Oak Woodlands

Climate Change Vulnerability Assessment for the Santa Cruz Mountains Climate Adaptation Project

This document represents an initial evaluation of mid-century climate change vulnerability for oak woodlands *in the* Santa Cruz Mountains region *based on expert input during an October 2019 vulnerability assessment workshop as well as information in the scientific literature.*

Habitat Description

Oak woodlands within the Santa Cruz Mountains region are commonly dominated by coast live oak (*Quercus agrifolia*), valley oak (*Q. lobata*), and/or blue oak (*Q. douglasii*)[1,2]. Other oak species that may co-occur (and occasionally dominate a stand) include interior live oak (*Quercus wislizeni*), canyon live oak (*Q. chrysolepis*), black oak (*Q. douglasii*), scrub oak (*Q. berberidifolia*), and leather oak (*Q. durata*; on serpentine soils)[1,3]. Oak distribution and woodland species composition are strongly influenced by slope, elevation, drainage, soils, and other site-specific characteristics[1,4]. Habitat structure is relatively open (30–60% canopy cover) with an understory comprised of native and non-native grasses and forbs, as well as a limited variety of shrubs such as poison oak (*Toxicodendron diversilobum*) and honeysuckle (*Lonicera* spp.)[1,2].

Vulnerability Ranking

High Vulnerability

Low → High

High Confidence

Oak woodlands are sensitive to climate stressors that alter water availability and/or soil temperature, including changes in precipitation amount and timing, reduced soil moisture, increased drought, and warmer air temperatures. These can impact acorn germination and seedling/sapling growth and survival, ultimately determining future habitat distribution. Climate-driven changes in disturbances (e.g., wildfire, disease, insect outbreaks) have the potential to increase oak mortality, and may alter habitat structure and composition due to age- or species-specific patterns of mortality. Non-climate stressors (e.g., development, fire suppression/exclusion, invasive plants, livestock grazing, nitrogen deposition) can further exacerbate habitat sensitivity by contributing to climate-driven changes in the fire regime, reducing species and structural diversity, altering ecosystem processes, and fragmenting or eliminating woodland areas.

Although oak woodlands remain widely distributed within the Santa Cruz Mountains region, historical habitat extent has been significantly reduced by development and other anthropogenic land uses, and many of the remaining woodlands have been degraded and/or fragmented. Overall, oaks are well-adapted to survive disturbances such as drought and wildfire, but low recruitment rates and increased mortality due to climate change and other stressors may limit the ability of this habitat to recover from future disturbances. Management strategies that may increase the resilience of oak woodlands to climate impacts include increased use of prescribed fire, restoration of native perennial grasses and forbs, climate-informed management of livestock grazing, and protection of oak woodlands within climatically-suitable areas and/or potential refugia.

As part of this project, Pepperwood Preserve modeled how major vegetation types in five landscape units of the Santa Cruz Mountains region are projected to shift in response to climate change.[1] For oak woodlands, they found that canyon live oak and black oak forests/woodlands are expected to undergo dramatic declines across all landscape units, while valley oak forests/woodlands are expected to increase in all units. Other oak woodland types show more varied responses within the region, with increases or relatively stable distribution in some areas and moderate to dramatic declines in others.

Vegetation Type	San Francisco	Santa Clara Valley	Santa Cruz Mtns. North	Santa Cruz	Sierra Azul
Valley oak forest/ woodland	△	△	△	△	△
Blue oak forest/ woodland	△	△	△	—	△
Interior live oak forest/woodland	—	△	△	—	△
Coast live oak forest/woodland	▽	▽	△	△	▽
Blue oak-foothill pine woodland	△	—	▽	▽	—
Oregon white oak woodland	—	▽	▽▽	—	▽
Black oak forest/ woodland	▽▽	▽▽	▽▽	▽▽	▽▽
Canyon live oak forest	▽▽	▽▽	▽▽	▽▽	▽▽

% Change BY MID-CENTURY: △ Increase; — Relatively stable; ▽ Moderate decline; ▽▽ Dramatic decline

Table 1. Projected trends in vegetation distribution (increase, relatively stable, moderate decline, or dramatic decline) by mid-century within five landscape units of the Santa Cruz Mountains region.

Sensitivity and Exposure

High Impact

Low → High

Mod Confidence

Sensitivity is a measure of whether and how a habitat is likely to be affected by a given change in climate and climate-driven factors, changes in disturbance regimes, and non-climate stressors. **Exposure** is a measure of how much change in these factors a resource is likely to experience.

Sensitivity and future exposure to climate and climate-driven factors

Oak woodlands are sensitive to climate stressors that alter water availability and/or soil temperature, which can impact oak growth, recruitment, and vulnerability to disturbance-related mortality.

[1] Information about the methods used to generate these projections can be found on the project page (http://ecoadapt.org/programs/awareness-to-action/santa-cruz-mountains).

Climate Stressor	Trend Direction	Projected Future Changes
Precipitation	▲ ▼	• Shorter winters and longer, drier summers likely, with higher interannual variability[5,6]
Soil moisture	▼	• Reduced soil moisture likely due to increased evaporative demand[5,7]
Drought	▲	• Increased frequency of drought years, including periods of prolonged and/or severe drought[5,8]
Air temperature	▲	• 1.5–3.1°C (2.7–5.6°F) increase in annual mean temperature[9,10]

- **Changes in precipitation (e.g., amount and timing) and soil moisture** are likely to reduce acorn production, seedling establishment, and tree growth[2,11–14], ultimately affecting oak woodland species composition and distribution[12,15]. In general, oak seedlings and saplings are more sensitive to water stress than adults[12,16,17], in part because their root systems are not able to reach the groundwater sources that often support mature oaks[17]. As a result of their sensitivity to moisture stress, range contractions may occur where seedlings are unable to survive in areas that would be considered climatically suitable for the persistence of adult trees[12]. The timing of precipitation also has a large impact on oak recruitment, which may be negatively impacted by saturated soils following continuous rain[3].

  Increases in winter rainfall would likely enhance spore production and transmission of the pathogen that causes sudden oak death, increasing infection risk and associated mortality[18,19]. By contrast, dry conditions and low soil moisture could limit the spread and severity of this disease[20,21].
- **Increases in the frequency and/or severity of drought** are likely to decrease growth and recruitment and increase mortality rates in oaks[11,12,17], especially where competition with annual plants (e.g., invasive grasses) further reduces available moisture for oak seedlings[14,22,23]. Persistence in moist, shaded microsites and areas with accessible groundwater may allow oaks to resist increasing drought stress[24]. However, greater drought sensitivity in seedlings and saplings could constrain the successful regeneration of mature oak woodlands[12,24,25].
- **Warmer air temperatures** and corresponding **increases in winter soil temperature**s are likely to reduce recruitment in species that require a period of cold temperatures to break seed dormancy and allow germination, including coast live oaks, canyon live oaks, and black oak[26].

Sensitivity and future exposure to climate-driven changes in disturbance regimes

Oak woodlands are sensitive to climate-driven changes in disturbance regimes that increase direct mortality and/or alter habitat composition and structure.

Disturbance Regimes	Trend Direction	Projected Future Changes
Wildfire	▲	• Slight to moderate increase in wildfire risk, particularly in areas of higher rainfall[9,10]
Disease	▲	• Likely increases in spore production and infection risk of *Phytophthora ramorum*[27,28]
Insect outbreaks	▲	• Likely increase in severity of insect outbreaks[29,30] and continued range expansion of non-native insects[31,32]

- Although oaks are well-adapted to low- and moderate-intensity fires[1,33,34], **climate-driven changes in the frequency and/or intensity of wildfires** may increase tree injury and mortality[33,35]. Seedlings/saplings and smaller trees are significantly more likely to experience damage or mortality[33,35]. As a result, increases in the frequency of high-severity fires may negatively impact the persistence of oak woodlands where seedlings and sprouted trees are unable to mature and produce acorns before the next fire[33]. Repeated high-severity fire can result in conversion of oak woodlands to chaparral or grasslands over time[36].
- **Increased disease** may cause more extensive tree mortality as changes in temperature and moisture impact pathogen production and transmission as well as tree defenses, host susceptibility, and community interactions[20,30,37,38]. Within the Santa Cruz Mountains region, sudden oak death (caused by the introduced pathogen *Phytophthora ramorum*) is of particular concern. Sudden oak death causes high rates of injury and mortality in coast live oak and several other *Quercus* species, with the highest mortality rates occurring among large trees[20,39–41]. Beetle attacks in infected trees can also speed mortality, reducing life expectancy by 65–70%[39]. High rates of tree mortality and resulting shifts in species composition may also change patterns of fuel composition and availability, potentially altering fire behavior[42–45].
- **Increased insect outbreaks** may cause higher rates of oak mortality[30], particularly if warmer temperatures drive range expansions in non-native insects such as the goldspotted oak borer (*Agrilus auroguttatus;* GSOB). The GSOB causes crown dieback and tree mortality within mature coast live oak, canyon live oak, and black oak[46], and has been responsible for the mortality of over 80,000 oaks in San Diego County since 2002[47]. Satellite infestations have more recently been discovered in Riverside (2012), Orange (2014, 2017), and Los Angeles (2015) counties as well[48]. Drought stress appears to increase the likelihood of GSOB-related mortality; conversely, insect damage to the phloem and cambium increases drought stress and vulnerability to secondary attack, particularly in older trees[32,49]. Projections suggest that much of the state will be climatically suitable for the GSOB by the end of the century, increasing the likelihood of range expansion[31].

Sensitivity and current exposure to non-climate stressors

Non-climate stressors can exacerbate habitat sensitivity to changes in climate factors and disturbance regimes by contributing to changes in the fire regime, reducing species and structural diversity, altering ecosystem processes, and fragmenting or eliminating woodland areas.

- R**esidential and commercial development** has resulted in the loss and fragmentation of oak woodlands in the Santa Cruz Mountains region[1,50], and has been associated with reduced genetic exchange and tree recruitment in fragmented populations[51–53], altered plant and wildlife composition, and overall decreases in biodiversity[54]. Development may also cause the loss of microrefugia that support oak regeneration, especially where human water use lowers groundwater tables[24,25]. Finally, development and associated human activity may increase wildfire ignitions, exacerbating climate-driven shifts in wildfire regimes[55,56].

- **Fire exclusion and suppression** has altered historical wildfire regimes in oak woodlands, increasing fire return intervals within the Santa Cruz Mountains region to over 150 years (compared to 1–2 years prior to Euro-American settlement)[57,58]. Reduced wildfire frequency within these fire-adapted communities has resulted in shifts in species composition and habitat structure across the region[34,59,60].
- **Invasive annual grasses** alter species composition within oak woodland understories, displacing native perennial bunchgrasses and reducing shallow soil moisture and light required for successful oak recruitment[1,23]. The establishment and spread of invasive grasses also increases available fine fuels and enhances fuel continuity, contributing to changes in fire frequency and behavior[61,62].
- **Livestock grazing** is common within oak woodlands[63], with varied impacts depending on grazing intensity, timing, and vegetation composition[14]. In general, the greatest adverse effects generally occur on drier sites and in more open areas[35]. Top browsing by cattle decreases oak seedling/sapling growth and survival to adulthood[14,35,64,65], and is believed to be a major factor contributing to lack of oak regeneration in some areas[64]. Livestock grazing can cause damage to understory shrubs, limiting nurse plants that protect fallen acorns and oak seedlings from high solar radiation, desiccation, and herbivory[14]. Grazing is also associated with the introduction of invasive annual grasses that reduce native herbaceous vegetation and contribute to changes in the fire regime[1].
- **Nitrogen deposition** from vehicle emissions near roads and highways can increase the productivity and dominance of non-native annual grasses[66], contributing to shifts in oak woodland understories and associated changes in the fire regime.

Adaptive Capacity

Moderate Adaptive Capacity

Low → High

High Confidence

Adaptive capacity is the ability of a habitat to accommodate or cope with climate change impacts with minimal disruption.

Habitat extent, integrity, continuity, and barriers to dispersal

Oak woodlands within the Santa Cruz Mountains region are widespread, though some types are highly restricted (e.g., black oak woodlands) while others are more common (e.g., coast live oak woodlands)[3]. Overall, oak woodland habitat extent has declined significantly over the past century due to anthropogenic factors such as land-use conversion to agriculture and development[15,35,52,53,67]. Changes in habitat structure and species composition (e.g., greater dominance of invasive annual grasses within the understory) have further degraded many remaining areas[1,2,35], particularly valley oak woodlands[3]. Low recruitment is occurring in many species within the region[3], and has been linked to state-wide population declines in valley oak and blue oak[11,14,68].

Barriers to dispersal have a relatively low impact on oaks within the Santa Cruz Mountains region[3]. However, short pollen and acorn dispersal distances can limit pollination and genetic exchange in fragmented blue oak and valley oak populations[51–53,69], which may reduce their ability to migrate in response to climate change[15,52,70]. Climate-driven changes in the distribution and/or abundance of seed-dispersing animals such as woodpeckers or ground squirrels could also limit regeneration and potential range shifts[3].

Habitat diversity

As dominant canopy species, oaks create favorable microclimates for diverse understory vegetation and provide habitat for many wildlife species[2,4,53,71]. Oak woodlands are particularly important for birds and butterflies, but are also utilized by many mammals, reptiles, and amphibians[3,4,71].

Historically, plant species diversity within oak woodlands was high[53,72], particularly in woodlands with more open canopies[3]. However, both plant and wildlife species diversity has declined over the past century due to factors such as fire suppression and invasive species[72].

Resistance and recovery

The long lifespan of oak trees may increase their resistance to changing conditions, as even relatively rare survival of seedlings and saplings to adulthood can potentially offset adult mortality[64]. Mast seeding strategies (i.e., the production of large volumes of seed every few years) also increase the chances of successful oak recruitment[73]. Mature oaks are generally more resilient than seedlings and saplings, and oaks have several adaptations that allow them to survive disturbances such as drought and wildfire[12,25,33]. For instance, blue oaks and valley oaks have deep root systems that can access groundwater during periods of drought[74–76]. However, changing climate conditions and ongoing non-climate stressors (e.g., grazing, invasive species, habitat fragmentation) may increase vulnerability to fire and other disturbances by limiting oak regeneration and increasing mortality rates in stressed trees[52,77].

Management potential

Oak woodlands are iconic in California and are highly valued by the public for their aesthetic beauty (e.g., scenic vistas), recreational opportunities, wildlife habitat, and livestock grazing[2,3,63,78]. Oak woodlands are also of great cultural significance to California tribes, who use cultural burning and other management practices to maintain abundant acorn crops[34,60,79]. Societal support for oak woodlands is increasing as a result of enhanced regulatory protection and additional funding for research on sudden oak death[3]. Coast live oak and black oak woodlands are also listed as California Department of Fish and Wildlife sensitive natural communities, requiring that they be considered within environmental review processes[3].

Several studies have documented successful restoration efforts in oak woodlands[64,80], suggesting that there is high potential for management strategies to support climate adaptation by creating favorable conditions for oak germination, growth, and reproduction[3]. For instance, ungulate and rodent exclusion can significantly reduce acorn and seedling/sapling herbivory, which contribute to low recruitment rates[64,81]. Exclusion is particularly effective when paired with restoration plantings of oak[35,82,83]. Restoring frequent low-intensity fire within these disturbance-adapted communities encourages oak recruitment and enhances native understory vegetation, though management of invasive annual grasses is often necessary[1,33,80]. The use of prescribed fire also has the potential to be scaled up over time in order to maintain oak woodlands at the landscape scale[3]. Other management strategies that may support oak woodland adaptation to future climate changes include restoration of native perennial grasses and forbs, climate-informed grazing management (e.g., altering grazing intensity and timing in response to changing climate conditions), hunting to reduce deer and boar consumption of acorns, and increased seed storage[3]. Protection efforts should focus on areas that are projected to remain climatically suitable for dominant oak species, as well as in microrefugia that alleviate water stress[24,25,70].

Recommended Citation

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Further information on the Santa Cruz Mountains Climate Adaptation Project is available on the project page (http://ecoadapt.org/programs/awareness-to-action/santa-cruz-mountains).

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