Focal Resource: BRISTLECONE PINE

Taxonomy and Related Information

Great Basin bristlecone pine (*Pinus longaeva* also known as *Pinus aristata* Engelm. var. *longaeva* (D.K. Bailey); White and Inyo Mountains.

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[1]. The following document represents the vulnerability assessment results for the **BRISTLECONE PINE**, 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[2].

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] 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.

[2] 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: whether the species is a generalist or specialist; physiological sensitivity to temperature, precipitation, and other factors (e.g., pH, salinity); dependence on sensitive habitats; species' life history; sensitivity of species' ecological relationships (e.g., predator/prey, competition, forage); sensitivity to disturbance regimes (e.g., wind, drought, flooding); and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: dispersal ability and barriers to dispersal, phenotypic plasticity (e.g., can the species express different behaviors in response to environmental variation), species' potential to adapt evolutionarily to climate change, species' intraspecific/life history diversity (e.g., variations in age at maturity, reproductive or nursery habitat use, etc.), and species' value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the species 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[3]. 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*[4].

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*[4].

Recommended Citation

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[3] 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.

[4] 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

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	**2 Between generalist & specialist**	**2 Moderate**
Physiology	**3 High**	**3 High**
Habitat	**3 High**	**3 High**
Life History	**3 K-selection**	**3 High**
Ecological Relationships	**2 Moderate**	**2 Moderate**
Disturbance Regimes	**Varied**	**1 Low**
Non-Climatic Stressors – Current Impact	**1 Low**	**3 High**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**1 Low**	**2 Moderate**
Other Sensitivities	**2 Moderate**	**2 Moderate**

Overall Averaged Confidence (Sensitivity)[5]: Moderate-High

Overall Averaged Ranking (Sensitivity)[6]: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	**3 High**	**3 High**
Barriers Affect Dispersal Ability	**1 High**	**3 High**
Plasticity	**1 Low**	**3 High**
Evolutionary Potential	**1 Low**	**2.5 Moderate-High**
Intraspecific Diversity/Life History	**1 Low**	**3 High**
Species Value	**3 High**	**3 High**
Specificity of Management Rules	**3 High**	**3 High**
Other Adaptive Capacities	**2 Moderate**	**2 Moderate**

Overall Averaged Confidence (Adaptive Capacity)[5]: High

Overall Averaged Ranking (Adaptive Capacity)[6]: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	**3 High**
Precipitation	**3 High**
Shifts in vegetation type	**3 High**
Climatic water deficit	**1 Low**
Snowpack	**1 Low**
Runoff	**3 High**

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

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

Relevant Exposure Factor	Confidence
Timing of flows	**3 High**
Other: Competition; Soils – White and Inyo Mountains	**3 High**

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**Not applicable**	**Not applicable**
Central Sierra Nevada	**Not applicable**	**Not applicable**
Southern Sierra Nevada	**Low-Moderate**	**3 High**

Overall Averaged Confidence (Exposure)[5]: Moderate

Overall Averaged Ranking (Exposure)[6]: Low-Moderate

Sensitivity

1. Generalist/Specialist.

   a. Where does species fall on spectrum of generalist to specialist: In between with some specialist tendencies
      i. Participant confidence: Moderate
   b. Factors that make the species more of a specialist: Seed dispersal dependency, other – soils.

Additional comments: Bristlecone may be closer to a specialist because it prefers a specific climate. It also prefers dolomitic soils, but is not dependent on them. It can handle granitic soils but gets outcompeted on them, by sagebrush, for example. It is primarily dependent on the Clark's nutcracker (*Nucifraga columbiana*) for seed dispersal.

References: Great Basin bristlecone pine is most common on thin, rocky substrates. Soils are usually derived from limestone or dolomite (Lanner 1985, Welsh et al. 1987, Kartesz 1988, Hickman 1993 cited in Fryer 2004), although some populations grow on sandstone or quartzite (Lanner 1999 cited in Fryer 2004). In the White Mountains, Great Basin bristlecone pine communities occur on dolomite soils with a rock content of 50% or more. Dolomite soils are alkaline, high in calcium and magnesium, and low in phosphorus. Those factors tend to exclude other plant species. For example, limber pine co-dominates or associates with Great Basin bristlecone pine on dolomite soils in the White Mountains, but becomes the dominant species on granitic soils (Fritts 1969 cited in Fryer 2004). Moreover, dolomite soils are light-colored, reflect more light, are cooler, and have a higher total water storage capacity (~20%) than surrounding soils, and those factors favor Great Basin bristlecone pine establishment (Wright 1965 cited in Fryer 2004). Some Great Basin bristlecone pine populations on Wheeler Peak occur on quartzite and monzonite soils, although most are on limestone (Bare 1982, Hiebert and Hamrick 1983, Hiebert 1977, Lanner 1985 cited in Fryer 2004).

Bristlecone pine only grows where *Artemisia* is sparse or absent. If *Artemisia* becomes established where bristlecone pine is expected to shift, *Artemisia* would likely reduce seedling establishment and growth (Wright and Mooney 1965, LaMarche 1973 cited in Van de Ven 2007).

2. Physiology.

   a. Species physiologically sensitive to one or more factors including: Temperature, precipitation, other – soils
   b. Sensitivity of species' physiology to one or more factors: High
      i. Participant confidence: High

Additional comments: There is uncertainty related with soils. Dolomitic soils may not be available at higher elevations. In terms of precipitation, some studies say it is sensitive, some say it is not.

References: High elevation forest responses appear to be largely dictated by water supply (Lloyd and Graumlich 1997; Fites-Kaufman et al. 2007).

A strong positive relationship exists between temperature and treeline growth (i.e. ring width) of bristlecone pine. No clear decadal-scale relationship between precipitation and growth was found however, weaker positive associations at sites in Sheep Mountain, California, Mt. Washington, Nevada, and Pearl Creek, Nevada may indicate precipitation contributed to growth (Salzer et al. 2009).

Habitat availability at higher elevations in the White and Inyo Mountains is limited by its aversion to granitic substrates. With an increase in temperature of 5°C, carbonate substrates at high enough elevations may not be available (Van de Ven et al. 2007). However, surveys of remnant bristlecone snags and logs show that the bristlecone pine occurred higher in the White Mountains, when temperatures were approximately 3.5°C warmer about 6000 years ago (LaMarche and Mooney 1967, LaMarche 1973 cited in Van de Ven 2007).

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3. Sensitive habitats.

- a. Species dependent on sensitive habitats including: Alpine/subalpine, other – soils
- b. Species dependence on one or more sensitive habitat types: High
  - i. Participant confidence: High

Additional comments: See soils comment above.

References: In California, Great Basin bristlecone pine occurs in montane, subalpine, and timberline communities. In California, it occurs between 2200-3700 m (7200–12000 ft) (Hickman 1993 cited in Fryer 2004). Schulman (1954, cited in Fryer 2004) suggested that longevity of bristlecone pines is directly related to site adversity.

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4. Life history.

- a. Species reproductive strategy: K-selection
  - i. Participant confidence: High
- b. Species polycyclic, iteroparous, or semelparous: Iteroparous

Additional comments: Although the population produces cones each year, individual trees do not. Trees may produce cones every few years. Dispersal, and especially recruitment are the limiting factors. Recruitment can be decadal.

References: Great Basin bristlecone pine does not mast, but is a steady cone and seed producer (Lanner 1988). Great Basin bristlecone pine has the longest life span of any non-clonal species, and can produce viable seed for thousands of years (Lanner 1985, Lanner 1988 cited in Fryer 2004). In the White Mountains, the Alpha tree continues to produce viable seed at 4,300+ years of age (Lanner 1985 cited in Fryer 2004). Although conditions required for seedling establishment are rarely met, endurance of seed production, together with the capacity to produce seeds yearly, allow bristlecone pines to take advantage of infrequent favorable conditions to germinate and grow (Billings and Thompson 1957, Keeley and Zedler 1998 cited in Fryer 2004).

Seedling establishment is a rare event for Great Basin bristlecone pine. Since Great Basin bristlecone pine primarily grows on dry, nutrient-poor soils, conditions favorable to Great Basin bristlecone pine germination and growth are infrequent (Billings 1957, Keeley and Zedler 1998 cited in Fryer 2004).

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5. Ecological relationships.

- a. Sensitivity of species' ecological relationships to climate change including: Habitat, hydrology, competition, other – fire at lower elevation edge of range
- b. Types of climate and climate-driven changes that affect these ecological relationships including: Temperature, precipitation, other – snow
- c. Sensitivity of species to other effects of climate change on its ecology: Moderate
  - i. Participant confidence: Moderate

Additional comments: Currently outcompetes in dolomitic soils but gets outcompeted in higher elevation granitic soils. Maybe with climate change and bristlecone moving upslope, it will be able to outcompete.

References:

As temperatures increase, bristlecone pine migrates to higher elevations in the White and Inyo mountains where its habitat availability is limited by its aversion to granitic substrates. With an increase in temperature of 5°C, carbonate substrates at high enough elevations may not be available (Van de Ven et al. 2007).

Great basin bristlecone pine may outcompete other plant species on dolomite soils, on which the high calcium and magnesium and low phosphorus tend to exclude other plants, but appears to be a poor competitor elsewhere, resulting in limber pine becoming the dominant species on granitic soils (Fritts 1969 cited in Fryer 2004).

Throughout its range, Great Basin bristlecone pine grows in pure stands in timberline and upper subalpine zones and co-dominates or associates with limber pine (*Pinus flexilis*) at lower elevations (Critchfield and Allenbaugh 1969, Vasek and Thorne 1977 cited in Fryer 2004). Great Basin bristlecone pine communities are surrounded by sagebrush (*Artemisia* spp.) and salt-desert communities at low elevations. Cushion plant communities and bare rock occur above Great Basin bristlecone pine communities (Hiebert 1977, Bare 1982 cited in Fryer 2004). Great Basin bristlecone pine communities usually merge with low sagebrush or limber pine communities at about 2900 m (9500 ft) elevation, but sometimes merge with singleleaf pinyon-western juniper (*Juniperus occidentalis*) woodlands, particularly on Nevada's eastern slope (Thorne 1976, Holland 1986 cited in Fryer 2004). Mooney et al. (1966, cited in Fryer 2004) concluded that Great Basin bristlecone pine was better adapted to colder, high-elevation sites, while big sagebrush was better adapted to the warmer temperatures typical of lower elevations.

Despite temperature increases, individual bristlecone pine may survive hundreds of years at low-elevations due to slow dieback and local refugia, while species like *Pinus monophylla* and *Juniperus osteosperma* rapidly migrate upslope, resulting in rare, transitory forest associations. The combination of bristlecone–pinyon–juniper forest is currently very rare in the White Mountains but could become more commonplace as temperatures increase (Van de Ven et al. 2007).

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6. Disturbance regimes.

  a. Disturbance regimes to which the species is sensitive include: Wildfire, drought, insects, disease
  b. Sensitivity of species to one or more disturbance regimes: Varied
    i. Participant confidence: Low

Additional comments: Sensitivity to disturbance regimes is categorized as varied overall, including low sensitivity to drought, moderate sensitivity to fire, and high sensitivity to disease and insects. Fire potential generally occurs at lower elevation edge of range. No known current insect or disease outbreaks (except black root), although uncertain if species is highly resistant or simply not exposed (likely susceptible to pine beetle). Drought leads to high sensitivity. Uncertainty in terms of sensitivity to disturbance regimes is high.

References:
Wildfire: Bristlecone is a thin-barked pine and not well-suited to survive fire (Zavarin and Snajberk 1973 cited in Fryer 2004). Methods of Great Basin bristlecone pine post-fire seedling establishment are undocumented (Fryer 2004). Stand dynamics in high-elevation Great Basin bristlecone pine communities are more influenced by climate and seed dispersal patterns than by fire (Lanner 1980, Lanner 1985, Lanner 1988, Bradley et al. 1991 cited in Fryer 2004). In the White Mountains, however, the low density of bristlecone trees and the general lack of flammable groundcover and litter between them generally

precludes widespread burning, at least under current conditions (LaMarche and Mooney 1967 cited in Fryer 2004).

Drought: Great Basin bristlecone pine is highly drought tolerant (Tang et al. 1999; Bare 1982 cited in Fryer 2004). In the White Mountains, average rainfall during the growing season is about 2.5 in (64 mm) (LaMarche and Mooney 1972 cited in Fryer 2004). Branched, shallow roots maximize water absorption, and waxy needles and thick needle cuticles increase water retention (Conner and Lanner 1991 cited in Fryer 2004). A high proportion of dead:live wood reduces respiration and water loss, potentially extending bristlecone life span by allowing the tree to maintain a constant ratio of photosynthesizing to non-photosynthesizing live tissue (Wright and Mooney 1965, Keeley and Zedler 1998 cited in Fryer 2004). Further, Great Basin bristlecone pines exhibit a high proportion of dead trunk- and branchwood on harsh sites (Lanner 1990 cited in Fryer 2004), indicating a diversity of morphologies that may support adaptive capacity. Factors slowing growth include high elevation; extreme temperatures; dry, nutrient-poor soils; strong winds; south and west aspects; and high amounts of solar radiation (Beasley and Klemmedson 1973 cited in Fryer 2004).

Insects and disease: Surveys have not found rust infections in Great Basin bristlecone pine in California (Maloney 2011), although populations in the White and Inyo Mountains lie close to moderately high white pine blister rust (*Cronartium ribicola*) infection centers in the Sierra Nevada, and may be at risk for infection and spread (Smith and Hoffman 2000 cited in Fryer 2004). Blister rust-infected white pines such as Great Basin bristlecone pine may take 2 years to decades to succumb, but infection is always fatal (Hoff 1992, Hoff et al. 1994 cited in Fryer 2004). The Great Basin bristlecone pine is also susceptible to mountain pine beetle (*Dendroctonus ponderosae* Hopkins) infestations throughout its range (Lanner 1985 cited in Fryer 2004), and rising minimum temperatures, combined with drought, may increase bark beetle infestations in the Sierra Nevada (Millar et al. 2007 cited in Millar et al. 2012).

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7. **Interacting non-climatic stressors.**
   a. Other stressors that make the species more sensitive include: Altered interspecific interactions, invasive and other problematic species
   b. Current degree to which stressors affect the species: Low
      i. Participant confidence: High
   c. Degree to which non-climate stressors make species more sensitive: Low
      i. Participant confidence: Moderate

Additional comments: Invasive species (e.g., cheatgrass) may increase fires however, drier temperatures with climate change could buffer cheatgrass invasions. Interspecific interactions were identified as a stressor due to the Clark's nutcracker likely moderate sensitivity to climate change, as it serves as a main dispersal mechanism for bristlecone pine. Interspecific interactions also include removal of competitors.

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8. **Other sensitivities.**
   a. Other critical sensitivities not addressed: Dispersal
      i. Participant confidence: Moderate
   b. Collective degree these factors increase species' sensitivity to climate change: Moderate

Additional comments: Dispersal is potentially dependent on Clark's nutcracker (and maybe chipmunks). Clark's nutcracker is likely moderately sensitive to climate change.

References: It has been suggested that Clark's nutcrackers disperse Great Basin bristlecone pine seeds (Lanner et al. 1984, Lanner 1988, Lanner 1996 cited in Fryer 2004).

9. **Overall user ranking.**
    a. Overall sensitivity of this species to climate change: High
        i. Participant confidence: Moderate

Additional comments: In an absolute sense, user ranking is high, but relative to other alpine/subalpine species, bristlecone pine may be considered moderate. Existing bristlecone pine might survive, but it may be very difficult or impossible to get new generations if recruitment and dispersal do not occur due to climate change.

Adaptive Capacity

1. **Dispersal ability.**
    a. Maximum annual dispersal distance: 5-50 km (3-31 mi)
        i. Participant confidence: Moderate
    b. Ability of species to disperse: High
        i. Participant confidence: High
    c. General types of barriers to dispersal include: Other – requires a disperser (Clark's nutcracker)
    d. Degree barriers affect dispersal for the species: High
        i. Participant confidence: High
    e. Possibility for individuals to seek out refugia: It may be possible for adult trees, but it is unlikely for seed dispersal and recruitment due to soil, climate conditions, and dispersal agent.

Additional comments: Maximum annual dispersal distance based on Clark's nutcracker. The ability to disperse is high, but it needs an animal species to disperse.

References: Great Basin bristlecone pine occurs in a relatively narrow latitudinal range in California, Nevada, and Utah (Little 1971, Lanner 1999 cited in Fryer 2004). In California, it occurs on the summits of the Panamint, Inyo, and White mountains of Mono and Inyo counties (Hickman 1993 cited in Fryer 2004).

Great Basin bristlecone pine is pollinated by wind (Lanner 1990, Lanner 1996 cited in Fryer 2004). 'Germinability' of Great Basin bristlecone pine pollen may be low. Great Basin bristlecone pine reproduces from seed (Lanner 1985 cited in Fryer 2004), and it has been suggested that Clark's nutcrackers disperse Great Basin bristlecone pine seeds (Lanner et al. 1984, Lanner 1988, Lanner 1996 cited in Fryer 2004).

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2. **Plasticity.**
    a. Ability of species to modify physiology or behavior: Low
        i. Participant confidence: High
    b. Description of species' ability to modify physiology or behavior: Not really able to modify physiology or behavior.

Additional comments: Bristlecone are very tough and able to persist in marginal habitats and drought conditions. Bristlecone pines are long-lived and not designed to change during their life.

References:
In the White Mountains, Johnson and Critchfield (1974, cited in Fryer 2004) noted a high degree of polymorphism in pollen and female cone characteristics of trees in the Sherman Grove. In addition, Great Basin bristlecone pine is a native conifer of highly variable growth form. Great Basin bristlecone pine bark is thin (Zavarin and Snajberk 1973 cited in Fryer 2004), however, Great Basin bristlecone pines on harsh sites have a high proportion of dead trunk- and branchwood. Old trunks and exposed roots have thick, vertical ribbons of dead wood. Between the dead ribbonwood, thin strips of living root and stem tissue support living branches (Lanner 1990 cited in Fryer 2004). In younger trees, branches are long and pendulous, forming an irregular crown (Tang et al. 1999).

Physiological and morphological adjustments made in the needles in response to summer drought in the White Mountains also protect trees from winter desiccation, which is largely responsible for inducing krummholz growth (LaMarche and Mooney 1972 cited in Fryer 2004). In addition, during the past 200 years, increased water use efficiency by bristlecone pine is attributed to increased atmospheric CO_2 (Tang et al. 1999).

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3. **Evolutionary potential.**
   a. Ability of species to adapt evolutionarily: Low
      i. Participant confidence: Moderate-High
   b. Description of characteristics that allow species to adapt evolutionarily: Bristlecone pine has genetic diversity within the population in White Mountains (small area), but generation time is slow that it is unlikely to keep up with climate change.

References: Few studies have been conducted on Great Basin bristlecone pine population genetics. In the White Mountains, Johnson and Critchfield (1974, cited in Fryer 2004) noted a high degree of polymorphism in pollen and female cone characteristics of trees in the Sherman Grove. Hiebert and Hamrick (1983, cited in Fryer 2004) conducted allozyme tests on 5 Great Basin bristlecone pine populations across eastern Nevada and western Utah. They found normal to high levels of genetic variation in Great Basin bristlecone pine compared to other pine species. Most variation occurred within, rather than among, populations. Polymorphic loci and number of alleles per loci were average for pines; level of heterozygosity was above average. The authors attributed high levels of heterozygosity to wind pollination, Great Basin bristlecone pine's multiple-age class structure, and its wide geographic distribution in the Pleistocene.

Populations in the White Mountains may be less genetically diverse than eastern Great Basin bristlecone pine populations. In the Ancient Bristlecone Pine Botanical Area, allozyme and DNA tests showed slightly lower than average genetic variation for Great Basin bristlecone pine compared to most pine species. Genetic variation at the population level was about average for pine species (Lee et al. 2002 cited in Fryer 2004).

Great Basin bristlecone pines on desert "sky islands" may be susceptible to inbreeding due to poor pollen and seed dispersal (Lanner et al. 1984 cited in Fryer 2004).

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4. **Intraspecific diversity/life history.**
   a. Degree of diversity of species' life history strategies: Low
      i. Participant confidence: High
   b. Description of diversity of life history strategies: Bristlecone pine exhibits one life history strategy without much variation.

References: There is no evidence of vegetative reproduction (Lanner et al. 1984).

Also refer to the references in *Question 3 'Evolutionary Potential'*.

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5. **Management potential.**
   a. Value level people ascribe to this species: High
      i. Participant confidence: High
   b. Specificity of rules governing management of the species: High
      i. Participant confidence: High
   c. Description of use conflicts: None. All federal and wilderness lands in which bristlecone pine occurs are almost all protected.
   d. Potential for managing or alleviating climate impacts: Some groves are in areas that have management potential, but how to manage is uncertain (e.g., fire and weeds can be

managed, but mechanical equipment is unlikely). Possible actions include seed dispersal or other planting projects.

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6. **Other adaptive capacity factors.**
   a. Additional factors affecting adaptive capacity: Ectomicrorhyzal fungus
      i. Participant confidence: Moderate
   b. Collective degree these factors affect the adaptive capacity of the species: Moderate

Additional comments: Very low diversity associated with bristlecone stands, which could predispose it to climate impacts. Bristlecone pine is dependent on fungi for water uptake. More research is needed to better understand adaptive capacity of the species.

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7. **Overall user ranking.**
   a. Overall adaptive capacity of the species: Moderate-High
      i. Participant confidence: No answer provided by participants

Additional comments: Bristlecone have long generation times. They are hardy but rely on species for dispersal, water uptake, and competition; those species are also likely sensitive to climate change.

Exposure

1. **Exposure factors[7].**
   a. Factors likely to be most relevant or important to consider for the species: Temperature, precipitation, snowpack, shifts in vegetation type, climatic water deficit, wildfire, other – competition, soils.
      i. Participant confidence: Low (climatic water deficit & wildfire); High (all others)

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2. **Exposure region.**
   a. Exposure by region: North – Not applicable; Central – Not applicable; South – Low-Moderate
      i. Participant confidence: High

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

Additional comments: Exposure is largely dependent on species that bristlecone relies on (e.g., for dispersal, water uptake, etc.). MC1 dynamic vegetation modeling demonstrates fewer climate impacts on White Mountains. However, uncertainty is high and more climate modeling is needed for White and Inyo Mountains.

References: Van de Ven et al. (2007) assert that despite temperature increases, individual bristlecone pine may survive hundreds of years at low-elevations due to slow dieback and local refugia, while species like *Pinus monophylla* and *Juniperus osteosperma* rapidly migrate upslope, resulting in rare, transitory forest associations. The combination of bristlecone–pinyon–juniper forest is currently very rare in the White Mountains but could become more commonplace as temperatures increase (Van de Ven et al. 2007).

Temperature: 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°C by 2049, and 2-3°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[8] and PCM[9]) 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).

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[7] Participants were asked to identify exposure factors (i.e., climate and climate-driven changes) most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

[8] Delworth, T. L., Broccoli, A. J., Rosati, A. et al. (2006) GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. Journal of Climate, 19:643-674.

[9] Washington, W. M., Weatherly J. W., Meehl G. A. et al. (2000) Parallel climate model (PCM) control and transient simulations. Climate Dynamics 16:755-744.

Vegetation shifts: Many models of climate change in the Sierra Nevada predict uphill migration and restricted distribution of alpine/subalpine plant communities (Hayhoe et al. 2004; Lenihan et al. 2006; Van de Ven et al. 2007). However, habitat availability at higher elevations in the White and Inyo Mountains may be limited by bristlecone pine's aversion to granitic substrates. With an increase in temperature of 5°C (9°F), carbonate substrates at high enough elevations may not be available (Van de Ven et al. 2007).

Precipitation: High elevation forests have seen pronounced increases in temperature over the past century (Dolanc et al. 2013). Over the next century, annual temperatures in the Sierra Nevada are expected to rise between 2.4-3.4˚C varying by season, geographic region, and elevation (Das et al. 2011; Geos Institute 2013). 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), with changes of least magnitude during both seasons anticipated 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).

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 (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 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). 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).

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).

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).

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). Wildfire would be expected to have greatest impact in denser stands and at lower elevations adjacent to relatively productive upper montane forests, where fuel loading is higher and spatially contiguous.

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 species 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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