<u>CalVeg types included</u>: **MHC**-Montane Hardwood-Conifer: Ponderosa Pine (*Pinus ponderosa)*, Incense Cedar, California Black Oak (*Quercus kelloggii*); **MHW**-Montane Hardwood: Canyon Live Oak (*Quercus chrysolepis*), California Black Oak (*Quercus kelloggii*), Oregon White Oak (*Quercus garryana*); **ASP**-Aspen: Aspen (*Populus tremuloides)*, Willow (*Salix spp.*), Alders (*Alnus spp.)*

Sensitivity Assessment

1. Direct sensitivities to changes in temperature and precipitation

- Temperature
  - Means and extremes
    - Historical
      - Black oak series are associated with cool upland sites, while blue oak are found on sites with lowest tree cover, and at lower elevation. Of black, blue and white oak, the white oak series generally found on the highest elevation, warmest sites, with highest mean slope (Jimerson and Carothers 2002). Acorn production may be influenced by rainfall and temperature (see: Koenig et al. 1999)
    - Future
      - Early life stages may not tolerate the same range of conditions as adults
- Precipitation
  - Means and extremes
    - Historical: Precipitation is a key discriminant variable determining oak woodland type (Waddell and Barrett).
      -
    - Future

2. Sensitivity of component species

- Dominant species
  - Precipitation:
    - Mean significant discriminant function analysis of sites in northwest California showed highest precipitation is associated with black oak woodlands in northwest California (Jimerson and Carothers 2002). Two-thirds of the forest type was found in areas with between 39 – 52 inches of precipitation per year (Waddell and Barrett 2005).
    - Blue oak series had the lowest average annual precipitation of common forest types, with a median precipitation of 21 inches, and was found at inland and southern sites. 2/3 of blue oak forest type surveyed experienced precipitation between 19 – 25 inches per year (Waddell and Barrett 2005).

        - White oak fell in the middle in terms of precipitation level (Jimerson and Carothers 2002). Two thirds of the forest type was found in areas with 39-58 inches of precipitation per year (Waddell and Barrett 2005).
        - Median average annual precipitation for canyon live oak forest was 42 in. per year (2/3 of the forest type experience between 35 – 53 in./year). Canyon live oak was the most numerous hardwood tree species in California forest lands, with an estimated 2.22 billion trees (Waddell and Barrett 2002).
- Ecosystem engineers
- Keystone species

3. Sensitivity to changes in disturbance regimes

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

- Wildfire
    - 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).
    - Fire does not necessarily have a positive impact on growth or recruitment of oaks (see: Bartolome et al. 2002, Swiecki and Bernhardt 2002).
    - Larger blue oak trees are fairly resistant to fire (see: Horney et al. 2002).
- Disease
    - Sudden oak death, *Phytophtora ramorum*, may produce a mortality rate of 0.4 trees per acre in areas where the disease is established (see: Kelly and Meentemeyer 2002). The pathogen has a wide range of tolerable microclimates (see: Rizzo et al. 2002). Species differ in their susceptibility to the disease, with tanoak, coast live oak, California black oak, and Shreve's oak (Q. parvula) particularly subject to lethal trunk infections (see: Rizzo et al. 2002). Douglas fir and redwood species are also listed as hosts for the *P. ramorum* pathogen (Waddell and Barrett 2005).
- Flooding
- Insects
- Wind
- Drought
    - 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 impacts

- Altered hydrology
- Altered fire regimes

  - The area of oak woodland burned by contained fires can be 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). Fire response seems to vary among California's oak tree species.
- Evapotranspiration and soil moisture
  - Groundwater availability may be important factors in local refugia. Valley oak is thought to be dependent on groundwater (McLaughlin and Zavaleta 2012).
- Extreme precipitation and temperature
- Water temperature
- Storm frequency and intensity

5. Sensitivity to impacts of other non-climate related threats

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).

- Residential and commercial development
- Agriculture and aquaculture
  - Over-grazed areas are vulnerable to invasion by aggressive alien grass species (Jimerson and Carothers 2002). Grazing may also lead to loss of soil productivity as a result of surface disturbance.
- Energy production and mining
- Transportation and service corridors
- Biological resource use
- Altered interspecific interactions
  - Positive tree effects on annual biomass productivity include microclimate amelioration, improved water availability and improved soil fertility and quality. However, belowground resource competition between annual species and fine oak roots near the soil surface may outweigh these benefits (Roche et al. 2012).
- Human intrusions and disturbance
- Natural system modification
- Invasive and other problem species
  - Annual grasses are the primary non-native invaders of oak woodlands (Jimerson and Carothers 2002). The alien grass hedgehog dogtail increases on overgrazed sites, and can lead to soil erosion (Jimerson and Carothers 2002). Invasive weeds are a potential threat because of the proximity of annual grasslands to oak woodlands, and because cattle tend to use oak woodlands for shade, and their feces serves as a vector for the weeds (Roche et al. 2012). Modern oak understory communities are mainly dominated by exotic European annuals (Roche et al. 2012).
- Pollution and poisons
- Geological events

6. Other Sensitivities

- Management
  - Aggressive fire suppression policy has lead to increase in cover of Douglas fir on oak woodland sites (Jimerson and Carothers 2002). 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).
- Low rates of regeneration may threaten oak woodlands (Jimerson and Carothers 2002).
- Recruitment from acorns and survival can be affected by predation from insects, rodents, deer, and cattle (see: Adams and McDougald 1995, Hall et al. 1992).

Adaptive Capacity

1. Habitat Extent and Characteristics

- Geographic extent in California
  - Hardwood forests make up 40 percent of California's forest land. Excluding reserved lands outside of national forests, the total estimated area of hardwood forest in California in the 1990s was 11.29 million acres (Waddell and Barrett 2005). The most common hardwood forest type inventoried in in California was blue oak (Waddell and Barrett 2005).
  - Oak woodlands lie between the coastal mixed evergreen forest and the valley grasslands of Central Valley (see: Griffin 1988). Since precipitation is a key discriminant variable, black oak are found more on western sites in the northern portion of northwest California, and blue oaks are found on more inland and southern sites. White oaks are found throughout (Jimerson and Carothers 2002).
  - California black oak forest type primarily (two-thirds inventoried) occurred between 1,890 – 5,050 feet (Waddell and Barrett 2005).
  - Blue oak forest type primarily (two-thirds inventoried) occurred between 680 – 2,680 feet (Waddell and Barrett 2005).
  - California live oak (*Q. chrysolepis*) forest type primarily (two-thirds) found between 1,780 to 4,600 feet elevation (Waddell and Barrett 2005).
  - Tanoak is the densest of the common hardwood forest types (Waddell and Barrett 2005).
  - Oregon white oak forest type primarily (two-thirds of forest inventoried) occurs between 1,470 – 3,860 feet.
- Oak woodlands are found in small patches (averaging 29.3 acres/patch), nested within a mosaic of annual grasslands and conifer forests, and hence contain species common to both vegetation types (Jimerson and Carothers 2002). Oak woodland plots in northwest California are found in nearly pure stands dominated by Oregon white oak (*Quercus garryana*), black oak (*Q. kelloggii*) and blue oak (*Q. douglasii*), or in association with other tree species such as Douglas fir (*Pseudotsuga menzisii*), Ponderosa pine (*Pinus ponderosa*), gray pine (*Pinus sabiniana*), canyon live oak (*Q. chrysolepis*), California

buckey (*Aesculus californica*) and bigleaf maple (*Acer macrophyllum*) (Jimerson and Carothers 2002). It is well established that blue oak (*Q. douglasii*) supports islands of greatly enhanced soil quality and fertility among the annual grassland matrix (see: Dahlgren et al. 1997, Camping et al. 2002, Dahlgren et al 2003). Purple needlegrass (*Nasella pulchra*) is California's flagship native species for restoration and conservation (Roche et al. 2012).

2. Landscape Permeability

- Barriers to dispersal or fragmentation
    - Recruitment from blue oak acorns and survival can be affected by predation from insects, rodents, deer, and cattle (see: Hall et al. 1992, Adams and McDougald 1995).

3. System Diversity

- Diversity of component species
    - Oak woodlands have been found to have significantly higher species richness than annual grassland, meadows and chaparral. A total of 714 plant species were identified from 446 ecology field plots in northwestern California (Jimerson and Carothers 2002).
    - Twenty species of oak are known in California (Nixon 2002).
- Community Structure
    - 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).
    - California black oak ay produce more than 6,000 acorns per oak (see: Bowyer and Bleich 1980)

Exposure

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). Precipitation is a key discriminant variable in northwest California oak woodlands. In a survey of California oak woodlands, black oak (*Quercus kelloggii*) was found more often on more westerly sites in the northern quadrant of sites in northwest California, in areas with higher rainfall, while blue oak was found on eastern sites in the southern portion of the study area, in areas where precipitation was generally lower. White oak (*Quercus garryana*) was found throughout the study area (Jimerson and Carothers 2002).

Although the prediction of distributional shifts for oak woodlands in response to climate change is not as consistent as for grasslands, oak woodlands may also be expected 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 CO2 increases in the future, aspen (*Populus tremuloides*) productivity should increase as longer roots and thus better nutrient uptake increases (Morelli and Carr 2011).

Fire

The area of oak woodland burned by contained fires can be 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). Fire response seems to vary among California's oak tree species. Many species of native California oaks are relatively fire resistant, either due to innate low fuel conditions or vegetative adaptation, and Spero (2002) suggests that fire may not play as much a role in regeneration as once thought, neither enabling nor preventing regeneration. 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*) (see: Plumb 1980).

However, even low intensity fires can result in substantial oak woodland mortality, and compromise re-sprouting from saplings and seedling advance regeneration (Spero 2002). A study (see: Swiecki and Bernhardt 1999) found that a relatively light grassfire in 1996 that burned an oak stand killed 6% of saplings and almost all saplings less than 150 cm tall. Nearly a year later, post-fire shoot biomass was still much lower than pre-fire biomass for all but the smallest topkilled saplings (Spero 2002). Spero (2002) adds that although blue oak is the most abundant hardwood forest type in California, it has sapling populations that may be insufficient to maintain current stand densities.

Pests

Habitat for sudden oak death *(Phytophthora ramorum)* is projected to extend from Los Angeles, California to the Puget Sound area in Washington by 2050, with limited inland expansion (Kliejunas 2011). Models predict the risk for sudden oak death will increase in California (Sturrock et al. 2011) and exist in the northern foothills of the Sierra Nevada (Kelly et al. 2007).

Risk of other pests may also increase. 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).

Blue oak woodlands *(Blue oak, Interior live oak, California buckeye)*

Blue oak is the most abundant hardwood forest type in California. The effects of climate change projected to 2070 forecast increases of blue oak (*Quercus douglasii*)/foothill pine (*Pinus sabiniana*) in the Sierra Nevada ecoregion (23 to 97%) and the California cascades (94 to 108%) (Gardali et al. 2011).

A study found no evidence that fire promotes blue oak regeneration (see: Swiecki and Bernhardt 2002). Rather, despite high rates of growth of topkilled sapling immediately following fire, over time these rates slowed, resulting in retarded advancement of small saplings to the overstory. Several years may be subsequently required for topkilled saplings to regain pre-fire above ground biomass, during which time they may be vulnerable to damaging agents (Spero 2002).

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). Micro-refugia of groundwater availability may contribute to the persistence of valley oak in California (McLaughlin and Zavaleta 2012). Saplings have a narrower climate tolerance than adults, particularly to maximum summer temperatures, likely restricting the potential for the species to persist (McLaughlin and Zavaleta 2012).

On the other hand, 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).

California black oak woodlands

Black oak (*Q. kelloggii*) was found more often on more westerly sites in the northern portion of sites in northwest California, where rainfall was typically greatest (Jimerson and Carothers 2002). Individual large California black oak trees that 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). A predicted increase in mixed woodland and hardwood-dominated forests in the Sierra Nevada during the 21st century may benefit the fisher (Martes pennant), as California black oaks are a key component of fisher habitat (Purcell et al. 2012).

Canyon live oak (*Q. chrysolepis*)

Canyon live oak was one of only three species with increases of large-diameter trees between the 1930s and 1990s in Yosemite National Park, while densities of 11 species declined (Lutz et al. 2009). Canyon live oak is extremely fire sensitive among California's oak tree species (see: Plumb 1980).

Animals

According to a vulnerability assessment by Gardali et al. (2012), along with grassland taxa, bird taxa of oak (*Quercus spp.*) 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).

Reproduction of California spotted owl (*Strix occidentalis occidentalis*) was correlated with temperature variables in both oak woodland and conifer forests. Reproduction was higher in years when the total March-May precipitation was less than 94mm in oak woodlands (50yr mean = 188mm, SD = 167) (North et al. 2000).

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