Focal Resource: BLUE OAK

Taxonomy and Related Information

Blue oak (*Quercus douglasii)*; widespread across Sierra Nevada foothills between 152-762 m (500-2500 ft) elevation.

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 **BLUE 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.

---

[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

Hauptfeld, R.S., J.M. Kershner, and K.M. Feifel, eds. 2014. Sierra Nevada Individual Species Vulnerability Assessment Technical Synthesis: Blue Oak *in* Kershner, J.M., editor. 2014. *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*. Version 1.0. EcoAdapt, Bainbridge Island, WA.

---

[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	**1.5 Low-Moderate**	**2.5 Moderate-High**
Habitat	**1 Low**	**3 High**
Life History	**3 K-Selection**	**3 High**
Ecological Relationships	**1.5 Low-Moderate**	**2 Moderate**
Disturbance Regimes	**2 Moderate**	**2 Moderate**
Non-Climatic Stressors – Current Impact	**2 Moderate**	**2 Moderate**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**2.5 Moderate – High**	**2.5 Moderate-High**
Other Sensitivities	**None**	**2.5 Moderate-High**

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

Overall Averaged Ranking (Sensitivity)[6]: Moderate

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Dispersal Ability	**2.5 Moderate-High**	**3 High**
Barriers Affect Dispersal Ability	**3 High**	**No answer provided by participants**
Plasticity	**3 High**	**3 High**
Evolutionary Potential	**2 Moderate**	**1 Low**
Intraspecific Diversity/Life History	**1 Low**	**1 Low**
Species Value	**1.5 Low-Moderate**	**2 Moderate**
Specificity of Management Rules	**1.5 Low-Moderate**	**2 Moderate**
Other Adaptive Capacities	**None**	**No answer provided by participants**

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

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

EXPOSURE

Relevant Exposure Factor	Confidence
Precipitation	**3 High**
Climatic water deficit	**3 High**
Wildfire (biomass consumed)	**3 High**

[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.

Exposure Region	Exposure Evaluation (2010-2080)	Confidence
Northern Sierra Nevada	**1.5 Low-Moderate**	**2.5 Moderate-High**
Central Sierra Nevada	**1.5 Low-Moderate**	**2.5 Moderate-High**
Southern Sierra Nevada	**1.5 Low-Moderate**	**2.5 Moderate-High**

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

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

Sensitivity

1. Generalist/Specialist.

   a. Where does species fall on spectrum of generalist to specialist: Not applicable

      i. Participant confidence: No answer provided by participants

   b. Factors that make the species more of a specialist: Seed dispersal dependency

Additional comments: Participants indicated that the Blue Oak species was generally captured by the coarse filter ecosystem vulnerability assessment for Oak Woodlands.

References identified by participants: Southern Sierra Nevada Adaptation Workshop (2013)[7].

---

2. Physiology.

   a. Species physiologically sensitive to one or more factors including: None identified

   b. Sensitivity of species' physiology to one or more factors: Low-Moderate

      i. Participant confidence: Moderate-High

Additional comments: Adult blue oaks are deep rooted and tolerant to drought; they are not very sensitive to temperature. Seedlings are more sensitive to water availability.

Several shrub and arborescent species of oaks (e.g., *Q. turbinella, Q agrifola* and *Q. engelmannii*) occupy drier and warmer sites on average, than *Q. douglasii*. Sustained and repeated droughts could adversely affect trees and make them more vulnerable to other stressors (e.g., insects and disease).

References: Periodic droughts appear to have little impact on mature trees (McCreary 1991). 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. Acorn crop size in blue oaks is also influenced by rainfall and temperature (Koenig et al. 1999 cited in Waddell and Barrett 2005).

---

3. Sensitive habitats.

   a. Species dependent on sensitive habitats including: Grasslands, seeps/springs

   b. Species dependence on one or more sensitive habitat types: Low

      i. Participant confidence: High

Additional comments: Blue oaks are intermixed in grasslands.

---

4. Life history.

   a. Species reproductive strategy: K-selection

      i. Participant confidence: High

   b. Species polycyclic, iteroparous, or semelparous: Iteroparous

Additional comments: Blue oak reproduce annually through seedling production.

---

5. Ecological relationships.

   a. Sensitivity of species' ecological relationships to climate change including: Competition, other – seed dispersal, disease susceptibility

   b. Types of climate and climate-driven changes that affect these ecological relationships including: Temperature, precipitation

[7] Southern Sierra Nevada Adaptation Workshop Information: http://climate.calcommons.org/aux/sscaw/index.htm

c. Sensitivity of species to other effects of climate change on its ecology: Low-Moderate
    i. Participant confidence: Moderate

Additional comments: Competition with other plants for water.

References: Exotic annual grasses compete more effectively with oak seedlings for water than native perennials (Gordon et al. 1989), and have been shown to significantly reduce oak seedling emergence, growth and survival (Gordon et. al 1989, Danielsen 1990, and Gordon and Rice 1993 cited in Tyler et al. 2006).

---

6. Disturbance regimes.

a. Disturbance regimes to which the species is sensitive include: Wildfire, insects, disease
b. Sensitivity of species to one or more disturbance regimes: Moderate
    i. Participant confidence: Moderate

Additional comments: The greatest impact of wildfire is on seedlings as their bark is thin and even low intensity ground fires can girdle them. However, the vast majority of top-killed seedlings will re-sprout the following year. Adults are able to survive fire.

References:
Wildfire: Relatively few studies have rigorously established the effects of fire on blue oak persistence (Allen-Diaz and Bartolome 1992; Swiecki and Bernhardt 1999). Some studies have linked fire with positive recruitment of blue oak woodlands (e.g., McClaran and Bartolome 1989, Bartolome 1991 cited in Tyler et al. 2006), however, the apparent correlation between fire and blue oak regeneration may be the result of removal of older stems by fire and establishment of even-aged stems from resprouting (McClaran and Bartolome 1989, Bartolome 1991 cited in Tyler et al. 2006). Other studies found no positive effect of fire treatments on recruitment, survival, and/or growth of blue oak seedlings (Bartolome and McClaran 1988, Bartolome 1991, and Allen-Diaz and Bartolome 1992, cited in Tyler et al. 2006; Swiecki and Bernhardt 2002). Despite high rates of growth of top-killed saplings immediately following fire, these rates slowed over time, resulting in retarded advancement of small saplings to the overstory (Swiecki and Bernhardt 2002). Moreover, moderate-intensity fire resulting in partial or complete top-kill were found to prolong the period that blue oak saplings were susceptible to subsequent fire and other damaging agents (Spero 2002). Frequent fire is negatively associated with blue oak sapling recruitment in California, whereas infrequent fire was not correlated or only slightly positively correlated with sapling recruitment (Swiecki et al. 1997b cited in Tyler et al. 2006). The long-term effects of fire on oak woodland persistence in the northwestern Sierra Nevada foothills are still unknown (Spero 2002).

Disease: California blue oaks are threatened by the introduced pathogen *Phytophthora ramorum* in coastal and montane forests (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 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).

---

7. Interacting non-climatic stressors.

a. Other stressors that make the species more sensitive include: Residential and commercial development, agriculture, altered interspecific interactions, natural system modifications, invasive and other problematic species
b. Current degree to which stressors affect the species: High
    i. Participant confidence: High
c. Degree to which non-climate stressors make species more sensitive: Moderate-High
    i. Participant confidence: Moderate-High

Additional comments: Although not marked, transportation corridors, biological resource use, and human intrusions and disturbance have minor impacts on the species' sensitivity to climate change. Altered interspecific interactions include reduction in predators and an abundance of deer. Invasive Eurasian grasses compete with seedlings for water.

Climate change could increase the abundance of invasive grasses in relation to native annuals and perennials.

References: While still on the tree, acorns are susceptible to mortality due to fungus, insects (predominantly weevils and moth larvae), birds (including jays, magpies, and acorn woodpeckers), mammals (including mice, squirrels, deer, pigs, and cattle), as well as heat (Griffin 1980b, Koenig et al. 2002 cited in Tyler et al. 2006).

Grazing has also been implicated in recruitment failure, although studies have yielded conflicting results (Tyler et al. 2006). Some studies identify predation of blue oak acorns, seedlings and saplings by rodents and deer as a major source of mortality (Borchert et al. 1989, Callaway 1992, and Swiecki et al. 1997b cited in Tyler et al. 2006; Adams and McDougald 1995), while Hall et al. (1992) suggest that grazing intensity plays a smaller role in seedling survival than seasonality of grazing. Spring and summer grazing of seedlings by livestock and wildlife alike is associated with significantly lower survivorship than areas in which seedlings were exposed only to winter grazing (Hall et al. 1992).

Loss of blue oak woodland is largely a product of urban expansion since the 1930s (Safford et al. 2012). Blue oak occurs predominantly on private lands in California where habitat conversion to agriculture and residential development reduce blue oak extent and abundance (Bolsinger 1988; Pavlik et al. 1991).

Exotic annual grasses compete more effectively with oak seedlings for water than native perennials and have been shown to significantly reduce oak seedling emergence, growth and survival (Gordon et. al 1989, Danielsen 1990, and Gordon and Rice 1993 cited in Tyler et al. 2006).

---

8. Other sensitivities.

a. Other critical sensitivities not addressed: None
    i. Participant confidence: Moderate-High
b. Collective degree these factors increase species' sensitivity to climate change: Not applicable

---

9. Overall user ranking.

a. Overall sensitivity of this species to climate change: Low-Moderate
    i. Participant confidence: Moderate-High

Additional comments: Blue oaks are widely distributed across a broad elevation range within the Sierra Nevada. This broad distribution and apparent broad tolerance for differences in soil types and depth, precipitation, water deficit, and fire regimes would offer them a substantial degree of resilience as a species to future climate changes. Range contractions and shifts (assuming dispersal and recruitment is possible) to the most suitable habitats is a likely outcome in the long term. In the short term, likely increases in fire frequency and severity would reduce conifer densities, leaving blue oaks relatively more abundant.

Adaptive Capacity

1. Dispersal ability.

  a. Maximum annual dispersal distance: <0.2 km (<0.12 mi)
    i. Participant confidence: High
  b. Ability of species to disperse: Moderate-High
    i. Participant confidence: High
  c. General types of barriers to dispersal include: Road – highway, agriculture, industrial or urban development, suburban or residential development
  d. Degree barriers affect dispersal for the species: High
    i. Participant confidence: No answer provided by participants
  e. Possibility for individuals to seek out refugia: Dependent on access to refugia.

Additional comments: The problem lies with seedlings becoming established, not with dispersal occurring. Sapling recruitment may be more limiting than seedling recruitment. Seedlings tend to be abundant following very wet years but most do not survive into sapling stage. Range contractions and shifts for this species are likely in the long term.

References: Poor natural regeneration of blue oak has been noted in portions of its range (Bartolome et al. 1987; Bolsinger 1988; Tyler et al. 2006). Blue oak seedlings and saplings are present but relatively rare in many stands, and absent from others. Some stands show no evidence of tree recruitment within the past 50 years, however, low mortality rates of adults, estimated between 2 to 4% per decade (Swiecki et al. 1993), may be sufficient to allow replacement even at low sapling survival rates.

---

2. Plasticity.

  a. Ability of species to modify physiology or behavior: High
    i. Participant confidence: High
  b. Description of species' ability to modify physiology or behavior: Plasticity is high; for example, oaks can reduce water use during times of drought.

References: Periodic droughts appear to have little impact on mature trees (McCreary 1991), in part because blue oaks lose leaves early during dry years (McCreary 1990) to reduce water loss.

---

3. Evolutionary potential.

  a. Ability of species to adapt evolutionarily: Moderate
    i. Participant confidence: Low
  b. Description of characteristics that allow species to adapt evolutionarily: Blue oak has adapted well to drier climates. The population base is large and well-connected, and genetic diversity seems high.

Additional comments: Blue oaks are distributed across a broad elevational and latitudinal range.

References: The blue oak woodland type, ranging from open savannas to dense woodlands, ranks first in terms of total land area among California oaks (Davies et al. 1998 cited in Tyler et al. 2006).

---

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: Blue oak reproductive strategy is mostly static.

References: Although not well documented, age of first reproduction is at least several decades old (Olson 1974 cited in Tyler et al. 2006), with maximum production occurring decades later. The acorn crop varies widely in quantity from tree to tree and from year to year (Griffin 1971, Koenig et al. 1994 cited in Tyler et al. 2006), and may be 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. 1994, Koenig et al. 1999, Knapp et al. 2001, and Sork et al. 2002 cited in Tyler et al. 2006).

---

5. Management potential.

a. Value level people ascribe to this species: Low-Moderate
    i. Participant confidence: Moderate
b. Specificity of rules governing management of the species: Varies but overall Low-Moderate
    i. Participant confidence: Moderate
c. Description of use conflicts: Heavy development pressure and grazing pressure on this species in the central Sierra Nevada.
d. Potential for managing or alleviating climate impacts: Potential actions include identifying cooler and wetter sites that might serve as refugia. However, it is difficult to manage for this species, given that much of it occurs on private lands.

Additional comments: The specificity of rules governing management depends on county ordinances.

---

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

---

7. Overall user ranking.

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

Exposure

1. Exposure factors[8].

a. Factors likely to be most relevant or important to consider for the species: Precipitation, climatic water deficit, wildfire

i. Participant confidence: High (for all)

---

2. Exposure region.

a. Exposure by region: North – Moderate; Central – Moderate; South – Moderate

i. Participant confidence: Moderate-High (for all regions)

---

3. Overall user ranking.

a. Overall exposure of the species to climate changes: Low-Moderate

i. Participant confidence: Moderate

Additional comments: Blue oaks currently occupy the driest sites of all oak species in California and are the most drought-tolerant. This may provide an increased level of resistance to a future warmer and drier climate. However, water deficit thresholds could be reached, leading to high tree mortality and a further reduction in new tree recruitment. Associated increases in fire frequency and severity could further reduce numbers, densities, and recruitment.

References: The effects of climate change projected to 2070 forecast increases of blue oak/foothill pine (*Pinus sabiniana*) in the Sierra Nevada ecoregion (23 to 97%) and the California Cascades (94 to 108%) (PRBO Conservation Science 2011).

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).

[8] Participants were asked to identify exposure factors most relevant or important to the species but were not asked to evaluate the degree to which the factor affects the species.

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).

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).

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).

We acknowledge the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) for its role in making available their database of climate change science to support this exposure assessment. Support of this database is provided by the Eastern Forest & Western Wildland Environmental Threat Assessment Centers, USDA Forest Service.

Literature Cited

Adams, T. E. and N. K. McDougald (1995). "Planted blue oaks may need help to survive in southern Sierras." California Agriculture **49**(5): 13-17.

Allen-Diaz, B. H. and J. W. Bartolome (1992). "Survival of Quercus douglasii (Fagaceae) seedlings under the influence of fire and grazing." Madroño **39**: 47-53.

Bartolome, J. W., P. C. Muick and M. P. McClaran (1987). Natural regeneration of California hardwoods. Proceedings of the Symposium on Multiple-Use Management of California's Hardwood Resources. T. R. Plumb and N. H. OPillsbury, USDA Forest Service Pacific Southwest Forest and Range Station. **GTR PSW-100:** 26-31.

Bolsinger, C. L. (1988). The hardwoods of California's timberlands, woodlands and savannas, USDA Forest Service Pacific Northwest Research Station **Resource Bulletin PNW-148**.

Bolsinger, C. L. (1989). California's western juniper and pinyon-juniper woodlands: area, stand characteristics, wood volume, and fenceposts. F. S. U.S. Department of Agriculture, Pacific Northwest Research Station. Portland, OR. **PNW-RB-166:** 37.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree and K. Hayhoe (2008). "Climate change scenarios for the California region." Climatic Change **87**(S1): 21-42.

Das, T., M. D. Dettinger, D. R. Cayan and H. G. Hidalgo (2011). "Potential increase in floods in California's Sierra Nevada under future climate projections." Climatic Change **109**(S1): 71-94.

Dettinger, M. D. (2005). "From climate-change spaghetti to climate-change distributions for 21st Century California." San Francisco Estuary and Watershed Science **3**(1): Article 4.

Flint, L. E., A. L. Flint, J. H. Thorne and R. Boynton (2013). "Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance." Ecological Processes ***2***: 25.

Geos Institute (2013). Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy (VAAS) process, Available online at: http://www.geosinstitute.org/climatewiseservices/completed-climatewise-projects.html.

Hall, L. M., M. R. George, D. D. McCreary and T. E. Adams (1992). "Effects of Cattle Grazing on Blue Oak Seedling Damage and Survival." Journal of Range Management **45**(5): 503-506.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan and J. H. Verville (2004). "Emissions pathways, climate change, and impacts on California." Proceedings of the National Academy of Sciences **101**(34): 12422-12427.

Maurer, E. P. (2007). "Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios." Climatic Change **82**(3-4): 309-325.

McCreary, D. (1990). "Blue oaks withstand drought." California Agriculture **44**(2): 15-17.

McCreary, D. (1991). The effects of drought on California oaks. Proceedings of 1991 Annual Beef and Range Field Day for the Sierra Foothill Research and Extention Center**:** 40-41.

Meentemeyer, R., D. Rizzo, W. Mark and E. Lotz (2004). "Mapping the risk of establishment and spread of sudden oak death in California." Forest Ecology and Management **200**(1-3): 195-214.

Miller, J. D., H. D. Safford, M. Crimmins and A. E. Thode (2009). "Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA." Ecosystems **12**: 16-32.

Pavlik, B. M. and M. G. Barbour (1991). "Seasonal Patterns of Growth, Water Potential and Gas Exchange of Red and White Fir Saplings across a Montan Ecotone." American Midland Naturalist **126**(1): 14-29.

PRBO Conservation Science (2011). Projected Effects of Climate Change in California: Ecoregional Summaries Emphasizing Consequences for Wildlife. **Version 1.0:** 68. Available at http://data.prbo.org/apps/bssc/uploads/Ecoregional021011.pdf.

Rizzo, D. M., M. Garbelotto, J. M. Davidson, G. W. Slaughter and S. T. Koike (2002). "Phytophthora ramorum as the Cause of Extensive Mortality of Quercus spp. and Lithocarpus densiflorus in California." Plant Disease **86**(3): 205-214.

Safford, H. D., J. T. Stevens, K. Merriam, M. D. Meyer and A. M. Latimer (2012). "Fuel treatment effectiveness in California yellow pine and mixed conifer forests." Forest Ecology and Management **274**: 17-28.

Spero, J. G. (2002). Development and Fire Trends in Oak Woodlands of the Northwest Sierra Nevada Foothills. F. S. U.S. Department of Agriculture, Pacific Southwest Research Station. **PSW-GTR-184**.

Swiecki, T. J. and E. Bernhardt (1999). Effects of fire on naturally occurring blue oak seedlings and planted valley oak seedlings Seventh Workshop on Seedling Physiology and Growth Problems in Oak Plants (abstracts). D. McCreary and J. G. Isebrand, USDA Forest Service North Central Forest Experimentation Station **GTR NC-206:** 3.

Swiecki, T. J. and E. Bernhardt (2002). Effects of Fire on Naturally Occurring Blue Oak (Quercus douglasii) Saplings. F. S. U.S. Department of Agriculture, Pacific Southwest Research Station. **PSW-GTR-184:** 251-259.

Swiecki, T. J., E. Bernhardt and C. Drake (1993). Factors Affecting Blue Oak Sapling Recruitment and Regeneration, Prepared for: Strategic Planning Program, California Department of Forestry and Forest Protection.

Thorne, J. H., R. Boynton, L. Flint, A. Flint and T.-N. G. Le (2012). Development and Application of Downscaled Hydroclimatic Predictor Variables for Use in Climate Vulnerability and Assessment Studies, Prepared for California Energy Commission, Prepared by University of California, Davis. **CEC-500-2012-010**.

Tyler, C. M., B. Kuhn and F. W. Davis (2006). "Demography and Recruitment Limitations of Three Oak Species in California." The Quarterly Review of Biology **81**(2).

Tyler, C. M., B. Kuhn and F. W. Davis (2006). "Demography and Recruitment Limitations of Three Oak Species in California." The Quarterly Review of Biology **81**(2): 127-152.

Waddell, K. L. and T. M. Barrett (2005). Oak Woodlands and Other Hardwood Forests of California, 1990s, USDA Forest Service, Pacific Northwest Research Station. **Resource Bulletin PNW-RB-245**.

Westerling, A. L. and B. P. Bryant (2006). Climate Change and Wildfire in and around California: Fire Modeling and Loss Modeling. Prepared for California Climate Change Center. **CEC-500-2005-190-SF:** 33.

Westerling, A. L., B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das and S. R. Shrestha (2011). "Climate change and growth scenarios for California wildfire." Climatic Change **109**(S1): 445-463.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan and T. W. Swetnam (2006). "Warming and earlier spring increase western U.S. forest wildfire activity." Science **313**: 940-943.

EcoAdapt, founded by a team of some of the earliest adaptation thinkers and practitioners in the field, has one goal - creating a robust future in the face of climate change. We bring together diverse players to reshape planning and management in response to rapid climate change.

P.O. Box 11195
Bainbridge Island, WA 98110

EcoAdapt.org
+1 (206) 201 3834