



Sierra Nevada Individual Species Vulnerability Assessment Briefing: Whitebark Pine

Pinus albicaulis

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 whitebark pine is ranked moderate-high, due to its moderate-high sensitivity to climate and non-climate stressors, moderate adaptive capacity, and moderate-high exposure.

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

- increased temperature,
- decreased snowpack,
- increased climatic water deficit, and
- altered wildfire regime.

Whitebark pine communities appear to have complex responses to variable climate conditions, but are likely sensitive to warming temperatures, decreasing snowpack, increasing climatic water deficit, and altered fire regimes. For example, although warming temperatures have been associated with increased growth, increased climatic water deficit and warming temperatures are associated with recent mortality events.

Whitebark pines are also sensitive to several non-climate stressors including:

- insects and pathogens, and
- dependence on seed disperser (Clark's nutcracker *Nucifraga columbiana*).

Blister rust and mountain pine beetle infestations are considered primary causes of whitebark pine decline in the western U.S. Blister rust infections can reduce the whitebark pine's ability to produce seed, and both blister rust and mountain pine beetle can interact to compound climatic stressors such as drought, contributing substantially to mortality rates. The adaptive capacity of whitebark pine may be facilitated by its long life and relative tolerance to wind,



drought and fire. However, adaptive capacity may be constrained by its limited genetic diversity and dependence on seed dispersers for regeneration.

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Whitebark pine communities appear to have complex responses to variable climate conditions, and are likely sensitive to warming temperatures, decreasing snowpack, increasing climatic water deficit, and altered fire regimes. Whitebark pine responses to warming temperatures may vary. Warming throughout the 20th century in the southeastern Sierra Nevada was positively correlated with annual branch growth rates of whitebark pine (Millar et al. 2004). That warming period produced abundant vertical branches in latter-century krummholz whitebark pine thickets at the upper treeline, compared with the compact, flat-topped crowns displayed at the start of the century (Millar et al. 2004), suggesting that warming temperatures may benefit whitebark pine growth. In contrast, whitebark pines that experienced significant mortality from 2007-2010 at low-elevations in the subalpine zone also experienced warmer, albeit drier conditions relative to the regional species distribution (Millar et al. 2004), suggesting that climatic water deficit may play an important role in whitebark pine persistence. Dolanc et al. (2013a) studied whitebark pine growth responses to climate in the central Sierra Nevada and found that radial growth was positively correlated with higher winter precipitation and higher spring temperatures, however whitebark and other drier-site subalpine species were somewhat sensitive to climate drivers than species found in more mesic sites. Although whitebark pine has been described as abundant on drier inland slopes and largely absent from wetter areas throughout its native range (Arno and Hoff 1989), in some semiarid areas it is more common on comparatively cold and moist sites (Mathiasen 1998 cited in Fryer 2002). Precipitation in whitebark pine communities ranges from 24 to 63 inches per year (Weaver 2001 cited in Fryer 2002), the majority (~66%) of which falls as snow (Arno and Hoff 1989 cited in Fryer 2002). Predicted reductions in snowpack volume and associated increased climatic water deficit may decrease site suitability for whitebark pine and increase mortality. Temperature and water availability also influence reproduction. Studies report that reproduction is best when July day/night temperatures exceed 68°/39°F (20°/4°C), and there is no water stress (Weaver 2001 cited in Fryer 2002).

Whitebark pine responses to fire are also complex, and little is known about the relationship between whitebark pine and fire in California, where stands tend to be much less dense than in the well-studied Rocky Mountain populations. Whitebark pine communities have a mixed-



severity fire regime of widely ranging fire intensities and frequencies (Arno and Hoff 1989, Agee 1994, Barrett 1994, Morgan et al. 1994 cited in Fryer 2002); fire-return intervals range from 30 to greater than 350 years (Arno and Hoff 1989, Barrett 1994, Morgan et al. 1994 cited in Fryer 2002). Fire may support whitebark pine recruitment and establishment by preparing seedbeds (Vogl and Ryder 1969, McCaughey 1990 cited in Fryer 2002), reducing competition (McCaughey 1994 cited in Fryer 2002), and creating forest openings for Clark's nutcracker seed caching (Tomback 1982 cited in Fryer 2002). Higher-severity fires may actually better prepare seedbeds than low-severity fires (McCaughey 1990, Vogl and Ryder 1969 cited in Fryer 2002). Although survivorship is considered best on burned sites (McCaughey 1990 cited in Fryer 2002), very hot fires may retard seedling establishment for several decades (Arno 1980), and surface and crown fires of moderate intensity may kill large mature trees (Barmore et al. 1976, Keane and Arno 2001, Morgan and Bunting 1990 cited in Fryer 2002).

Future climate exposure

Important climate and climate-driven factors to consider for whitebark pine include changes in temperature, precipitation timing and volume, snowpack timing and volume, climatic water deficit, and wildfire. In regions outside of the Sierra Nevada, models predict a decline in whitebark pine due to warming temperature and more frequent summer droughts (McCaughey 1994, Mattson and Reinhart 1997, McCaughey and Tomback 2001 cited in Fryer 2002).

Temperature: 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, 2004 b; 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). 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). 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).

Climatic water deficit: 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. 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). 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 modeling using the Basin Characterization Model predicts increased water deficits (i.e., decreased soil moisture) by up to 44%, with the greatest increases in the northern Sierra Nevada (Thorne et al. 2012; Flint et al. 2013; Geos Institute 2013).

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. 2013b). 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/602b58f9bbd44dff487a04a1c5c0f52>).

Sensitivity to non-climate stressors

Whitebark pines are sensitive to non-climate stressors such as pathogens and insect infestations. Whitebark pine is experiencing the most significant ongoing mortality episode in subalpine forests of western North America (Millar et al. 2012), in which mortality trends have increased since 1998 (Gibson et al. 2008 cited in Millar et al. 2012). The primary reason for these declines has been attributed to mountain pine beetles (*Dendroctonus ponderosae* Hopkins) and blister rust (*Cronartium ribicola*) (Tomback and Achuff 2010). In contrast to reported low-levels of mountain pine beetle mortality in California from 1998-2005 (Gibson et al. 2008 cited in Millar et al. 2012), a major mortality event occurred in eastern California from 2007-2010 (Millar et al. 2012), and expanding centers of pine beetle-caused mortality are currently found in the Warner Mountains and parts of the Inyo National Forest. Mountain pine beetle infestations often occur in conjunction with other pathogens, insects and environmental stressors, such as drought. Pest pressure can increase tree sensitivity to drought (Waring et al. 1987), and drought combined with increasing minimum temperatures, may enhance infestation of pine beetles in whitebark and limber pines (Millar et al. 2010). Warming temperatures may also facilitate an upward elevational shift of mountain pine beetle populations into whitebark pine habitats (Logan et al. 1995, Logan and Powell 2001 cited in Fryer 2002).

Whitebark pines in the western U.S. are also sensitive to the exotic pathogen white pine blister rust (Tomback and Achuff 2010). Although infected trees may not die for several decades, white pine blister rust inhibits the trees' ability to produce seeds (Arno and Hoff 1989). White pine blister rust can also increase whitebark pine susceptibility to beetle-related mortality (Tomback and Achuff 2010). Field surveys in high-elevation forests in 2004-2006 found white pine blister rust in 24% of whitebark pine in the northern Sierra Nevada, and the pathogen is spreading southward in California (Maloney 2011). Currently, white pine blister rust does not appear to be advancing into upper subalpine zones (Millar et al. 2012). However, spread of white pine blister rust may have been limited by climate conditions (Dolanc et al. 2013b), and extended growing seasons may facilitate uphill expansion.



Additionally, because whitebark pine cones do not split open when ripe, the species is heavily dependent on the caching habits of the Clark's nutcracker for seed dispersal (Hutchins and Lanner 1982 cited in Fryer 2002). Clark's nutcrackers break cones and bury the seeds in shallow caches (Tomback 1978, 1982, cited in Fryer 2002), where un-retrieved seeds may germinate into new trees (Hutchins and Lanner 1982, Lanner 1982, Lanner and Gilbert 1994 cited in Fryer 2002). However, when whitebark pines are impacted by blister rust or other disturbance that limits seed production, predation by Clark's nutcracker may leave very few seeds for regeneration (Tomback 2002 cited in Fryer 2002). Seed establishment is aided by ectomycorrhizal fungi (Cripps and Antibus 2011). Climate-driven changes in ectomycorrhizal fungi or Clark's nutcracker may have an important impact on whitebark pine ability to regenerate.

Adaptive Capacity

The adaptive capacity of whitebark pine may be supported by its relative tolerance of drought, wind and fire, and its long life span, but constrained by its dependence on seed dispersers, such as Clark's nutcracker, and its limited genetic diversity. Historically, whitebark pine was a major component of subalpine forests in the Sierra Nevada (Arno and Hoff 1989) and although the majority of whitebark pine range in California occurs within protected areas and designated wilderness, it has experienced significant declines in the western US and is now a candidate species for federal listing under the Endangered Species Act. Whitebark pine is slow-growing and long-lived (Arno and Hoff 1989). Stands older than 600 years have been found in Wyoming and Alberta (Luckman et al. 1984, Steele et al. 1983 cited in Fryer 2002), and the oldest recorded specimen was over 1200 years old (Perkins and Swetnam 1996 cited in Fryer 2002). Despite unfavorable changes in climate, long life may allow whitebark pine to take advantage of climatic conditions favorable for regeneration.

Seed cones are first produced at 20 to 30 years; peak production is achieved at approximately 60 to 100 years, and lasts several hundred years (Lewis 1971, McCaughey and Tomback 2001 cited in Fryer 2002). Stand-wide and population-wide production of cones can be episodic. Clark's nutcracker seed-caching habits may result in tree clusters composed of related individuals. On a larger scale, long-distance dispersal by Clark's nutcracker may contribute to low inter-population diversity (Bruederle et al. 2001, Bruederle et al. 1998 cited in Fryer 2002). Low genetic diversity may limit whitebark pine's capacity to accommodate changes in climate.

However, differential responses to water deficit and maximum temperatures suggest that at least two genotypic groups of whitebark pines exist, with some trees better able to take advantage of warm conditions (Millar et al. 2012). In seedlings, drought tolerance is conferred in part rapid growth of deep roots and thick, drought-resistant stems (Bruederle et al. 1998 cited in Fryer 2002). Whitebark pines at high elevations also frequently experience near-hurricane-force winds (Biswell n.d. cited in Fryer 2002), and develop variations in trunk morphology (i.e. krummholz) that may provide protection against wind (Fites-Kaufman et al. 2007) and other disturbances. Moderate-thickness bark may support survival of mature trees during moderate- and low-intensity fires (Fryer 2002). In addition, whitebark pine forest growth



patterns that form discontinuous canopies and sparse understories may further limit the spread and extent of fire (Botti 1979, Brown et al. 1994, Steele et al. 1983 cited in Fryer 2002).

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