



Sierra Nevada Individual Species Vulnerability Assessment Briefing: Bristlecone Pine

Pinus longaeva; also known as *Pinus aristata* Engelm. var. *longaeva* (D.K. Bailey)

Background and Key Terminology

This document summarizes the primary factors that influence the vulnerability of a focal resource to climate change over the next century. In this context, vulnerability is a function of the sensitivity of the resource to climate change, its anticipated exposure to those changes, and its capacity to adapt to changes. Specifically, sensitivity is defined as a measure of whether and how a resource is likely to be affected by a given change in climate, or factors driven by climate; exposure is defined as the degree of change in climate or climate-driven factors a resource is likely to experience; and adaptive capacity is defined as the ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011). The purpose of this assessment is to inform forest planning by government, non-profit, and private sector partners in the Sierra Nevada region as they work to integrate climate change into their planning documents.

Executive Summary

The overall vulnerability of bristlecone pine is ranked moderate, due to its moderate sensitivity to climate and non-climate stressors, moderate adaptive capacity, and low-moderate exposure.

Bristlecone pines are sensitive to climate and climate-driven changes such as:

- increased temperature,
- decreased water supply (e.g. climatic water deficit), and
- increased fire frequency or intensity.

Great Basin bristlecone pine sensitivity to changes in temperature, water supply and fire regimes is largely undetermined. Despite drought tolerance, soils with greater moisture retention capacity may favor establishment. Increased temperatures have been associated with recent unprecedented treeline growth, however warming temperatures may also shift bristlecone pine upslope, where adequate soils may not be available.

Bristlecone pines are also sensitive to non-climate stressors including:

- insects and disease.

Although not currently affected, bristlecone pines are sensitive to blister rust and pine beetle infestations, which may be aggravated by changing climate. The adaptive capacity of bristlecone pines is facilitated by drought tolerance, long life span, extended seed production, and genetic diversity.



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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Bristlecone pines are extremely long-lived and drought tolerant, and their sensitivity to changes in temperature, water supply and fire regimes is unclear. High elevation forest responses appear to be largely dictated by water supply (Lloyd and Graumlich 1997; Fites-Kaufman et al. 2007). Although bristlecone pines are highly drought tolerant (Bare 1982 cited in Fryer 2004), they occur largely on limestone and dolomite soils (Lanner 1985, Welsh et al. 1987, Kartesz 1988, and Hickman 1993 cited in Fryer 2004), which are cooler and have higher water storage capacity than surrounding soils, and favor bristlecone pine establishment (Wright 1965 cited in Fryer 2004). Altered precipitation and increased temperature may reduce soil water availability, impacting mortality and/or recruitment.

In California, Great Basin bristlecone pines occur between 7200 ft to 12000 ft (2200 m to 3700 m) (Hickman 1993 cited in Fryer 2004). Warming temperatures may shift bristlecone pine ranges to higher elevations in the White and Inyo Mountains, where suitable (i.e. carbonate) substrates at sufficiently high elevations may not be available (Van de Ven et al. 2007). 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 (Fritts 1969 cited in Fryer 2004), but appears to be a poor competitor elsewhere. Bristlecone pine co-dominates with limber pine (*Pinus flexilis*) on dolomite soils in the White Mountains, California, but limber pine becomes the dominant species on granitic soils (Fritts 1969 cited in Fryer 2004). Similarly, 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). 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), suggesting that adequate substrate may be available for bristlecone pines to shift to higher elevations.

Although no clear decadal-scale relationship between precipitation and growth was found at sites in California and Nevada, temperatures and growth (i.e. ring-width) of treeline bristlecone pines displayed a strong positive relationship during the last 50 years (Salzer et al. 2009), suggesting that increased temperatures may benefit bristlecone pine. In addition, during the past 200 years, increased water use efficiency by bristlecone pine is attributed to increased



atmospheric CO₂ (Tang et al. 1999).

Stand dynamics in high-elevation Great Basin bristlecone pine communities are less influenced by fire than by climate and seed dispersal patterns (Lanner 1980, Lanner 1985, Lanner 1988, Bradley et al. 1991 cited in Fryer 2004). However, because bristlecone is a thin-barked pine and not well-suited to survive fire (Zavarin and Snajberk 1973 cited in Fryer 2004), an increase in high-elevation wildfire may be detrimental. 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).

Future climate exposure

Important climate and climate-driven factors to consider for bristlecone pine include changes in temperature, precipitation, snowpack, climatic water deficit, and wildfire.

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).

Temperature: 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; 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), with decreases in summer and fall (Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 18-55% by the end of the century (Das et al. 2011).

Snow volume and timing: Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack and earlier timing of runoff (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; 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 (Thorne et al. 2012; Flint et al. 2013), with declines of 10-25% above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). The greatest declines in snowpack are anticipated for the northern Sierra Nevada (Safford et al. 2012), with current pattern of snowpack retention in the higher-elevation southern Sierra Nevada basins expected to continue through the end of the century (Maurer 2007). Under scenarios of 2-6°C warming, snowpack is projected to decline 10-25% at elevations above 3750 m (12303 ft) (Young et al. 2009). The greatest losses in snowmelt volume are projected 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).

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). 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). However, 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). 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 mean annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

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).

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). Fire severity in the Sierra Nevada also rose from 17% to 34% high-severity (i.e. stand replacing) fire, especially in middle elevation conifer forests (Miller et al. 2009). In the Sierra Nevada, increases in large fire extent have been correlated with increasing temperatures and earlier snowmelt (Westerling and Bryant 2006), as well as current year drought combined with antecedent wet years (Taylor and Beaty 2005). Occurrence of large fire and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing by up to 74% by 2085 (Westerling et al. 2011). The area burned by wildfire in the Sierra Nevada is projected to increase between 35-169% by the end of the century, varying by bioregion, with the greatest increases projected at mid-elevation sites along the west side of the range (Westerling et al. 2011; Geos Institute 2013). 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 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>).

Sensitivity to non-climate stressors

Although not currently exposed, bristlecone pines are also sensitive to non-climate stressors such as disease and insects. 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).

Adaptive Capacity

The adaptive capacity of Great Basin bristlecone pine is largely facilitated by its drought tolerance, long life span, extended seed production, and genetic diversity. 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.

Moreover, the 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). 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).



Although few studies have been conducted on Great Basin bristlecone pine population genetics, a high degree of polymorphism in pollen and female cone characteristics of trees was recorded in Sherman Grove in the White Mountains (Johnson and Critchfield 1974 cited in Fryer 2004). Populations were also found to have normal to high levels of genetic variation compared to other pine species, with most variation occurring within, rather than among, populations. Polymorphic loci and number of alleles per loci were average for pines, while the above average level of heterozygosity was attributed to wind pollination, a multiple-age class structure, and wide geographic distribution in the Pleistocene (Hiebert and Hamrick 1983 cited in Fryer 2004). However, isolated Great Basin bristlecone pines may be susceptible to inbreeding due to poor pollen and seed dispersal (Lanner et al. 1984 cited in Fryer 2004).

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