Sierra Nevada Individual Species Vulnerability Assessment Briefing: California Black Oak

Quercus kelloggii

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 black oak species is ranked as moderate, due to their overall moderate sensitivity to climate and non-climate stressors, moderate adaptive capacity, and low to moderate exposure.

The California black oak species is sensitive to climate-driven changes such as:

- decreased precipitation,
- increased soil moisture (e.g. climatic soil moisture), and
- increased fire severity and frequency.

Soil moisture deficits are predicted to increase over the next century due to climate change, which is likely to 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 black oak persistence by impacting recruitment, establishment and distribution.

California black oaks are also sensitive to several non-climate stressors including:

- fire suppression,
- invasive species and disease,
- land conversion, and
- grazing.

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, grazing may limit recruitment and establishment of seedlings and saplings, which may be further limited by future climatic water deficit. The capacity of California black oak to adapt to changes in climate, however, will likely be facilitated by its broad distribution and phenotypic plasticity, and the ability of mature trees to tolerate a wide range of environmental conditions, in part by modifying their physiology to accommodate unfavorable environmental conditions (e.g. drought).

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

California black oaks are sensitive to climate and climate-driven changes, including decreased precipitation, decreased soil moisture, and fire. Precipitation is a key discriminant variable determining oak series, highest among black oak series, which are associated with higher rainfall on western slopes in California (Jimerson and Carothers 2002). While mature California black oaks are drought tolerant, individual large trees established circa 1700, and located near the species range limit, may be at risk of water deficit related mortality (Lutz et al. 2010). Black oak recruitment may also be dependent on sufficient soil moisture and sensitive to climatic water deficit.

Reports of black oak fire tolerance are mixed in the literature. Studies have suggested that crown fires kill trees of all ages and that ground fires are often fatal (McDonald in Silvics of North America, 1957), while others cite high survival of larger trees after low-moderate intensity fires (Kauffman and Martin 1987; Jimerson and Carothers 2002) and vigorous re-sprouting or seedling recruitment after fire (Kauffman and Martin 1987, McDonald 1990 cited in Bouldin 1999). Several authors have also suggested that, at least in the short term, frequent low intensity fire benefits oak, including California black oak, by inhibiting conifer encroachment (Fritzke 1997; Jimerson and Carothers 2002; Swiecki and Bernhardt 2002) and by preparing adequate seedbed conditions (Kauffman and Martin 1987).

Future climate exposure

Climate and climate-driven factors most relevant to consider for California black oaks include changes in precipitation, climatic water deficit, and altered wildfire regimes.

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, 2004b; 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).

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 projected to increase by 65% in Northern California in response to climate change (Fried et al. 2004), and the long-term effects of fire on oak woodland persistence in the northwestern Sierra Nevada foothills are still unknown (Spero 2002).

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

California black oaks are also impacted by a number of non-climate stressors, including fire suppression, invasive species, disease (Davidson et al. 2002), land conversion (Jimerson and Carothers 2002), and grazing (Hall et al. 1992; Adams and McDougald 1995; Jimerson and Carothers 2002). Fire exclusion may benefit conifers while reducing the relative abundance of black oaks, and may promote higher severity fires when they do occur, with negative consequences for oak survival (Miller et al. 2009). Climate changes are anticipated to increase the incidence of large fires, which may compound the effects of fire suppression and augment the incidence of stand replacing fire (Jimerson and Carothers 2002). Conversion of forest for agriculture and development and intense grazing (Hall et al. 1992; Adams and McDougald 1995; Jimerson and Carothers 2002) restrict dispersal and recruitment. For example, residential development fragments habitat and reduces sites for potential expansion. New tree recruitment may be limited by grazing by cattle and wild deer (Hall et al. 1992; Adams and McDougald 1995; Jimerson and Carothers 2002), which are thought to preferentially consume acorns and seedlings, and which may be exacerbated by the removal of top predators. Combined with predicted future water deficit, predation may intensify reductions in black oak recruitment and establishment. Climate change may augment competition for water with non-native grasses, and moisture stress may leave California black oak susceptible to attack by beetles or other pathogens.

Conversely, moisture is important for the introduced pathogen *Phytophthora ramorum,* the cause of sudden oak death, which affects black 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, and heavy late-spring rain associated with El Niño events (e.g., 1998) may have played a role in the current distribution of *P. ramorum* in California (Meentemeyer 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 the California black oak to adapt to changes in climate will likely be facilitated by its broad distribution and phenotypic plasticity. The California black oak is one of the most common hardwood forest types in California, evenly divided between public and private ownership (Waddell and Barrett 2005). Surveys by Waddell and Barrett (2005) found California black oak forests along the length of the Sierra Nevada, with two-thirds occurring between 1890 ft - 5050 ft (576 m – 1539 m). However, California black oak distribution is greater than that of its woodland type, because individual California black oak typically occur outside of California black oak woodlands as a subdominant component of lower- to mid-elevation mixed conifer forests and hardwood forests (Waddell and Barrett 2005).

The California black oak's capacity to modify physiology in response to environmental conditions may also support its ability to cope with the effects of climate change. For instance, black oaks can control stomata in response to water stress (Grulke et al. 2005). Crop sizes for California black oaks can exceed 6,000 acorns per oak (Bowyer and Bleich 1980 cited in Waddell and Barrett 2005), although the annual acorn crop for oaks varies widely in quantity from tree to tree and from year to year (Griffin 1971 cited in Tyler et al. 2006; Koenig et al. 1994). Variation in acorn crop appears to be influenced by a given tree's age, size, and health, the size of the tree's previous year's crop, and perhaps the distance to and density of neighboring trees (Koenig et al. 1999, Knapp et al. 2001, and Sork et al. 2002 cited in Tyler et al. 2006). Large crops may support evolutionary potential of the species in response to climate changes.

Conversely, the adaptive capacity of the California black oak may be limited by its slow maturity and long generation time. California black oaks are long-lived species, and age of maturity varies usually between 20 and 30 years old. Acorns can also be slow maturing, taking two years to develop and ripen (Tyler et al. 2006).

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