Sierra Nevada Ecosystem Vulnerability Assessment Briefing: Oak Woodlands

CWHR types[1]**: MHC**: Ponderosa pine (*Pinus ponderosa)*, incense cedar (*Calocedrus decurrens*), California black oak (*Quercus kelloggii*); **MHW**: Canyon live oak (*Quercus chrysolepis*), California black oak (*Quercus kelloggii*), Oregon white oak (*Quercus garryana*); **ASP**: Aspen (*Populus tremuloides)*, willow (*Salix spp.*), alders (*Alnus spp.)*

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 oak woodland system is ranked low-moderate, due to its moderate-high sensitivity to climate and non-climate stressors, moderate-high adaptive capacity, and low exposure.

Oak woodlands are sensitive to climate-driven changes such as:

- decreased precipitation,
- decreased soil moisture (climatic water deficit), and
- increased fire severity and frequency.

Soil moisture deficits are predicted to increase over the next century due to climate change and may increase oak seedling mortality and/or decrease recruitment. Fire frequency and area burned are also predicted to increase over the next century, and may impact oak woodland persistence by impacting recruitment, establishment and distribution.

Oak woodlands are also sensitive to several non-climate stressors including:

- habitat conversion,
- herbivory, and
- pathogens and insects.

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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

These non-climate stressors can exacerbate species sensitivity to climate-driven changes by altering reproductive cycles and/or amplifying the effects of climate-driven changes. For example, herbivory may limit recruitment and establishment of seedlings and saplings, which may be further limited by future climatic water deficit. The capacity of oak woodlands to adapt to changes in climate, however, will likely be facilitated by its broad distribution and ability of mature trees to tolerate a wide range of environmental conditions (e.g. drought).

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Oak woodlands are sensitive to climate and climate-driven changes including decreased precipitation, decreased soil moisture, and increased fire severity and frequency. Oak woodlands are a large ecosystem, composed of oak species displaying a broad range of sensitivities (Jimerson and Carothers 2002; Waddell and Barrett 2005). Although sensitivity to soil moisture stress depends on life stage, mature oaks generally fare well in warm weather and withstand drought (McCreary 1991), owing to deep root systems, long lifespans, and drought deciduousness. However, precipitation is a key discriminant variable determining oak series, with higher rainfall on western slopes associated with black oaks, and drier, more inland and southerly sites associated with white oak and blue oak (Jimerson and Carothers 2002). Environmental gradients within oak series are favored by different component species. For instance, Douglas fir is found on mesic sites within white and black oak series, while California buckeye (*Aesculus californica*) is found on warm, dry sites (Jimerson and Carothers 2002), and valley oak may be dependent on groundwater (McLaughlin and Zavaleta 2012).

In addition, oaks are masting species and yearly acorn crop sizes can vary significantly, potentially with precipitation and temperature (Koenig et al. 1999 cited in Waddell and Barrett 2005). With blue oaks, wet years can produce nearly double the seedling emergence of dry years (Borchert et al. 1989 cited in Tyler et al. 2006), and all published studies on the regeneration of blue oak woodlands reviewed by Tyler et al. (2006) found saplings to be more common on mesic sites.

Although the literature indicates that mature oaks generally withstand moderate fire (Holmes et al. 2008), fire response seems to vary among California's oak species, and by life stage. Several authors have suggested that, at least in the short term, frequent, low intensity fire benefits oak by inhibiting conifer encroachment (Fritzke 1997; Swiecki and Bernhardt 2002;

Jimerson and Carothers 2002) and by preparing adequate seedbed conditions (Kauffman and Martin 1987). Conversely, other studies have shown that fire is negatively associated with blue oak sapling recruitment in California (Swiecki et al. 1997b cited in Tyler et al. 2006). Similarly, moderate intensity fire resulting in partial or complete topkill was found to confer no survival or regrowth benefits to blue oak saplings, but instead to prolong the period that saplings were susceptible to subsequent fire and other damaging agents (Spero 2002). The long-term effects of fire on oak woodland persistence in the northwestern Sierra Nevada foothills are still unknown (Spero 2002).

Future climate exposure

Important climate and climate-driven changes to consider for oak woodlands include changes in precipitation, climatic water deficit, and wildfire. Although the prediction of distributional shifts for oak woodlands in response to climate change is not as consistent as for grasslands, oak woodlands in California are projected to increase (Gardali et al. 2012). Broadleaf associations expected to expand include the California white oak/valley oak (*Quercus lobata*), which can tolerate relatively warm and dry conditions. Conversely, red alder (*Alnus rubra*) and Oregon white oak (*Q. garryana*) are expected to shift potential ranges from the west to the east of the northern Sierras (Shafer et al. 2001). See Kueppers et al. (2005) for modeled ranges of California endemic oaks under regional climate changes.

Precipitation and snow volume: 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). 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). 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).

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). The area of oak woodland burned by contained fires is expected to increase by 65% in Northern California in response to climate change (Fried et al. 2004).

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

Oak woodlands are sensitive to several non-climate stressors, such as conversion to agriculture, firewood harvesting, and development pressure, which directly reduce oak woodland distribution, especially at lower elevations in hardwood rangelands (Jimerson and Carothers 2002), as well as herbivory, and insect and pathogen outbreaks, which may compound climate-driven impacts on recruitment and establishment. Several studies identify herbivory of acorns, seedlings and saplings by cattle, deer, rodents and insects as a major source of oak mortality (Plumb 1980; Borchert et al. 1989, Callaway 1992, and Adams and McDougald 1995 cited in Tyler et al 2006; Hall et al. 1992), while other studies suggest that grazing intensity may play a smaller role in seedling survival than the seasonality of grazing. Grazing of seedlings by livestock and wildlife in both spring and summer is associated with significantly lower survivorship than grazing in winter only (Hall et al. 1992). In addition, wild pigs can disrupt soil surfaces and facilitate an increase in introduced annual grasses, which can lead to soil erosion (Jimerson and Carothers 2002). These exotics outcompete native annual and perennial grasses for water.

Oaks are sensitive to both insects and disease (Jimerson and Carothers 2002; Rizzo et al. 2002), especially introduced ones, which may become significant in the future. Sudden oak death, caused by the introduced pathogen *Phytothphora ramorum*, affects oaks in coastal and montane forests of California (Rizzo et al. 2002). Moisture is essential for survival and sporulation of *P. ramorum*, and the duration, frequency, and timing of rain events during winter and spring play a key role in inoculum production. Heavy late-spring rain associated with El Niño events (e.g., 1998) may have played a key role in the current distribution of *P. ramorum* in California (Meentemeyer et al. 2004). Increases in winter rain may produce optimal conditions for the pathogen in some areas, and modeling projects future oak infection risk to be moderate and high in scattered areas of the Sierra Nevada foothills in Butte and Yuba counties (Meentemeyer et al. 2004).

Adaptive Capacity

The capacity of oak woodlands to accommodate changes in climate is facilitated by its broad distribution, system diversity, and tolerance of fire and drought. However, while adult trees are often drought tolerant, seedling establishment may be highly limited with reduced soil moisture, which could limit future adaptive capacity. The total estimated area of hardwood forest in California was 11.29 million acres in the 1990s, excluding reserved lands outside of national forests. Oak woodlands occurring within national forest lands in California cover an estimated 725,000 acres (Jimerson and Carothers 2002). Oak woodlands are found in small patches (averaging 29.3 acres/patch), nested within a mosaic of annual grasslands and conifer forests, and comprise over 700 species of plants (Jimerson and Carothers 2002), including 20 species of oak (Nixon 2002). Broad distribution of many species over a wide range of microclimates and site conditions may help the oak woodland system accommodate changes in future climatic conditions. However, species such as canyon live oak, which are confined to cooler canyon bottoms and north facing slopes, may be further limited in a warmer and drier climate. Despite widespread distribution of oak woodlands on public lands at higher elevations (4000 to 6000 ft), oak woodlands at lower elevations occur primarily on private lands. Private ownership increases the threat of fragmentation and may complicate management of conflicts with agriculture, grazing, and water use.

Moreover, although long-term effects of fire on oak woodland persistence in the northwestern Sierra Nevada foothills are still unknown (Spero 2002), several studies have suggested that, at least in the short term, frequent, low intensity fire benefits oaks by inhibiting conifer encroachment (Fritzke 1997; Jimerson and Carothers 2002; Swiecki and Bernhardt 2002) and by preparing adequate seedbed conditions (Kauffman and Martin 1987). However, because saplings are largely impacted by fire, current low rates of regeneration in many oak species (Jimerson and Carothers 2002) may be exacerbated by the impact of increased fire frequency on seedling and sapling mortality. Although Tyler et al. (2006) caution that insufficient quantitative data exist to indicate a regeneration problem currently exists in California oak woodlands, they note that, because oaks are slow-growing and 50-100 years may be required to functionally replace lost individuals, managing for oak persistence in foothill woodlands may be warranted before mortality is demonstrated to exceed recruitment.

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