Sierra Nevada Individual Species Vulnerability Assessment Briefing: Red Fir

Abies magnifica

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 red fir species is ranked moderate-high, due to their high sensitivity to climate and non-climate stressors, moderate adaptive capacity, and moderate-high exposure.

Red firs are sensitive to climate-driven changes such as:

- increased temperature,
- decreased snowpack, and
- reduced soil moisture (i.e. increased climatic water deficit).

Temperatures are predicted to increase over the next century due to climate change, and are associated with decreased snowpack volume and rising snowline. Red fir occurrence closely corresponds with freezing level and the red fir ecotone experiences the highest snowpack of any vegetation type in California, suggesting that changes in snowpack may adversely impact red fir distribution.

Red firs are also sensitive to several non-climate stressors including:

- pathogens, insects and parasites.

Numerous pathogens and pests can cause mortality and growth-loss in red fir, and these may amplify the effects of climate-driven changes. For example, the impacts of drought may be exacerbated by the fir engraver bark beetle, which attacks in conjunction with drought or fire damage. Moreover, the capacity of red fir to adapt to changes in climate is strongly limited by its fragmented distribution, low recruitment, and long generation time.

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Red firs tolerate a narrow range of relatively cool and wet climatic conditions, and exhibit sensitivity to warming temperatures, reduced snowpack, and reduced soil moisture. Red fir is confined to cool/moist areas with summer temperatures rarely exceeding 84˚F (29˚C) (Laacke 1990). Climate change, as indicated by warmer mean annual temperatures, may partially explain reduction of red fir at a high elevation stand between 1948-2004 in the Sierra Nevada (Gonzalez et al. 2009). Red fir typically occur in the upper montane zone at elevations above approximately 6000 ft to 7500 ft (1829 m to 2286 m) on the western slope of the Sierra Nevada (Laacke 1990; North et al. 2002; Long et al. 2013). Their occurrence, however, is strongly correlated with long-term mean April 1 snow water equivalence (SWE) rather than elevation (Barbour et al. 1991). The upper montane red fir forests of northern California experience the highest snowpack of any vegetation type in the state (Barbour et al. 1991). Almost all precipitation occurs between October and March, 80% of it falling as snow (Laacke 1990). The red fir is considered a climax species (Laacke 1990), and the shift of dominance from white fir (*Abies concolor*) to red fir closely corresponds with the freezing level during months of maximum precipitation (Barbour et al. 1991). The shift in dominance to red fir may relate to snowpack characteristics and tolerance of sapling to snowpack (Kunz 1988 cited in Barbour et al. 1990; Barbour et al. 1991), which are well adapted to heavy snows and ice. For example, red fir saplings bent by the snow can straighten during the growing season (Gordon 1978). Projected decreases in snowpack and long-term shifts in the freezing level may contribute to the reduction of red fir distribution.

Alternatively, association of red fir recruitment with El Niño events may relate to increased soil moisture levels from enhanced winter snowpack (Barbour et al. 1991; North et al. 2005). For example, the sandy loam soil 20 cm below the surface of a red fir site in Stanislaus National Forest contained 50% moisture in late May and 17% in late August, while similar texture soil beneath the white fir site contained only 28% and 10% respectively (Barbour et al. 1990). In comparison, red fir growth is poor and stands are open on steep slopes where soils are shallowest (Laacke 1990). A climate induced uphill shift to steeper slopes and shallower soils, combined with reduced soil moisture may prove detrimental to red fir maintenance. Hurteau et al. (2007) however, suggest that buffering by microclimate at riparian zone locations in the southern Sierra Nevada may reduce red fir susceptibility to annual climate fluctuations.

Fire effects on red fir forests are generally poorly understood (Caprio 2000; see Long et al. 2013 for a discussion of relevant fire research). For red fir forests in Sequoia National Park, the average fire-free interval prior to 1886 was 65 years (Pitcher 1987), and fires appear to be a major historic element in creating small openings in dense red fir forests and preparing seedbeds for regeneration (Laacke and Tappeiner 1996). Fire regimes in red fir forests were historically dominated by low- and moderate-intensity fires that resulted in small, scattered groups of regeneration (Taylor and Halpern 1991; Laacke and Tappeiner 1996) and a patchwork of tree ages (Kane et al. 2013). Intense fires, however, resulted in high mortality of red firs (Kane et al. 2013) and comparatively benefit species that are more fire-tolerant or regenerate quickly after fire.

Future climate exposure

Important climate and climate-driven factors to consider for red firs include changes in temperature, snowpack, soil moisture (i.e. climatic water deficit), and wildfire.

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).

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). 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: 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: 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).

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

Red firs also experience stress from various non-climate factors that may interact with climate to increase species vulnerability, including various pathogens, insects and parasites. Exposure to such pests can weaken and kill trees and increase tree susceptibility to further pathogens, insects, and environmental stressors. Major causes of red fir and white fir mortality include fir engraver beetle (*Scolytus ventralis*), dwarf mistletoe (*Arceuthobium abietinum f. sp. magnificae*), and annosus root disease (*Heterobasidion annosum*), while infestations of broom rust (*Melamsporella caryophyllacearum)*, trunk rot (*Echinodontium tinctorium*), and the Douglas fir-tussock moth (*Orygia pseudotsgata)* have been shown to cause growth-loss in both red and white fir (Laacke 1990; North et al. 2002). Pest pressure can increase tree sensitivity to drought (Waring et al. 1987), and vice versa. The syncopated stressors of tree pests with fire and drought may result in greater mortality in red fir forests than solely from future increases in area burned. Pests such as pocket gophers (*Thomomys sp*.), which reduce red fir establishment through burrowing activity (Laacke 1990; Laurent et al. 1994), may exacerbate the limitations that increased climatic water deficit increased fire represent for red fir establishment and distribution.

Adaptive Capacity

The capacity of red fir to adapt to changes in climate is limited by its fragmented distribution, low recruitment, and long generation time. Red fir exists in fragmented patches in a relatively narrow elevational band, approximately 6000 ft to 9000 ft (1829 m to 2743 m) (Laacke 1990; North et al. 2002) and has limited ability to shift upslope. Red firs produce heavy seed crop sufficient for reliable regeneration every 1 to 4 years, after sexual maturity is reached after 35-45 years (Laacke 1990). Seed production varies with tree age, size and dominance (Laacke 1990). Future distribution on shallower soils and steeper slopes may produce smaller trees, contributing to reduced reproductive potential of red fir.

Moreover, the effects of fire on red fir forests are poorly understood (Caprio 1999). Although fire intervals for individual trees in red fir dominated systems varied from frequent to infrequent (25-110 years) in the Southern Cascade region (Skinner and Taylor 2006), red firs may have limited capacity to adapt to increased frequency of fire due to low recruitment and retarded seed production. Red fir seedlings often establish 3-4 years following fire (Chappell and Agee 1996), but reconstructed regeneration patterns in Sequoia National Park indicate that red fir regeneration can be delayed 60 years following fire, with the delay attributed to variations in fire behavior (Pitcher 1987). In addition, because seed cones are located in the crown, damages to the crown, for example, from windthrow, insects, and crown fires, may restrict cone production (Laacke 1990) and dispersal.

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