermal microhabitat conditions at a scale of centimeters, due to the presence of low-lying plants, which transpire and shade the soil surface. Fellfield habitats may offer significant buffering from climate warming because the temperature differences are greater than the range of warming scenarios over the next century in projects by the Intergovernmental Panel on Climate Change (IPCC). However, understanding of the relative significance of limiting factors such as temperature means and extremes, and moisture availability in species establishment and survival in alpine habitats remains poor (Graham et al. 2012).

Temperature: High elevation forests have seen pronounced increases in temperature over the past century (Dolanc et al. 2013). Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004: Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1^{o}C by 2049, and 2-3^{o}C by 2099 (Das et al. 2011). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GDFL[10] and PCM[11]) predict summer temperatures to increase 1.6-2.4˚C by mid- century (2049), with the least increases expected in the northern bioregion, and greatest increases expected in the southern bioregion (Geos Institute 2013). By late century (2079), summer temperatures are forecast to increase 2.5-4.0˚C, with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Winter temperatures are forecast to increase 2.2-2.9˚C by late century (2079), with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

Precipitation: Precipitation has increased slightly (~2%) in the Sierra Nevada over the past 30 years compared with a mid-twentieth century baseline (1951-1980) (Flint et al. 2013). Projections for future precipitation in the Sierra Nevada vary among models; some demonstrate little to no change (e.g. PCM) while others demonstrate more substantial changes (e.g. GFDL). In general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

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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. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation that falls as snow at the high elevations that characterize this part of the range (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. 2012), with the current pattern 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). Increased rain:snow ratio and advanced timing of snowmelt initiation are expected to advance the runoff center of mass by 1-7 weeks by 2100 (Maurer 2007), although advances will likely be non-uniformly distributed in the Sierra Nevada (Young et al. 2009). 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, decreasing meal annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

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).

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).

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).

Historically, forest fires were relatively rare in alpine and subalpine vegetation, and did not play as strong a role in structuring these ecosystems as they did in lower elevation systems (Van de Water and Safford 2011, Safford and Van de Water 2013).However, with earlier snowmelt and warmer temperatures, models and current trends suggest that fire may become a more significant ecological disturbance in high elevation forests through the 21st century (Fites-Kaufman et al. 2007; Mallek et al. 2013), especially if climate warming leads to densification of bristlecone stands (Dolanc et al. 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). The area burned by fire and the fire severity is expected to increase with a changing climate in the alpine and sub-alpine. Models indicate that there may be a 125% increase in small wildfires that cannot be readily suppressed and turn into large wildfires. This could cause a potential increase in the area burned at high elevation by 41% (Fites-Kaufman et al. 2007).

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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