Focal Resource: CALIFORNIA BLACK OAK

Taxonomy and Related Information

Black oak (*Quercus kelloggii)*; Sierra Nevada-wide distribution between approximately 609-2134 m (2000-7000 ft). Rarely forms woodlands; usually subdominant component of lower to mid-elevation mixed conifer forests.

General Overview of Process

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop[1]. The following document represents the vulnerability assessment results for the **CALIFORNIA BLACK OAK**, which is comprised of evaluations and comments from a participant breakout group during this workshop, peer-review comments following the workshop from at least one additional expert in the subject area, and relevant references from the literature. The aim of this synthesis is to expand understanding of resource vulnerability to changing climate conditions, and to provide a basis for developing appropriate adaptation responses. The resulting document is an initial evaluation of vulnerability based on existing information and expert input. Users are encouraged to refer to the Template for Assessing Climate Change Impacts and Management Options (TACCIMO, http://www.taccimo.sgcp.ncsu.edu/) website for the most current peer-reviewed literature on a particular resource. This synthesis is a living document that can be revised and expanded upon as new information becomes available.

Geographic Scope

The project centers on the Sierra Nevada region of California, from foothills to crests, encompassing ten national forests and two national parks. Three geographic sub-regions were identified: north, central, and south. The north sub-region includes Modoc, Lassen, and Plumas National Forests; the central sub-region includes Tahoe, Eldorado, and Stanislaus National Forests, the Lake Tahoe Basin Management Unit, and Yosemite National Park; and the south sub-region includes Humboldt-Toiyabe, Sierra, Sequoia, and Inyo National Forests, and Kings Canyon/Sequoia National Park.

Key Definitions

Vulnerability: Susceptibility of a resource to the adverse effects of climate change; a function of its sensitivity to climate and non-climate stressors, its exposure to those stressors, and its ability to cope with impacts with minimal disruption[2].

Sensitivity: A measure of whether and how a species or system is likely to be affected by a given change in climate or factors driven by climate.

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[1] For a list of participant agencies, organizations, and universities please refer to the final report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* available online at: http://ecoadapt.org/programs/adaptation-consultations/calcc.

[2] Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

Adaptive Capacity: The degree to which a species or system can change or respond to address climate impacts.

Exposure: The magnitude of the change in climate or climate driven factors that the species or system will likely experience.

Methodology

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: whether the species is a generalist or specialist; physiological sensitivity to temperature, precipitation, and other factors (e.g., pH, salinity); dependence on sensitive habitats; species' life history; sensitivity of species' ecological relationships (e.g., predator/prey, competition, forage); sensitivity to disturbance regimes (e.g., wind, drought, flooding); and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: dispersal ability and barriers to dispersal, phenotypic plasticity (e.g., can the species express different behaviors in response to environmental variation), species' potential to adapt evolutionarily to climate change, species' intraspecific/life history diversity (e.g., variations in age at maturity, reproductive or nursery habitat use, etc.), and species' value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the species and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation[3]. For more information on each of these elements of sensitivity, adaptive capacity, and exposure, including how and why they were selected, please refer to the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[4].

During the workshop, participants assigned one of three rankings (High (>70%), Moderate, or Low (<30%)) to each finer resolution element and provided a corresponding confidence score (e.g., High, Moderate, or Low) to the ranking. These individual rankings and confidence scores were then averaged (mean) to generate rankings and confidence scores for each vulnerability component (i.e., sensitivity, adaptive capacity, exposure score) (see table below). Results presented in a range (e.g. from moderate to high) reflect variability assessed by participants. Additional information on ranking and overall scoring can be found in the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[4].

Recommended Citation

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[3] Geos Institute. 2013. *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis report in support of the Vulnerability Assessment/Adaptation Strategy process.* Ashland, OR. http://ecoadapt.org/programs/adaptation-consultations/calcc.

[4] Kershner, J.M., editor. 2014. *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada.* Version 1.0. EcoAdapt, Bainbridge Island, WA. http://ecoadapt.org/programs/adaptation-consultations/calcc.

This document is available online at EcoAdapt (http://ecoadapt.org/programs/adaptation-consultations/calcc).

Table of Contents

Overview of Vulnerability Component Evaluations

SENSITIVITY

Sensitivity Factor	Sensitivity Evaluation	Confidence
Generalist/Specialist	**Not applicable**	**No answer provided by participants**
Physiology	**2 Moderate**	**2 Moderate**
Habitat	**Not applicable**	**Not applicable**
Life History	**1 Low**	**No answer provided by participants**
Ecological Relationships	**2 Moderate**	**2 Moderate**
Disturbance Regimes	**No answer provided by participants**	**No answer provided by participants**
Non-Climatic Stressors – Current Impact	**3 High**	**2 Moderate**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**3 High**	**2 Moderate**
Other Sensitivities	**No answer provided by participants**	**No answer provided by participants**

Overall Averaged Confidence (Sensitivity)[5]: Moderate

Overall Averaged Ranking (Sensitivity)[6]: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	**3 High**	**3 High**
Barriers Affect Dispersal Ability	**3 High**	**3 High**
Plasticity	**2.5 Moderate–High**	**2 Moderate**
Evolutionary Potential	**2 Moderate**	**2 Moderate**
Intraspecific Diversity/Life History	**1 Low**	**1 Low**
Species Value	**2 Moderate**	**3 High**
Specificity of Management Rules	**2 Moderate**	**3 High**
Other Adaptive Capacities	**None**	**No answer provided by participants**

Overall Averaged Confidence (Adaptive Capacity)[5]: Moderate-High

Overall Averaged Ranking (Adaptive Capacity)[6]: Moderate

EXPOSURE

Relevant Exposure Factor	Confidence
Temperature	**2 Moderate**

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[5] 'Overall averaged confidence' is the mean of the entries provided in the confidence column for sensitivity, adaptive capacity, and exposure, respectively.

[6] 'Overall averaged ranking' is the mean of the perceived rank entries provided in the respective evaluation column.

Precipitation	**2 Moderate**
Climatic water deficit	**2 Moderate**
Wildfire	**2 Moderate**
Snowpack	**2 Moderate**

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**1.5 Low-Moderate**	**2 Moderate**
Central Sierra Nevada	**1.5 Low-Moderate**	**2 Moderate**
Southern Sierra Nevada	**1.5 Low-Moderate**	**2 Moderate**

Overall Averaged Confidence (Exposure)[5]: Moderate

Overall Averaged Ranking (Exposure)[6]: Low-Moderate

Sensitivity

1. **Generalist/Specialist.**
   a. <u>Where does species fall on spectrum of generalist to specialist</u>: Not applicable
      i. Participant confidence: No answer provided by participants
   b. <u>Factors that make the species more of a specialist:</u> Seed dispersal dependency

Additional comments: California black oak is dependent on birds and rodents for longer distance seed dispersal.

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2. **Physiology.**
   a. <u>Species physiologically sensitive to one or more factors including:</u> Temperature, precipitation
   b. <u>Sensitivity of species' physiology to one or more factors</u>: Moderate
      i. Participant confidence: Moderate

Additional comments: Temperature and precipitation were marked to indicate soil water deficit.

References: Precipitation is a key discriminant variable determining oak woodland type, with higher rainfall on western slopes in northwest California associated with black oaks (Jimerson and Carothers 2002). Black oak (*Q. kelloggii*) was found more often on more westerly sites in the northern portion of sites in northwest California, where rainfall was typically greatest (Jimerson and Carothers 2002). Acorn crop size is influenced by rainfall and temperature (Koenig et al. 1999). In addition, individual large California black oak trees established circa 1700, and located near the species range limit, may be at risk of water deficit related mortality (Lutz et al. 2010). However, California black oaks have the capacity to modify physiology in response to environmental conditions, and control stomata in response to water stress (Grulke et al. 2005).

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3. **Sensitive habitats.**
   a. <u>Species dependent on sensitive habitats including</u>: None
   b. <u>Species dependence on one or more sensitive habitat types</u>: Not applicable
      i. Participant confidence: No answer provided by participants

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4. **Life history.**
   a. <u>Species reproductive strategy</u>: R-selection
      i. Participant confidence: No answer provided by participants
   b. <u>Species polycyclic, iteroparous, or semelparous</u>: Iteroparous

Additional comments: California black oaks reproduce every year, producing lots of acorns although few survive to adulthood. Acorn production is dependent on climatic and weather conditions, such as springtime weather and previous year's precipitation.

References: California black oaks are long-lived species, and age of maturity varies usually between 20 and 30 years old. They are capable of producing more than 6,000 acorns per oak (Bowyer and Bleich 1980 cited in Waddell and Barrett 2005), which take two years to develop and ripen (Tyler et al. 2006). 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), influenced by weather, tree 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).

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5. **Ecological relationships.**
    a. Sensitivity of species' ecological relationships to climate change including: Competition
    b. Types of climate and climate-driven changes that affect these ecological relationships including: Temperature, precipitation
    c. Sensitivity of species to other effects of climate change on its ecology: Moderate
        i. Participant confidence: Moderate

Additional comments: Competition for water with non-native grasses is sensitive to climate change. Likewise, changes in temperature and precipitation will affect water availability.

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6. **Disturbance regimes.**
    a. Disturbance regimes to which the species is sensitive include: Wildfire, insects, drought
    b. Sensitivity of species to one or more disturbance regimes: No answer provided by participants
        i. Participant confidence: No answer provided by participants

Additional comments:
Fire: Adults can usually survive fire and resprout from root crown, but seedlings and saplings are usually killed by fire. Increased frequency of fire would benefit California black oak in the short term by reducing the abundance of conifers.

Drought: California black oaks are drought tolerant, but mortality will occur if the threshold is reached.

Insects: If trees are stressed by other factors, it leaves them susceptible to attack by beetles or other insects.

References: Reports of black oak fire tolerance are mixed in the literature. McDonald (Silvics of North America, 1957) suggests that crown fires kill trees of all ages, and ground fires are often fatal, while other studies report 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 (Kaufmann 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). Fire exclusion may benefit conifers, reduce the relative abundance of black oaks, and may promote increased severity fires when they do occur, with negative consequences for oak survival (Miller et al. 2009).

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7. **Interacting non-climatic stressors.**
    a. Other stressors that make the species more sensitive include: Residential and commercial development, biological resource use, natural system modifications
    b. Current degree to which stressors affect the species: High
        i. Participant confidence: Moderate
    c. Degree to which non-climate stressors make species more sensitive: High
        i. Participant confidence: Moderate

Additional comments: Other stressors include cattle grazing (included under 'biological resource use'), reduction of top predators (under 'altered interspecific interactions'), and fire exclusion and suppression (under 'natural system modification'). Cattle grazing and high deer densities are thought to limit new tree recruitment because, for example, deer preferentially eat acorns and seedlings. Reductions in top predators may result in higher deer densities. Fire exclusion benefits conifers and reduces relative abundance of black oaks. Suburban development fragments habitat and reduces sites for potential expansion or climate refugia.

References: California black oaks are also impacted by a number of non-climate stressors, including fire exclusion (Miller et al. 2009), 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.

Conversely, increased moisture is important in the spread of 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).

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8. **Other sensitivities.**
    a. Other critical sensitivities not addressed: None
        i. Participant confidence: No answer provided by participants
    b. Collective degree these factors increase species' sensitivity to climate change: No answer provided by participants

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9. **Overall user ranking.**
    a. Overall sensitivity of this species to climate change: Moderate
        i. Participant confidence: No answer provided by participants

Additional comments: In the short-term California black oaks will likely benefit, as conifer cover is reduced due to increased fire. In the long term, California black oaks may contract their distribution to the wetter / cooler microsites. A warming climate will likely reduce recruitment, because recruitment (within existing distribution and into new areas) will be dependent on sufficient moisture.

Adaptive Capacity

1. **Dispersal ability.**
    a. Maximum annual dispersal distance: <1 km (<0.62 mi)
        i. Participant confidence: High
    b. Ability of species to disperse: High
        i. Participant confidence: High
    c. General types of barriers to dispersal include: Road (highway), agriculture, industrial or urban development, suburban or residential development, other – low recruitment linked to over-browsing by cattle and deer
    d. Degree barriers affect dispersal for the species: High
        i. Participant confidence: High
    e. Possibility for individuals to seek out refugia: California black oak will likely contract into wetter / cooler sites. Cattle grazing, deer browsing, and suburban development may greatly impact suitability of potential climate refugia.

References: 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).
Intense grazing and conversion of forest for agriculture and development (Hall et al. 1992; Adams and McDougald 1995; Jimerson and Carothers 2002) may restrict dispersal and recruitment.

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2. **Plasticity.**
    a. Ability of species to modify physiology or behavior: Moderate-High
        i. Participant confidence: Moderate
    b. Description of species' ability to modify physiology or behavior: California black oak shut their stomata and display retarded growth in response to water stress. California black oak can alter the timing of flowering and leaf-out, and can adjust acorn production in response to climate changes.

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3. **Evolutionary potential.**
    a. Ability of species to adapt evolutionarily: Moderate
        i. Participant confidence: Moderate
    b. Description of characteristics that allow species to adapt evolutionarily: California black oak have a large population size and are genetically adapted to local / regional environmental conditions. On the other hand, they are a long-lived species that does not become reproductive until 20-30 years of age.

References: California black oaks are long-lived species, and age of maturity varies usually between 20 and 30 years old. 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), influenced by the 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). California black oaks are capable of producing more than 6,000 acorns per oak (Bowyer and Bleich 1980 cited in Waddell and Barrett 2005), which take two years to develop and ripen (Tyler et al. 2006).

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4. Intraspecific diversity/life history.

- a. Degree of diversity of species' life history strategies: Low
  - i. Participant confidence: Low
- b. Description of diversity of life history strategies: No answer provided by participants

Additional comments: Age at maturity varies, as does crop size of flowers and acorn production each year. Age at maturity may be 20-30 years.

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5. Management potential.

- a. Value level people ascribe to this species: Moderate
  - i. Participant confidence: High
- b. Specificity of rules governing management of the species: Moderate
  - i. Participant confidence: High
- c. Description of use conflicts: Much of California black oak distribution is on Forest Service lands that support cattle grazing. Lower elevations outside public lands are being developed and are expected to have lots of future development pressure.
- d. Potential for managing or alleviating climate impacts: Cooler / wetter sites could be identified and prioritized for conservation and/or restoration.

Additional comments: California black oaks are not valued as a timber species but are culturally highly valued by Native Americans, and for their aesthetic beauty. On the other hand, they are usually omitted as a component of the mixed conifer community.

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6. Other adaptive capacity factors.

- a. Additional factors affecting adaptive capacity: None
  - i. Participant confidence: No answer provided by participants
- b. Collective degree these factors affect the adaptive capacity of the species: No answer provided by participants

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7. Overall user ranking.

- a. Overall adaptive capacity of the species: Moderate
  - i. Participant confidence: Moderate

Additional comments: Adaptive capacity varies depending on life stage and existence of other stressors (e.g., cattle, deer, and development).

Exposure

1. **Exposure factors[7].**
    a. Factors likely to be most relevant or important to consider for the species: Temperature, precipitation, climatic water deficit, wildfire, snowpack
        i. Participant confidence: Moderate (all)

2. **Exposure region.**
    a. Exposure by region: North – Low-Moderate; Central – Low-Moderate; South – Low-Moderate
        i. Participant confidence: Moderate (all)

3. **Overall user ranking.**
    a. Overall exposure of the species to climate changes: Moderate
        i. Participant confidence: Moderate

Additional comments: In the short-term, California black oaks are likely to do okay or even expand, if they can recruit to new locations. In the longer term, fire and water deficits could reduce distributions to wet and cool micro-sites.

References: Although the prediction of distributional shifts for oak woodlands in response to climate change is not as consistent as for grasslands, oak woodlands are projected to increase in California (PRBO Conservation Science[8] 2011). However, the area of oak woodland burned by contained fires is also 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).

Temperature: Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004: Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1°C by 2049, and 2-3°C by 2099 (Das et al. 2011). 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; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GDFL[9] and PCM[10]) predict summer temperatures to increase 1.6-2.4˚C by mid- century (2049), with the least increases expected in the northern bioregion, and greatest increases expected in the southern bioregion (Geos Institute 2013). By late century (2079), summer temperatures are forecast to increase 2.5-4.0˚C, with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Winter temperatures are forecast to increase 2.2-2.9˚C by late century (2079), with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

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[7] Participants were asked to identify exposure factors (i.e., climate and climate-driven changes) most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

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

[9] Delworth, T. L., Broccoli, A. J., Rosati, A. et al. (2006) GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. Journal of Climate, 19:643-674.

[10] Washington, W. M., Weatherly J. W., Meehl G. A. et al. (2000) Parallel climate model (PCM) control and transient simulations. Climate Dynamics 16:755-744.

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; some demonstrate little to no change (e.g. PCM) while others demonstrate more substantial changes (e.g. GFDL). 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; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011).

Climatic water deficit: 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). 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. 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 projections using the Basin Characterization Model (Thorne et al. 2012; Flint et al. 2013) and IPCC A2 emissions scenario predict increased water deficits (i.e., decreased soil moisture) by up to 44% in the northern Sierra Nevada, 38% in the central Sierra Nevada, and 33% in the southern Sierra Nevada (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). Increasing temperatures and earlier snowmelt in the Sierra Nevada have been correlated with an increase in large (>1000 acre or >404 ha) extent fire since the 1980s (Westerling and Bryant 2006). Between 1972-2003, years with early arrival of spring conditions accounted for 56% of wildfires and 72% of area burned in the western U.S., as opposed to 11% of wildfires and 4% of area burned in years with a late spring (Westerling et al. 2006; Geos Institute 2013). Fire severity also rose from 17% to 34% high severity (i.e. stand replacing) from 1984-2007, especially in middle elevation conifer forests (Miller et al. 2009).

Fire activity within the Sierra Nevada is influenced by distinct climate patterns and diverse topography. Higher fire activity is weakly associated with El Niño (warm) conditions in parts of the southern Cascades (Taylor et al. 2008) and northern Sierra Nevada (Valliant and Stephens 2009 cited in Taylor and Scholl 2012), while in Yosemite National Park (YNP) large fires are associated with La Niña (cool) conditions, which are characteristically drier (Taylor and Scholl 2012). Some evidence suggests that fire frequency is higher on southern aspect than northern aspect slopes in mid- and upper-montane forests (Taylor 2000); however, in YNP mixed conifer forests, no spatial trend in fire frequency was found (Scholl and Taylor 2010). 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).

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 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).

Large fire occurrence and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing 7-41% by 2050, and 12-74% by 2085 (Westerling et al. 2011). Models by Westerling et al. (2011) project annual area burned in the northern, central and southern Sierra Nevada to increase by 67-117%, 59-169%, and 35-88%, respectively (Geos Institute 2013). Greatest increases in area burned in the Sierra Nevada are projected to occur at mid-elevation sites along the west side of the range (Westerling et al. 2011).

<u>Snowpack:</u> Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of interannual variability and spatial heterogeneity (Mote et al. 2005; Safford et al. 2012). SWE in the southern Sierra Nevada has actually increased during the last half-century, due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013).

Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009) and earlier timing of runoff center of mass (Miller et al. 2003; 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 (2060-2079) (Thorne et al. 2012; Flint et al. 2013; Geos Institute 2013). Under scenarios of 2-6˚C warming, snowpack is projected to decline 10-25% at elevations above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). Several models project greatest losses in snowmelt volume 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), because snowfall is comparatively light below that elevation, and above that elevation, snowpack is projected to be largely retained. The greatest declines in snowpack are anticipated for the northern Sierra Nevada (Safford et al. 2012), with the current patterns of snowpack retention in higher-elevation southern Sierra Nevada basins expected to continue through the end of the century (Maurer 2007).

Average fractions of total precipitation falling as rain in the Sierra Nevada can be expected to increase by approximately 10% under a scenario of 2.5˚C warming (Dettinger et al. 2004b). 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).

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 species 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).

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