Focal Resource: 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.)*

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[2]. The following document represents the vulnerability assessment results for the **OAK WOODLANDS ECOSYSTEM**, 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[3].

---

[1] From California Wildlife Habitat Relationship (CWHR) habitat classification scheme http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp

[2] 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.

[3] 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.

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.

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: direct sensitivity of the system to temperature and precipitation, sensitivity of component species within the system, ecosystem sensitivity to disturbance regimes (e.g., wind, drought, flooding), sensitivity to other climate and climate-driven changes (e.g., snowpack, altered hydrology, wildfire), and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: ecosystem extent, integrity, and fragmentation; ecosystem ability to resist or recover from stressors; landscape permeability; ecosystem diversity (e.g., physical, topographical, component species, functional groups); and ecosystem value and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the ecosystem 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[4]. 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*[5].

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*[5].

Recommended Citation

Hauptfeld, R.S., J.M. Kershner, and K.M. Feifel, eds. 2014. Sierra Nevada Ecosystem Vulnerability Assessment Technical Synthesis: Oak Woodlands *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.

---

[4] 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.

[5] 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
Direct Sensitivities – Temperature	**1.5 Low-Moderate**	**2.5 Moderate-High**
Direct Sensitivities – Precipitation	**2 Moderate**	**3 High**
Component Species	**1 Low**	**2 Moderate**
Disturbance Regimes	**3 High**	**3 High**
Climate-Driven Changes	**3 High**	**2 Moderate**
Non-Climatic Stressors – Current Impact	**3 High**	**3 High**
Non-Climatic Stressors – Influence Overall Sensitivity to Climate	**3 High**	**3 High**
Other Sensitivities	**None**	**2 Moderate**

Overall Averaged Confidence (Sensitivity)[6]: Moderate-High

Overall Averaged Ranking (Sensitivity)[7]: Moderate–High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation	Confidence
Extent and Integrity – Distribution	**3 High**	**3 High**
Extent and Integrity – Fragmentation	**2 Moderate**	**3 High**
Resistance and Recovery	**2 Moderate**	**2 Moderate**
Landscape Permeability	**2 Moderate**	**2 Moderate**
System Diversity – Physical/Topographical	**3 High**	**3 High**
System Diversity – Component Species/Functional Groups	**3 High**	**2 Moderate**
System Value	**2 Moderate**	**1 Low**
Specificity of Management Rules	**2 Moderate**	**2 Moderate**
Other Adaptive Capacities	**None**	**2 Moderate**

Overall Confidence (Adaptive Capacity)[6]: Moderate

Overall Averaged Ranking (Adaptive Capacity)[7]: Moderate-High

EXPOSURE

Relevant Exposure Factor	Confidence
Precipitation	**2 Moderate**
Climatic water deficit	**3 High**
Wildfire	**3 High**
Runoff	**2.5 Moderate-High**

---

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

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

Exposure Region	Exposure Evaluation	Confidence
Northern Sierra Nevada	**1 Low**	**1 Low**
Central Sierra Nevada	**1 Low**	**More certainty about impacts**
Southern Sierra Nevada	**2 Moderate**	**1 Low**

Overall Averaged Confidence (Exposure)[6]: Moderate

Overall Averaged Ranking (Exposure)[7]: Low

Sensitivity

1. **Direct sensitivities to changes in temperature and precipitation.**
   a. Sensitivity to temperature (means & extremes): Low – Moderate
      i. Participant confidence: Moderate – High
   b. Sensitivity to precipitation (means & extremes): Moderate
      i. Participant confidence: High

Additional comments: The participants rate the overall sensitivity of oaks as moderate, because while mature oaks can be fairly resilient to variability in precipitation, seedlings can be substantially affected by rainfall amounts. Oak woodlands are a large ecosystem, and the different oak species have a broad range of sensitivities. (1) Temperature: Oaks are thought to have fared better during warmer times in the past, and established individuals generally do well in drought environment because they are long-lived and have deep root systems. (2) Precipitation: Precipitation affects regeneration and recruitment. Established trees are more tolerant to fluctuations in precipitation, although precipitation can affect their fecundity. Oak woodlands are likely more sensitive to precipitation than temperature, although these systems are also thought to have expanded their ranges during past times of drier climates.

References: Oak woodlands are a large ecosystem, composed of oak species displaying a broad range of sensitivities (Jimerson and Carothers 2002; Waddell and Barrett 2005).

Precipitation: 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).

Oaks are masting species and yearly acorn crop sizes can vary significantly, potentially with water availability (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.).

---

2. **Sensitivity of component species.**
   a. Sensitivity of component species to climate change: Low
      i. Participant confidence: Moderate

Additional comments: In addition to oaks, component species include understory grasses, as well as deer, pocket gophers, ground squirrels, acorn woodpeckers, songbirds, and insects. High faunal diversity is tied to acorns as a primary food source. Like many flowering plants, oaks are masting species and acorn crop sizes can vary significantly year-to-year, thus affecting the fauna that utilize acorns as food. Component wildlife species that are dependent upon acorns may suffer if climate changes force them to shift their distributions to be disjunct with oak woodlands; wildlife species are likely to be able to shift their distributions much more rapidly than the long-lived oaks in response to changing climate. Oaks, especially younger individuals, are likely to be more sensitive to increased fire frequency that could occur as a result of warming and drying climate than the animals within the system. Soil types and depth to water table are also likely to be factors affecting species shifts and future ranges of oak species. In general, different oak species display a broad range of sensitivities.

References: Mean significant discriminant function analysis of sites in northwest California showed highest precipitation is associated with black oak woodlands in northwest California, while white oak is associated with mid-level precipitation (Jimerson and Carothers 2002). Blue oak series at inland and southern sites had the lowest average annual precipitation of common forest types, with a median precipitation of 21 inches (533 mm) and a range of 19-25 in/yr (482-635 mm/yr) (Waddell and Barrett 2005). Two-thirds of the white oak forest type was found in areas with 39-58 inches (990-1473 mm) of precipitation per year (Waddell and Barrett 2005). Median average annual precipitation for canyon live oak forest was 42 in/yr (1066 mm/yr) with a range of 35-53 in/yr (889-1346 mm/yr) (Waddell and Barrett 2005). Individual large California black oak trees (*Q. kelloggii)* established circa 1700, and are located near their range limit for the species and may be at risk of water deficit related mortality (Lutz et al. 2010).

---

3. **Sensitivity to changes in disturbance regimes.**
    a. Sensitivity to disturbance regimes including: Wildfire, drought, insects, other – grazing
    b. Sensitivity to these disturbance regimes: High
        i. Participant confidence: High

Additional comments: Among the choices of disturbance regimes, wind is not selected because windthrow is typically not a significant source of tree mortality for oaks. To date, confirmed sudden oak death disease has been confined to coastal California since it is associated with cooler and moister areas. There are many suspected cases in the central Sierra Nevada foothills, but no confirmed cases in the broader Sierra Nevada currently. The gold-spotted oak borer beetle currently only affects oaks in San Diego County where they have contributed to significant oak mortality. The disturbance regimes selected -- wildfire, drought and insects -- are all related to some extent. Although fire can be a significant factor in shaping oak population structure, both insects and disease are not a present factor (though may become significant in the future), leaving grazing as probably the largest source of disturbance to oak woodlands. In addition, grazing may shift in intensity from lower to higher elevations as the temperature warms (and cattle are moved from the valleys further upslope). However, under a future warmer climate, fire regimes may change, becoming more frequent and intense, which may negatively impact oak woodlands.

References: Seral status is determined by disturbance regimes of grazing, fire, drought, and competition from invasive species (Jimerson and Carothers 2002).

Wildfire: 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. While many native species of oak in California are relatively fire resistant (Horney et al. 2002) either due to innate low fuel conditions or vegetative adaptation (Spero 2002), smaller individuals often experience topkill (Holmes et al. 2008). Swiecki and Bernhardt (1998) found that a relatively light grassfire in 1996 that burned an oak stand killed 6% of saplings and almost all saplings less than 1500 mm (59 in) tall. Nearly a year after a fire, post-fire shoot biomass was still much lower than pre-fire biomass for all but the smallest topkilled saplings (Spero 2002). Canyon live oak (*Quercus chrysolepis*) is extremely sensitive to fire, and blue oak (*Quercus douglasii*) is more fire resistant than interior live oak (*Quercus wislizenii*) (Plumb 1980).

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).

<u>Drought</u>: Mature oaks generally fare well in warm weather and withstand drought (McCreary 1991), owing to deep root systems, long lifespans, and drought deciduousness. Young valley oaks may be especially vulnerable to drought effects of climate change (McLaughlin and Zavaleta 2012).

---

4. **Sensitivity to other types of climate and climate-driven changes.**
    a. <u>Sensitivity to climate and climate-driven changes including</u>: Altered fire regimes, evapotranspiration and soil moisture
    b. <u>Sensitivity to these climate and climate-driven changes</u>: High
        i. Participant confidence: Moderate

Additional comments: As mentioned above, a warmer future climate is likely to lead to increased fire frequency and severity. While oaks are generally adapted to survive most fires, young trees are at the highest risk of mortality from fires, therefore, increased fire frequency and severity could negatively impact recruitment of new trees, leading to overall population declines. Although oaks are deep rooted and often take advantage of deeper perennial water, a reduction in soil moisture, lowering of the water table, and increases in evapotranspiration under a warmer climate would be likely to increase tree stress and mortality, especially for younger trees. Mature oaks generally fare well in warm weather, withstand drought due to deep root systems, long lifespans and drought deciduousness, and are fairly resistant to fire, a characteristic directly related to bark thickness. Seedling recruitment and sapling survival, in contrast, are sensitive to reduced soil moisture and precipitation, which affect tree stress and mortality.

References:
<u>Altered fire regimes</u>: Due to fire suppression over the past 50 years, Douglas fir has become increasingly common on oak woodland sites. Fewer fires have increased the fuel load within oak woodland forests, which can cause more intense, stand-replacing fires when they do occur. Northwest California oak woodlands would naturally be subjected to frequent low intensity fires that tend to kill invading Douglas fir seedlings and saplings. High cover of Douglas fir under an oak canopy is an indication of an altered fire regime (Jimerson and Carothers 2002).

<u>Evapotranspiration and soil moisture</u>: Groundwater availability may be an important factor in local refugia. Valley oak is thought to be dependent on groundwater (McLaughlin and Zavaleta 2012).

---

5. **Sensitivity to impacts of other non-climate stressors.**
    a. <u>Sensitivity to other non-climate stressors including</u>: residential and commercial development, agriculture and aquaculture, biological resource use, natural system modifications, invasive and other problematic species, other – firewood harvesting
    b. <u>Current effects of these identified stressors on system</u>: High
        i. Participant confidence: High
    c. <u>Degree stressors increase sensitivity to climate change</u>: High
        i. Participant confidence: High

Additional comments: The participants chose the category ‘biological resource use’ to reflect wood harvest, and recognize that energy production may be a disturbance in the future. The categories ‘residential and commercial development’, ‘agriculture and aquaculture’, and ‘invasive species‘ all have substantial impact on oak woodland systems.

Oaks are probably more sensitive to development and agriculture because their range occurs at low elevation (which is closer to human population centers). Significant losses of oak habitat have already resulted from urban and suburban development, and conversion of lands to high intensity agriculture. As human populations expand, loss of oak woodlands to these expansion processes will worsen. The reduction or elimination of top predators (i.e. natural system modification) has probably led to higher densities of their prey, such as deer and rodents. The herbivory of these animals (e.g., cattle, deer, rodents, and insects) on seeds and seedlings has been implicated in low recruitment rates for many plant species, including oaks. Grazing may affect surface and subsurface water quality through expansion of bare ground and concentrated nutrient inputs. In addition, wild pigs (i.e. problem species) disrupt surface soils, and Eurasian grasses (many of which are invasive species) outcompete native annual and perennial grasses for water. The potential exists for the goldspotted oak borer beetle to spread from southern California and impact oak woodlands in the Sierra Nevada. Overall, the impacts discussed so far are greater in the central Sierra Nevada due to more extensive development and conversion of lands to agriculture.

References: Threats to oak woodlands in California include urbanization, conversion to agriculture, fragmentation, low rates of regeneration, competition from introduced species and sudden oak death (Jimerson and Carothers 2002).

Grazing: 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). Grazing may also impact oak woodlands by introducing exotic annuals through the cattle feces vector (Jimerson and Carothers 2002).

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

Invasive flora: Oak woodlands have a lower frequency of invasive weeds when compared to adjacent grasslands. Annual grasses are the primary non-native invaders of oak woodland. Invasive weeds are a potential threat because of the proximity of annual grasslands to oak woodlands. The alien grass hedgehog dogtail increases on overgrazed sites, and can lead to soil erosion. In general, invasive weeds are more common in oak woodlands if there has been significant surface disturbance the leads to bare ground being exposed (Jimerson and Carothers 2002). Modern oak understory communities are mainly dominated by exotic European annuals (Roche et al. 2012).

Pathogens and insects: 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).

A study in Utah suggests that incremental temperature increases in the next century will facilitate widespread introductions of gypsy moth into previously temperature-limited elevation zones containing hardwoods with no previous exposure to gypsy moth, which may lead to the destruction of large stands of quaking aspen (*Populus tremuloides*), bigtooth maple (*Acer grandidentatum*) and Gambel oak (*Quercus gambelii*) (Shepperd et al. 2006).

6. Other sensitivities.

a. Other critical sensitivities not addressed: None
    i. Participant confidence: Moderate

References: Low rates of regeneration of oaks have been noted in oak woodlands (Jimerson and Carothers 2002). Recruitment from acorns and survival can be affected by predation from insects, rodents, deer, and cattle (Hall et al. 1992; Adams and McDougald 1995). 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. However, Tyler et al. (2006) do not find that sufficient quantitative data exist to indicate a regeneration problem currently exists in California oak woodlands.

Past management strategies: Management to remove native oak and shrub species to enhance understory forage production have significantly impacted ecosystem services, including soil and water resources (Roche et al. 2012).

7. Overall user ranking.

a. Overall sensitivity of this system to climate change: Moderate
    i. Participant confidence: Moderate

Additional comments: Sensitivity of oaks to climate and non-climate stressors varies according to the life stage in which the species finds itself. In general, adult oaks are less sensitive, and seedlings are more sensitive. Water availability is a concern to oak woodlands, and the effects of browsing pressure (on young trees) by both cattle and deer are a concern. Likewise, development pressure and land use conversion to agriculture is also a concern on private lands.

Adaptive Capacity

1. **System extent and integrity.**
    a. System extent throughout the Sierra Nevada (e.g., widespread to narrow distribution): High
        i. Participant confidence: High
    b. Level of fragmentation across the Sierra Nevada: Moderate
        i. Participant confidence: High

Additional comments: Although participants ranked level of fragmentation 'moderate' for oak woodlands as a whole in the Sierra Nevada, at lower elevations on privately held lands, oak woodlands are highly fragmented, while on public land further upslope, they are widespread with low fragmentation from north to south and across elevations (121-1829 m) (400-6000 ft). Blue oak woodlands in the western Sierra Nevada display more fragmentation than the system as a whole.

References: Kueppers et al. (2005) modeled regional climate change and California endemic oak ranges.

Geographic extent: 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 (293,397 ha) (Jimerson and Carothers 2002). The most common hardwood forest type inventoried in in California was blue oak. 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). Canyon live oak was the most numerous hardwood tree species in California forestlands, with an estimated 2.22 billion trees (Waddell and Barrett 2005).

Fragmentation: Oak woodlands are found in small patches (averaging 29.3 ac/patch or 11.9 ha/patch), nested within a mosaic of annual grasslands and conifer forests, and contain species common to both respective vegetation types (Jimerson and Carothers 2002).

---

2. **Resistance, recovery, and refugia.**
    a. Ability of system to resist or recover from impacts: Moderate
        i. Participant confidence: Moderate
    b. Suitable microclimates within the system that could support refugial communities: Some species (e.g. canyon live oak) are confined to cooler canyon bottoms and north-facing slopes and would be further limited to theses location in a warmer/drier future. Most species of oak, however, are more broadly distributed over a wider range of microclimates and site conditions. For these species, a substantial contraction to the most favorable sites (based on water, temperature, soils, and fire regime conditions) would be a likely outcome, although this contraction may be slow and uneven. Many species of oaks grow larger when on deep soils where access to perennial groundwater is best, and so in these areas, adults may be more resilient to future climate changes. Generally however, soil types and depth to water table are likely to influence future shifts of species to future ranges.

Additional comments: Being long-lived, oaks are resistant to short-term climatic changes, but populations are slow to recover from major disturbances, in part because recruitment and masting are affected by age structure. Really old trees can depress acorn production, while really young trees take a while to produce acorns. In addition, oaks are somewhat adapted to survive fire. Adults may be able to resist increases in fire frequency in the short term, but may exhibit higher mortality in the longer term. While oaks survive fire regime changes in the long-term because they are able to sprout, acorns may shift in abundance for dependent species that utilize acorns. Since many oak species appear to lack sufficient recruitment, an increase in fire frequency and consequent increase in seedling mortality would further reduce oak recruitment rates. Warming and drying of the climate may also reduce acorn production and mast size.

References: Due to the long generation time of valley oak (*Quercus lobata*), population adaptation to new climate is unlikely (Sork et al. 2010). Geographic analysis shows a strong association of genetic structure of valley oak with climate variables, indicating that regional populations are likely adapted to local climate conditions. This climatically based genetic structure may constrain the ability of valley oak populations to tolerate rapid shifts in climate zones expected in some regions in California, and result in region-specific climate impacts to valley oak populations (Sork et al. 2010). However, local populations might include individuals that can tolerate new conditions, especially in regions where present climate conditions are variable, such as the Sierra foothills (Sork et al. 2010).

---

3. **Landscape permeability.**
    a. <u>Degree of landscape permeability</u>: Moderate
        i. Participant confidence: Moderate
    b. <u>Potential types of barriers to dispersal that apply</u>: Road-highway, agriculture, industrial or urban development, suburban or residential development, geologic features

Additional comments: The participants chose the category ‘geologic features’ to reflect soil types.

Land use conversion to urban or suburban development, or intensive agriculture will significantly reduce oak population sizes and densities, and reduce available habitat. These landscape conversion processes will reduce or eliminate dispersal to new areas. Oak woodlands not directly converted, but used as rangelands are also known to experience increased adult mortality and low recruitment rates. These problems are greatest at lower elevations, where agriculture and development is greatest, resulting in low connectivity and low permeability at the lower elevations of oak woodland range. At high elevations however, on public lands, there is much higher connectivity and permeability than at lower elevations.

References: Recruitment from blue oak acorns and survival can be affected by predation from insects, rodents, deer, and cattle (Hall et al. 1992; Adams and McDougald 1995). 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.

---

4. **System diversity.**
    a. <u>Level of physical and topographic diversity</u>: High
        i. Participant confidence: High
    b. <u>Level of component species/functional group diversity</u>: High
        i. Participant confidence: Moderate
    c. <u>Description of diversity</u>: Oak woodlands exhibit high faunal species diversity and faunal functional group diversity, and display high tolerance for varying soil, temperature and precipitation.

Additional comments: Oak woodlands display high biodiversity. If one species of seed disperser is lost, others can fill its functional role. However, if climate changes force shifts in a group of related wildlife, such as dispersers, seed dispersal could be reduced.

References: A total of 714 species were identified within oak woodlands at 446 field sites in northwest California, including 20 species of oak (Jimerson and Carothers 2002; Nixon 2002). Oak woodlands can be found in nearly pure stands or in association with other tree species like the Douglas fir, Ponderosa pine, gray pine, canyon live oak, California buckeye or bigleaf maple (Jimerson and Carothers 2002). Compared to annual grasslands, meadows, or chaparral, oak woodlands have a higher index of species richness and within the oak woodlands series, blue oak tends to have the highest number of associated species (29.8 species/plot) and black oak had the lowest (23.1 species/plot). Species richness can be correlated with tree canopy closure, with open canopies displaying higher species richness (Jimerson and Carothers 2002).

Vegetation cover in oak woodlands is high compared to other vegetation types in northwestern California. Trees accounted for 64% of cover, shrubs 22%, grass 26%, and forbs 14% (Jimerson and Carothers 2002). Oaks may facilitate a spatial niche for some native plant species within drier regions, however it may suppress understory productivity on in more mesic and productive regions in California (Roche et al. 2012). It is well established that blue oak (*Q. douglasii*) supports islands of greatly enhanced soil quality and fertility among the annual grassland matrix (Dahlgren et al. 1997; Camping et al. 2002; Dahlgren et al. 2003).

According to an analysis by Gardali et al. (2012), bird taxa in grassland habitats, along with oak woodland habitats, are the least vulnerable to climate change in California.

---

5. Management potential.

- a. Value level people ascribe to this system: Moderate
  - i. Participant confidence: Low
- b. Specificity of rules governing management of the system: Moderate
  - i. Participant confidence: Moderate
- c. Description of use conflicts: Conflicts include private ownership of oak woodlands, suburban development, and conversion to agriculture. When all oak species are lumped together, the large majority of their distribution (>80%) exists on privately held lands, which severely limits the potential for management of the system. Although valued for their aesthetics, as a wood source, and historically as important components of Native American heritage, oak woodlands and the habitats they provide are unfortunately located in areas also valued for other land uses. These conflicts will make it difficult to manage for oak woodland persistence and health, now and under future climates. As an example, groundwater depletion (for human uses) could prove detrimental to oaks.
- d. Potential for managing or alleviating climate impacts: Oak recruitment and restoration could be facilitated on private lands to protect seedlings from cattle and deer. Groundwater use (for human uses) could be limited. Movement to wetter microclimates (either upslope or to other sites within the same elevation range) could be assisted.

Additional comments: Some counties highly value oaks, but in the Sierra Nevada, a higher value is placed on rangeland. Oaks have high aesthetic value, but since they are not a timber species, they have low economic value. Oak woodlands exist within a public/private dichotomy. The management potential on public lands is high, but most oak woodlands occur on private lands, where management potential is low.

References: Aggressive fire suppression policy has led to increase in cover of Douglas fir on oak woodland sites (Jimerson and Carothers 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).
After fire, protection against grazing pressure from deer and cattle increased oak regrowth (Bartolome et al. 2002).

6. **Other adaptive capacity factors.**
    a. Additional factors affecting adaptive capacity: None
        i. Participant confidence: Moderate

---

7. **Overall user ranking.**
    a. Overall adaptive capacity of the system: Moderate-High
        i. Participant confidence: Moderate

Additional comments: In general, oak woodlands have high adaptive capacity to a changing climate compared to other communities in the Sierra Nevada, but their limited recruitment of some oak species is a big problem that may be exacerbated by a drier climate, potentially causing adaptive capacity in the long-term to be low. In the short term, trees are adapted to fires and can tolerate droughts.

References: Poor natural regeneration has been noted in portions of the blue oak 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, with some stands showing no evidence of tree recruitment within the past 50 years. 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.

Exposure

1. **Exposure factors[8].**
    1. Factors likely to be most relevant or important to consider for the system: Precipitation, climatic water deficit, wildfire, runoff
        1. Participant confidence: Moderate (precipitation); High (climatic water deficit); High (wildfire); Moderate-High (runoff)

2. **Exposure region.**
    1. Exposure by region: North – Low; Central – Low; South – Moderate
        1. Participant confidence: North – Low; Central – more certainty in impacts due to land use and urbanization in this region; South – Low

3. **Overall user ranking.**
    1. Overall exposure of the species to climate changes: Moderate
        1. Participant confidence: Moderate-High

References:

Vegetation shifts: Principal trends in vegetative changes during the last 80 years in the Sierra Nevada include the loss of blue oak (*Quercus douglasii*), attributed to management choices, and the loss of hardwood-dominated forests, with a strong connection to climate warming (Safford et al. 2012). Although the prediction of distributional shifts for oak woodlands in response to climate change is not as consistent as for grasslands, oak woodlands is also be projected to increase in California (Gardali et al. 2012). Broadleaf species whose potential distributions are simulated to expand to the area west of the northern Sierra Nevada 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). As CO_2 increases in the future, aspen (*Populus tremuloides*) productivity should increase as longer roots and thus better nutrient uptake increases (Morelli and Carr 2011).

See Kueppers et al. (2005) for modeled ranges of California endemic oaks under regional climate changes.

Wildlife - According to a vulnerability assessment by Gardali et al. (2012), along with grassland taxa, bird taxa of oak woodlands are least vulnerable to climate change in California. This may be due in part because oak woodlands are expected to increase in California (Gardali et al. 2012).

Valley oak woodlands *(Valley oak, California walnut, California sycamore)* - Future displacement of valley oaks will be a factor of both regional differences in the magnitude of climate changes, and the steepness of local topographically induced temperature and precipitation gradients (Sork et al. 2010). Rather than simply shifting northward and upward in elevation, valley oak may shift its range in all directions, including to the south of existing ranges. This is due to the topographic complexity and steep environmental gradients of western North American mountain ranges, which provide a high diversity of bioclimatic habitat under future climatic scenarios (Shafer et al. 2001).

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)

---

[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.

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).

Snow volume and timing: 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 (Null et al. 2010).

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).

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). 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). 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). However, 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).

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

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. (1988). The Hardwoods of California's Timberlands, Woodlands, and Savannas. Portland, OR, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. **PNW-RB-148:** 148.

Camping, T. J., R. A. Dahlgren, K. W. Tate and W. R. Horwath (2002). Changes in soil quality due to grazing and oak tree removal in California blue oak woodlands. Proceedings of the fifth symposium on oak woodlands: oaks in California's challenging landscape. 22–25 October 2001. R. B. Standiford, D. McCreary and K. L. Purcell. Albany, CA, USDA Forest Service, Pacific Southwest Research Station. **PSW-GTR-184:** 75-85.

Cayan, D., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio and D. H. Peterson (2001). "Changes in the Onset of Spring in the Western United States." Bulletin of the American Meteorological Society **82**(3): 399-145.

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.

Dahlgren, R. A., W. R. Horwath, K. W. Tate and T. J. Camping (2003). "Blue oak enhance soil quality in California oak woodlands." California Agriculture **57**: 42-47.

Dahlgren, R. A., M. J. Singer and X. Huang (1997). "Oak tree and grazing impacts on soil properties and nutrients in a California oak woodland." Biogeochemistry **39**(45-64).

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.

Dettinger, M. D., D. R. Cayan, N. Knowles, A. Westerling and M. K. Tyree (2004a). Recent Projections of 21st-Century Climate Change and Watershed Responses in the Sierra Nevada, USDA Forest Service. **Gen. Tech. Report PSW-GTR-193**.

Dettinger, M. D., D. R. Cayan, M. K. Meyer and A. E. Jeton (2004b). "Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900–2099." Climate Change **62**: 283-317.

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.

Fried, J. S., M. S. Torn and E. Mills (2004). "The impact of climate change on wildfire severity: A regional forecast for northern California." Climatic Change **64**: 169-191.

Fritzke, S. L. (1997). A California Black Oak Restoration Project in Yosemite Valley, Yosemite National Park, California. Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues. N. H. Pillsbury, J. Verner and W. D. Tietje. San Luis Obispo, CA, USDA Forest Service Pacific Southwest Research Station,. **PSW-GTR-160:** 281-288

Gardali, T., N. E. Seavy, R. T. DiGaudio and L. A. Comrack (2012). "A climate change vulnerability assessment of California's at-risk birds." PLoS One **7**(3).

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.

Hamlet, A. F., P. W. Mote, M. P. Clark and D. P. Lettenmaier (2007). "Twentieth-Century Trends in Runoff, Evapotranspiration, and Soil Moisture in the Western United States*." Journal of Climate **20**(8): 1468-1486.

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.

Holmes, K. A., K. E. Veblen, T. P. Young and A. M. Berry (2008). California oaks and fire: A review and case study. . Proceedings of the sixth California oak symposium: today's challenges, tomorrow's opportunities. A. Merenlender, D. McCreary, K. L. Purcell and K. L. Albany, CA, US Department of Agriculture Forest Service Pacific Southwest Research Station,. **General Technical Report PSW-GTR-217**.

Horney, M., R. B. Standiford, D. McCreary, J. Tecklin and R. Richards (2002). Effects of wildfire on blue oak in the Sacramento Valley. Proceedings of the fifth symposium on oak woodlands: oaks in California's changing landscape. R. B. Standiford, D. McCreary and K. L. Purcell. Albany, CA, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. **PSW-GTR-126:** 261-267.

Kauffman, J. B. and R. E. Martin (1987). Effects of fire and fire suppression on mortality and mode of reproduction of California black oak (*Quercus kelloggii Newb.*) Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. . T. R. P. Plumb, Norman H., , U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station**:** 122-126.

Knowles, N. and D. Cayan (2004). "Elevational dependence of projected hydrologic changes in the San Francisco Estuary and Watershed." Climate Change **62**: 319-336.

Knowles, N., M. D. Dettinger and D. Cayan (2006). "Trends in Snowfall versus Rainfall in the Western United States." Journal of Climate **19**(18): 4545-4559.

Koenig, W. D., D. R. McCullough, C. E. Vaughn, J. M. H. Knops and W. J. Carmen (1999). "Synchrony and asynchrony of acorn production at two coastal California sites." Madroño **46**(1): 20-24.

Kueppers, L. M., M. A. Snyder, L. C. Sloan, E. S. Zavaleta and B. Fulfrost (2005). "Modeled regional climate change and California endemic oak ranges." PNAS USA **102**(45): 16281-16286.

Lutz, J. A., J. W. van Wagtendonk and J. F. Franklin (2010). "Climatic water deficit, tree species ranges, and climate change in Yosemite National Park." Journal of Biogeography **37**: 936-950.

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.

Maurer, E. P., I. T. Stewart, C. Bonfils, P. B. Duffy and D. Cayan (2007). "Detection, attribution, and sensitivity of trends toward earlier streamflow in the Sierra Nevada." Journal of Geophysical Research **112**(D11).

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.

McKenzie, D., Z. Gedalof, D. L. Peterson and P. W. Mote (2004). "Climate Change, Wildfire, and Conservation." Conservation Biology **18**(4): 890-902.

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.

Miller, N. L., K. E. Bashford and E. Strem (2003). "Potential impacts of climate change on California hydrology." Journal of American Water Resources Association **39**(4): 771-784.

Morelli, T. L. and S. C. Carr (2011). A Review of the Potential Effects of Climate Change on Quaking Aspen (Populus tremuloides) in the Western United States and a New Tool for Surveying Aspen Decline. Albany, CA, USDA, Forest Service, Pacific Southwest Research Station. **PSW-GTR-235:** 31.

Moser, S. C., G. Franco, S. Pittiglio, W. Chou and D. Cayan (2009). The Future Is Now: An Update On Climate Change Science Impacts And Response Options For California, Prepared for: California Energy Commission, Public Interest Energy Commission. **CEC-500-2008-071**.

Mote, P. W. (2006). "Climate-Driven Variability and Trends in Mountain Snowpack in Western North America." Journal of Climate **19**(23): 6209-6220.

Mote, P. W., A. F. Hamlet, M. P. Clark and D. P. Lettenmaier (2005). "Declining Mountain Snowpack in Western North America*." Bulletin of the American Meteorological Society **86**(1): 39-49.

Nixon, K. C. (2002). The Oak (Quercus) Biodiversity of California and Adjacent Regions. F. S. U.S. Department of Agriculture, Pacific Southwest Research Station. **PSW-GTR-184:** 3-20.

Null, S. E., J. H. Viers and J. F. Mount (2010). "Hydrologic response and watershed sensitivity to climate warming in California's Sierra Nevada." PLoS One **5**(4).

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.

Plumb, T. R. (1980). Proceedings of the symposium on the ecology, management and utilization of California oaks; 1979 June 26-28. PSW-GTR-144. T. R. Plumb. Berkeley, CA, U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station**:** 202-215.

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.

Roche, L. M., K. J. Rice and K. W. Tate (2012). "Oak conservation maintains native grass stands in an oak woodland-annual grassland system." Biodiversity and Conservation **21**(10): 2555-2568.

Safford, H., M. North and M. D. Meyer (2012). Chapter 3: Climate Change and the Relevance of Historical Forest Condition. Managing Sierra Nevada Forests, USDA Forest Service, Pacific Southwest Research Station. **Gen. Tech. Rep. PSW-GTR-237**.

Shafer, S. L., P. J. Bartlein and R. S. Thompson (2001). "Potential Changes in the Distributions of Western North America Tree and Shrub Taxa under Future Climate Scenarios." Ecosystems **4**(3): 200-215.

Sheffield, J., G. Goteti, F. Wen and E. F. Wood (2004). "A simulated soil moisture based drought analysis for the United States." Journal of Geophysical Research: Atmospheres (1984-2012) **109(D24)**.

Shepperd, W. D., P. C. Rogers, D. Burton and D. L. Bartos (2006). Ecology, Biodiversity, Management, and Restoration of Aspen in the Sierra Nevada. Fort Collins, CO, USDA, Forest Service, Rocky Mountain Research Station. **Gen Tech Rep RMRS-GTR-178:** 122.

Sork, V. L., F. W. Davis, R. Westfall, A. Flint, M. Ikegami, H. Wang and D. Grivet (2010). "Gene movement and genetic association with regional climate gradients in California valley oak (Quercus lobata Née) in the face of climate change." Molecular Ecology **19**: 3806-3823.

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**.

Stewart, I., D. Cayan and M. D. Dettinger (2005). "Changes toward Earlier Streamflow Timing across Western North America." Journal of Climate **18**: 1136-1155.

Swiecki, T. J. and E. Bernhardt (1998). "Understanding oak regeneration." Fremontia **26**(1): 19-26.

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): 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.

Young, C. A., M. I. Escobar-Arias, M. Fernandes, B. Joyce, M. Kiparsky, J. F. Mount, V. K. Mehta, D. Purkey, J. H. Viers and D. Yates (2009). "Modeling The Hydrology Of Climate Change In California's Sierra Nevada For Subwatershed Scale Adaptation." Journal of American Water Resources Association **45**(6): 1409-1423.

Meeting the challenges of climate change

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