Sierra Nevada Ecosystem Vulnerability Assessment Briefing: Red Fir

CWHR Type[1]**: RFR**- Red fir (*Abies magnifica*), white fir (*Abies concolor*), lodgepole pine (*Pinus contorta*)

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 the red fir system is ranked moderate, due to its moderate-high sensitivity to climate and non-climate stressors, moderate adaptive capacity, and moderate exposure.

Red fir systems are sensitive to climate-driven changes such as:

- decreased snowpack,
- increased climatic water deficit, and
- altered fire regimes.

Temperatures are predicted to increase over the next century due to climate change, and are associated with decreased snowpack volume and rising snowline. Growth and establishment of red fir systems, as well as its component species, are strongly affected by soil moisture in the form of winter snowpack. Reductions in winter snowpack and increases in climatic water deficit may lead to compositional changes and reductions in red fir system distribution.

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

- pathogens and insects.

Numerous pathogens and pests can cause mortality and growth-loss in red fir systems, and these may amplify the effects of climate-driven changes. For example, pest pressure can increase tree sensitivity to drought and vice versa. The capacity of red fir systems to adapt to changes in climate is strongly limited by its fragmented distribution.

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[1] Following the California Wildlife Habitat Relationship (CWHR) System found at: http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Red fir forests occupy relatively cool and wet conditions, making them sensitive to warming temperatures, reduced snowpack, and reduced soil moisture. Red fir is confined to cool/moist areas with summer temperatures rarely exceeding 29˚C (84˚F) (Laacke 1990), and typically occurs 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 northern and southern Sierra Nevada, respectively (Laacke 199; North et al. 2002; Long et al. 2013). The upper montane red fir forests of northern California experience the highest snowpack of any vegetation type in the state and are strongly correlated with long-term mean April 1 snow water equivalence (SWE) rather than elevation (Barbour et al. 1991). The red fir is considered a climax species, and shares climax status with white fir at the upper limit of the white fir distribution (Laacke 1990). The shift in 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 red fir saplings to snowpack (Kunz 1988 cited in Barbour et al. 1990; Barbour et al. 1991), which are well adapted to heavy snows and ice (Gordon 1978). Projected reduction in snowpack and long-term shifts in the freezing level may reduce distribution and alter dominance of component species within red fir forest.

The component species display distinct associations with soil moisture gradients. For example, within red fir forests throughout the Sierra Nevada, lodgepole pine occupies wet sites, whereas dry sites in the south may be shared with sugar pine (*P. lamberiana*), mountain hemlock (*Tsuga mertensiana*) and incense cedar (*Calocedrus*) (Laacke 1990; North et al. 2002). The association between El Niño events and red fir recruitment may be related to enhanced winter snowpack increasing soil moisture levels (Barbour et al. 1991; North et al. 2005). For example, Barbour et al. (1990) found that red fir and white fir seedlings established differentially in response to soil moisture. White fir were favored in open/xeric microhabitats, whereas red fir were favored in open/mesic microhabitats (Barbour et al 1990). The soil 20 cm below the surface of a red fir site in Stanislaus National Forest contained 50% moisture (percent dry weight) 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, on steep slopes where soils are shallowest, red fir growth is poor and stands are open (Laacke 1990). At lower elevations, red fir is associated with riparian areas (North et al. 2002). Projected increases in climatic water deficit (i.e., reduced soil moisture) and reduced snowpack may limit red fir forest distribution and impact species composition.

Red fir systems may be sensitive to altered fire regimes, although fire effects on red fir forests are generally poorly understood (Caprio 2000; and see Long et al. 2013 for a discussion of relevant fire research). It has both been suggested that upper montane red fir forests are not fire dependent (Barbour et al 1990) and that fire was a major historic element in creating small openings in dense forests and preparing seedbeds for regeneration (Chappell and Agee 1996; Laacke and Tappeiner 1996). Historically, fires in red fir forests appear to be low frequency (>50 years) (Pitcher 1987), with seedlings often establishing 3 to 4 years after fire (Chappell and Agee 1996). Red fir forests were dominated by low- and moderate-intensity fires, resulting in small, scattered groups of regeneration (Taylor and Halpern 1991; Laacke and Tappeiner 1996) and a mosaic of tree ages (Kane et al. 2013). Intense fires, however, result in high mortality of red firs (Kane et al. 2013) and comparatively benefit species that are more fire-tolerant or regenerate quickly after fire. Changing fire regimes may result in altered species composition in red fir forests.

Future climate exposure

Important climate and climate-driven factors to consider for red fir systems include changes in temperature, snowpack, 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). Loss of red fir/lodgepole communities in the Sierra Nevada may be accelerated by changes in the severity and frequency of fire (PRBO Conservation Science[2] 2011), although increased fire may create opportunities to expand for some component species, such as lodgepole pine (Bartlein et al. 1997).

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 fir systems also experience stress from various non-climate factors that may interact with climate to increase vulnerability, including tree pathogens and pests.

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[2] PRBO Conservation Science now called 'Point Blue'

Exposure to pests can weaken and kill trees and increase tree susceptibility to further pathogens, pests 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 the impact of future increases in area burned. However, dwarf mistletoe infection and decay of red fir stands may be important for wildlife in red fir forest (Laacke and Tappeiner 1996).

Adaptive Capacity

The red fir system may be limited in its capacity to adapt to climate change by its fragmented distribution and restricted space to shift upslope. 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). As snow retreats to higher elevations and topographically shaded areas, red fir forests may shift to cooler northern-aspect and uphill slopes, although shifts may be restricted if adequate soils do not align with new climate bands. Some component species in the system, such as white fir (Laacke and Tappeiner 1996) and lodgepole pine, may be better able to adjust to climatic changes than red fir.

Moreover, the effects of fire on red fir forests are poorly understood (Caprio 1999). Although fire intervals in white and red fir systems varied from frequent to infrequent (25-110 years) (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 to 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 located in the crown, damages to the crown, such as from windthrow, insects, and crown fires, may restrict cone production (Laacke 1990) and dispersal.

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+1 (206) 201 3834