Sierra Nevada Ecosystem Vulnerability Assessment Briefing: Yellow Pine/Mixed Conifer

CWHR types[1]: PPN: Ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*P. jeffreyi*), Douglas fir (*Pseudotsuga menziesii*), black oak (*Quercus kellogii*); **JPN**: Jeffrey pine, ponderosa pine, sugar pine (*P. lambertiana*); **EPN**: Ponderosa pine, Jeffrey pine, white fir (*Abies concolor*); **SMC**: Douglas fir, ponderosa pine, white fir, black oak and canyon live oak (*Quercus chrysolepis*); **DFR**: Douglas fir, tanoak (*Notholithocarpus densiflorus*), ponderosa pine, canyon live oak; **WFR**: White fir, Douglas fir, sugar pine

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 yellow pine/mixed conifer system is ranked moderate, due to moderate-high sensitivity to climate and non-climate stressors, moderate-high adaptive capacity, and moderate exposure.

The yellow pine/mixed conifer system is sensitive to climate-driven changes such as:

- increased temperature,
- decreased precipitation (snowpack),
- increased climatic water deficit, and
- altered fire regimes.

Despite component species within yellow pine/mixed conifer forests exhibiting varying sensitivities to climate, exposure to increasing temperatures, decreasing winter snowpack and increasing climatic water deficits over the next century are likely to limit tree growth and seedling establishment.

The yellow pine/mixed conifer system is also sensitive to non-climate stressors including:

- logging,
- fire suppression, and

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

- insects and disease.

These non-climate stressors can reduce abundance, alter distribution and reduce fitness of yellow pine and mixed conifer species, and can compound the effects of climate-driven changes. For example, attacks by bark beetles have been associated with years of water shortage, increasing mortality under syncopated stressors. The adaptive capacity of the yellow pine/mixed conifer system may be supported by its wide distribution across the Sierra Nevada, and its diverse topographical, structural and biological characteristics.

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Despite substantial heterogeneity and varying species' sensitivities to climate (Battles et al. 2008; Scholl and Taylor 2010), the yellow pine/mixed conifer system displays sensitivity to climate-driven changes in temperature, precipitation (snowpack), climatic water deficit, and fire regimes. Growth and establishment of component species within the mixed conifer system are often positively associated with above average precipitation. For example, growth (e.g. annual diameter increment) is positively correlated with winter precipitation (i.e. October – February) for white fir, sugar pine and giant sequoia on the western slopes of the southern Sierra Nevada (York et al. 2010). Similarly, establishment of Jeffrey pine and sugar pine are significantly associated with El Niño events, which cause wetter and warmer average conditions and deep snowpack in winter (North et al. 2005). Conversely, multiyear episodes of low annual and seasonal precipitation and high spring and summer temperatures have been correlated with mixed conifer forest mortality in Yosemite National Park (Guarín and Taylor 2005). Snowpack losses of 70-90% are projected below 2000 m (6562 ft) on the western slopes of the Sierra Nevada, corresponding with mixed conifer forest occurrence between 1300 to 2200 m (4265 ft to 7218 ft) (Guarín and Taylor 2005; Scholl and Taylor 2010; York et al. 2010; Safford et al. 2012a), suggesting possible impacts to conifer establishment and growth.

In addition, available soil moisture during the summer growing season is important for mountain hemlock and white fir (Anderson 2004), as well as other conifer species. Growth of ponderosa pines, which prefer warmer, drier sites (Scholl and Taylor 2010), is strongly limited by summer soil moisture in the western U.S. (Fagre et al. 2003), and earlier drying of soils could result in reduced or delayed germination and increased seed mortality in pine stands (Puhlick et al. 2012). As soil water availability decreased, daily maximum temperature optimums for Douglas fir in western Oregon also decreased (Beedlow et al. 2013), suggesting that warming temperatures, in conjunction with anticipated climatic water deficit, could become increasingly limiting for several species in the mixed conifer system. Although mixed conifer forests in the Sierra Nevada have persisted through more severe droughts (Cook and Krusic 2004 cited in North et al. 2009) than those experienced today, the long-term effects of warming and drying are largely unknown (North et al. 2009).

Reconstruction of pre-suppression fire regimes using fire scars indicates that years with widespread fires in dry pine and mixed conifer forests are strongly related to drought in Yosemite National Park (YNP) (Taylor and Scholl 2012), other sites in California (Taylor and Beaty 2005; Taylor et al. 2008), and the southwest U.S. (Swetnam and Betancourt 1998, Sakulich and Taylor 2007 cited in Taylor and Scholl 2012). Current year drought combined with antecedent wet years with increased production of fine fuels are associated with fire in the southwest U.S. (Swetnam and Betancourt 1990, McKenzie et al. 2004 cited in Strom and Fule 2007) as well as at some sites in the Sierra Nevada (Taylor and Beaty 2005), but not in YNP, suggesting that "heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales" (Taylor and Scholl 2012). Burn condition heterogeneity may promote different forest understory responses in mixed conifer forests across a landscape, with lower intensity burns promoting tree regeneration, and higher intensity or more frequent burns creating shrub habitat (Lydersen and North 2012). Increases in fire will likely benefit comparatively fire-tolerant broadleaf trees on historically mixed conifer landscapes (Lenihan et al. 2008).

Future climate exposure

Important climate and climate-driven factors to consider for the yellow pine/mixed conifer system include changes in temperature, reduced precipitation and snowpack, climatic water deficit, altered wildfire regimes, and changes in dominant vegetation type.

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. 2012a), 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).

Vegetation distribution: In the Sierra Nevada, the Sierra mixed conifer/white fir/Jeffrey pine vegetation type is projected to decrease (by 12-32%), while blue oak/foothill pine and ponderosa pine/Klamath mixed conifer are projected to increase by 2070 (PRBO Conservation Science 2011).

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

Yellow pine/mixed conifer systems are affected by various non-climate stressors, including logging, fire suppression, and exposure to insects and disease, which can reduce mixed conifer abundance directly and compound the impacts of climate change. Since the mid-19th century, management practices have fundamentally changed the structure, biota, and ecological processes in mixed conifer and yellow pine forest (Sugihara et al. 2006, Barbour et al. 2007 cited in Safford et al. 2012b). Historical logging partially explains the loss and homogenization of yellow pine-dominated forests (Safford et al. 2012b). Similarly, fire suppression has lead to structural homogenization and changes in species composition, facilitating increased tree densities and occupation by shade-tolerant species at the expense of species like Jeffrey pine, sugar pine and western white pine (Bouldin 1999; Beaty and Taylor 2008; Scholl and Taylor 2010; Safford et al. 2012b). In the Lake Tahoe Basin, for instance, the greatest compositional changes during the 115-year fire-free period prior to 2008 occurred in pine-dominated stands in valley bottoms and on south aspects, shifting composition from fire-tolerant species to fire-intolerant white fir (Beaty and Taylor 2008). Shade-tolerant species that currently dominate forests because of fire suppression and logging are less drought and fire tolerant than the pines they are supplanting. Fire suppression could alter species and individual growth response to climate in Sierran forests (Hurteau et al. 2007), and increase the probability of catastrophic burns by “laddering” fire into the canopy crown (Miller and Urban 2000; North et al. 2002).

In addition, outbreaks of insects and disease can exacerbate the effects of climate change, increasing conifer mortality. Dwarf mistletoe (*Arceuthobium abietinum f. sp. magnificae*), bark beetle (*Scolytus ventralis*), and annosus root disease (*Heterobasidion annosum*) are major causes of white fir mortality, 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 white fir (Laacke 1990; North et al. 2002). Exposure to pests can reduce tree vigor and increase tree susceptibility to additional pathogens and pests, potentially exacerbating the impacts of climate change. For instance, annosus root rot can increase the likelihood a tree will become infested by insects (Laacke 1990), and pest pressure can increase tree sensitivity to drought (Waring et al. 1987) and vice versa. Attacks of bark beetle and pine beetle on Jeffrey pine and ponderosa pine have been associated with years of water shortage in the western U.S. (Grulke et al. 2009; Grulke

2010). The risk of widespread beetle-related mortality may also increase as winter temperatures warm, since prolonged periods of low temperatures result in significant overwintering mortality in some bark beetle species, but not others (Amman 1973, and Safranyik and Linton 1991 cited in Fettig et al. 2007). Moreover, pest pressure may indirectly reduce the capacity of conifers to adapt to climate change. For instance, Grulke (2010) suggests that the low ecophysiological trait variability displayed by sugar pine populations may be a result of pine blister rust experienced California-wide in the mid-1970s and 1980s.

Adaptive Capacity

The capacity of the yellow pine/mixed conifer system to accommodate changes in climate may be supported by its wide distribution across the Sierra Nevada (Scholl and Taylor 2010; Franklin and Fites-Kaufman 1996 cited in Ansley and Battles 1998) and its diverse topographical, structural and biological characteristics. The mixed conifer forest covers an estimated 10% of the vegetated area in the Sierra Nevada and is the dominant community in the lower montane zone (Sierra Nevada Ecosystem Project 1996 cited in Ansley and Battles 1998). However, as of 1998, less than 15% of the mixed conifer forest in the Sierra Nevada retained old-growth or late-successional features, which primarily occur within national parks in the southern Sierra Nevada (Franklin and Fites-Kaufmann 1996 cited in Ansley and Battles 1998). Mixed conifer forests generally occupy elevations ranging from 1300 m to 2200 m (Guarín and Taylor 2005; Scholl and Taylor 2010; York et al. 2010; Safford et al. 2012b) often at lower elevations in moist sites, and at higher elevations in the southern Sierra Nevada. Microsite preferences and seedling requirements vary by species within the system (North et al. 2005). Broad distribution and wide elevational range may aid future elevational shifts and facilitate access to climate refugia in canyons or north facing slopes, as well as favorable edaphic and micro-climate conditions. For example, in the Teakettle Experimental Forest, sugar pine established 1-4 years after fire, preferentially during wet years, while white fir and incense cedar began to recruit into burned areas much later (~13 years after fire; North et al. 2005).

Heterogeneity of microsite preferences and responses to fire may facilitate adaptation of mixed conifer systems to shifting fire and soil moisture regimes. For example, in mixed conifer old-growth forests in the Sierra Nevada (with restored fire regimes), burn intensity and forest productivity is influenced by the interaction of fire and topography, which in turn create structurally heterogeneous forests (Lydersen and North 2012). Taylor and Scholl (2012) suggest that the “heterogeneity of forest floor vegetation may influence the temporal structure of fire-climate relationships, even at local scales”. However, significant increases in the frequency and severity of fire could also result in changes (Lenihan et al. 2008) in structure and landscape patterns of seral stages, as well as type conversion to chaparral or grassland.

The ability of co-occurring populations of montane conifers in the western U.S. to adapt to climate change appears positively correlated with the variability of key ecophysiological traits (Grulke 2010). Of the four species studied, white fir exhibited the highest variability, ponderosa pine and Jeffrey pine intermediate variability, and sugar pine the least variability in ecophysiological traits (Grulke 2010), suggesting that the species have varying capacities to adapt to climate change. Redistribution of white fir uphill in the Peninsular Range of southern California lends support to the idea that white fir has the capacity to respond to environmental change (Grulke 2010).

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