California Black Oak (*Quercus kelloggii*)

Climate Change Vulnerability Assessment for the Golden Gate Biosphere Region

This document represents an evaluation of climate change vulnerability for California black oak in the Golden Gate Biosphere (GGB) region of California. The following information is based on stakeholder input provided during and following a winter 2022 vulnerability workshop as well as sources from the scientific literature.

Species Description

California black oak (*Quercus kelloggii*) is a shade-intolerant, fire-dependent hardwood tree typically found as a component of hardwood or mixed hardwood and conifer communities in climates with hot, dry summers and cool, moist winters (McDonald 1990; Davis et al. 2016b). The species is distributed from the southern Cascade mountains in central Oregon to southern California along the Coast Range and through the Sierra Nevada (McDonald 1990). Black oak reaches its highest abundances in northern California and in the northern Sierra Nevada (McDonald 1990) and is patchily distributed within the Golden Gate Biosphere (GGB) region (Figure 1; Long et al. 2016).

California black oak grows best on medium-to-coarse, deep, well-drained soils, and does poorly in soils with high clay or water content (McDonald 1969, 1990; Niemiec et al. 1995). Black oak requires two years from flowering to acorn production (McCreary 2009), and the acorns are often carried away from the parent tree by caching species including a variety of birds and small mammals (Niemiec et al. 1995; Davis et al. 2016b). Black oak exhibits extensive post-fire vegetative resprouting, and frequent low-to-moderate-intensity fire regimes promote seedling establishment and sprout growth (CNPS 2023). In the absence of disturbance it can be replaced by more shade tolerant or competitive associates such as pines, tanoak, and firs (Niemiec et al. 1995). Black oaks support a wide variety of wildlife, including many species of birds, small mammals, and ungulates that feed on their acorns (Bowyer & Bleich 1980; McDonald 1990; Davis et al. 2016b). The number of insects in the food web of a large tree during one year may range into the millions; resulting in an even richer source of food for birds and other animals (Pavlik et al. 1991).

In Sonoma county, the majority of oak woodlands are on private property (Gaman & Firman 2006). There are approximately 219 acres of black oak woodlands found in Marin County, and 62% of these are on open space lands protected by Marin County Parks and Marin Water (Vuln. Assessment Worksheets, pers. comm., 2022). San Mateo County hosts 130 acres of black oak woodland stands and an additional 954 acres of mixed oak stands that may include black oak along with coast live oak (*Q. agrifolia*), blue oak (*Q. douglasii,* Oregon white oak (*Q. garryana*)*,* valley oak (*Q. lobata*), and interior live oak (*Q. wislizeni*). Less than half of the black oak stands in San Mateo County are on protected open space lands, and only 18% (167 acres) of the mixed oak stands are on protected open space (Vuln. Assessment Worksheets, pers. comm., 2022).

Figure 1. California black oak distribution within the GGB region (map provided by the National Park Service).

Species Vulnerability → Moderate *(moderate confidence)*

Vulnerability is evaluated by considering the species' sensitivity and exposure to various climate and non-climate stressors as well as the species' adaptive capacity (i.e., ability to cope with these stressors), and is given a ranking of low, moderate, or high. The confidence ranking represents confidence in the accuracy of the ranking based on available scientific knowledge, and is similarly ranked on a scale from low to high.

Summary of species vulnerability

Black oak is sensitive to climate stressors that alter the timing or availability of water, including changes in precipitation, soil moisture, flooding, and drought. These changes can impact acorn production, germination, and seedling and sapling growth and survival, with consequences for the persistence of black oak as dominant or co-dominant trees in woodland systems. Climate-driven shifts in disturbances (e.g., wildfire, disease) can increase oak mortality, and may alter population demographics of black oak due to age- or stage-specific mortality patterns. Non-climate stressors such as development, fire suppression and exclusion, invasive species, introduced pathogens, agriculture, and livestock grazing can exacerbate black oak sensitivity to climate change by increasing fragmentation and competition from other tree species, and reducing genetic connectivity and seedling recruitment.

Although there are several hundred acres of black oak and mixed oak woodlands in the GGB region, the historical extent of black oak has significantly declined as a result of development and other land uses, and remaining black oaks are increasingly threatened by development and degradation. While mature oaks are well adapted to disturbances including drought and wildfire, acorns and young oaks are more sensitive to these stressors and their loss may limit the ability of this species to recover from future disturbances. Management strategies that may increase the resilience of black oak to climate impacts include increased use of prescribed fire, predator exclusion to reduce acorn and seedling mortality, climate-informed grazing management, and protection of black oaks within cooler and wetter microclimates that may be able to support them under future climate conditions.

Sensitivity and Exposure → Moderate *(moderate confidence)*

Sensitivity *is a measure of whether and how a species is likely to be affected by a given change in climate factors, climate-driven changes in disturbance regimes, and non-climate stressors. By contrast,* ***exposure*** *is a measure of how much change in these factors a species is likely to experience. Sensitivity and exposure are combined here into one score representing both components of vulnerability, with high scores corresponding to increased vulnerability and low scores suggesting a species is less vulnerable.*

Modeling of climate-driven changes in the future distribution of black oak by Ackerly et al. (2015) found that it is expected to decline across many of the landscape units where it is currently found, particularly under hotter and drier scenarios and in the southern portions of the GGB region (Figure 2). Similarly, species distribution modeling conducted by the Conservation Biology Institute found areas within the GGB region where climatic conditions are expected to be suitable for black oak are projected to contract by 25–96% (Figure 3; Syphard & Rustigian-Romsos 2024). These changes are most closely associated with projected increases in summer maximum and winter minimum temperatures. Across all models, the existing areas of suitable habitat for black oak in the northern portion of the GGB region would decline in both size and degree of suitability, leaving some small patches of suitable habitat surrounded by large areas of contraction to the west and northwest of Austin Creek State Recreation Area.

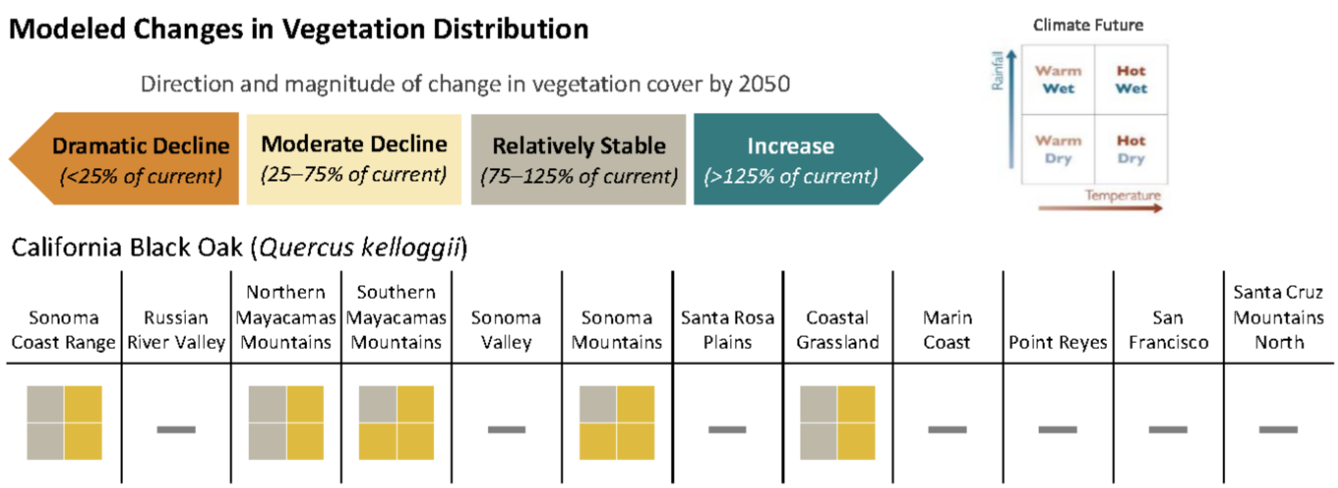

Figure 2. Projected trends in vegetation distribution by mid-century (~2050) within landscape units overlapping the GGB region, based on results from Ackerly et al. (2015). The four squares refer to a range of possible climate futures that vary with respect to temperature and precipitation, with the top and bottom squares representing wetter and drier scenarios, respectively, and the left and right squares representing scenarios projecting average annual temperature increases of greater than and less than 4.5°C, respectively. The color of the squares indicates the direction and magnitude of change in vegetation cover by 2050, with orange representing dramatic declines (less than 25% of current cover present), yellow representing moderate declines (25–75% of current), gray representing relatively stable cover (75–125% of current), and green represents increases (more than 125% of current).

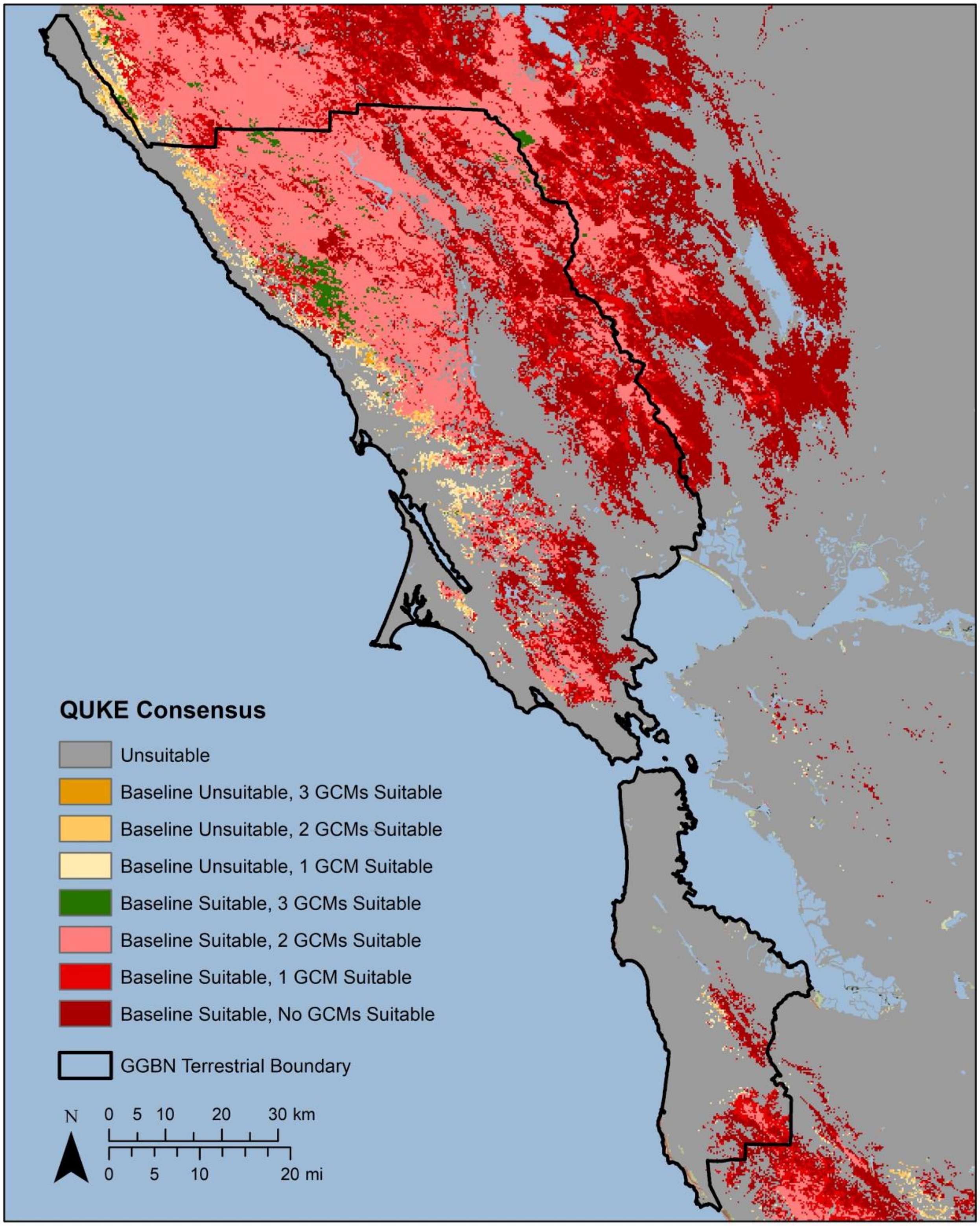

Figure 3. Future climatic suitability for California black oak (QUKE) for an end-of-century time frame (2070–2099 compared to 1981–2010). Species distribution model compares baseline (current distribution) to three global climate models (GCMs) under the RCP 8.5 emissions scenario. GCMs included are CNRM-CM5 (warm/high rainfall), CCSM4 (warm/moderate rainfall), and MIROC-ESM (hot/low rainfall), all using the RCP 8.5 emissions scenario.

Sensitivity and future exposure to climate factors → Moderate *(moderate confidence)*

- **Changes in amount and/or timing of precipitation and soil moisture** are likely to decrease acorn production, seedling establishment, and growth rates of black oak (Cocking 2011; Davis et al. 2016a). Black oak occupies wetter and cooler environments compared to many other oak species in the region (Davis et al. 2016b). Projected increases in winter rainfall (Flint et al. 2023) are likely to create saturated soil conditions that are not well tolerated by black oak (McDonald 1990), which require well-drained soils (McDonald 1969; Niemiec et al. 1995). Increased winter precipitation together with warmer springs may also enhance spore production and transmission of *Phytophthora ramorum*, the fungal pathogen which causes sudden oak death and to which black oak is susceptible (Davidson et al. 2003; Davis et al. 2016b; Cobb et al. 2020). Black oak may also be vulnerable to drier conditions; oak seedlings and saplings are more sensitive to water stress than adults, in part because their root systems cannot connect to groundwater resources that the adult trees are able to reach (Mahall et al. 2009; McLaughlin & Zavaleta 2012).
- **Increases in the frequency and/or severity of drought** are likely to stress black oaks and decrease recruitment of oak seedlings (Mahall et al. 2009; McLaughlin & Zavaleta 2012). Mature black oak tends to be associated with cooler, wetter environments and exhibit lower cumulative water stress across its range compared to other oak species including blue oak and coast live oak (Davis et al. 2016b), which suggests it may be restricted by water availability and thus may be more sensitive to extended drying and drought compared to other oaks. Moisture stress is likely to be particularly high where competition with annual plants (e.g., invasive grasses) further reduces available moisture for oak seedlings (McCreary 2009; Gedalof et al. 2022). Black oak seedlings and saplings are significantly more sensitive to drought compared to adults, and this may constrain successful regeneration of the species, even in areas that are considered climatically viable for adults (Davis et al. 2016a). Oak acorns are also very sensitive to drying and quickly lose moisture after falling from the tree, so germination can be suppressed by very low soil moisture conditions (McDonald 1969; McCreary 2009). While critical climate thresholds are still not well understood for oak woodlands, unusually dry or wet likely play an important role in determining oak persistence and distribution (Davis et al. 2016a). Drought may make black oaks more sensitive to other stressors such as competition and disease (Vuln. Assessment Worksheets, pers. comm., 2022).
- In general, upper temperature limits for black oak are not well understood (Vuln. Assessment Worksheets, pers. comm., 2022). However, **warmer winter temperatures** may reduce recruitment in black oak, as they require a period of cold temperatures to break seed dormancy and allow generation (McCreary 2009). Recent modeling results for black oak within the GGB region have also found that the current distribution is most closely associated with moderate summer maximum and winter minimum temperatures, and that increases in these

temperature extremes are expected to drive significant contractions in the availability of climatically suitable habitat for the species (Syphard & Rustigian-Romsos 2024).

Sensitivity and future exposure to climate-driven changes in disturbances → Moderate *(moderate confidence)*

- Black oak is well-adapted to low- and moderate-intensity fires, which enhance acorn germination (Kauffman & Martin 1987) and prevent oaks from being overtopped by conifers and hardwoods that compete with them for moisture and light (Cocking et al. 2012; Long et al. 2016). Mature black oaks can resprout following severe wildfires, allowing rapid post-fire regeneration (Cocking et al. 2012; Hammett et al. 2017). However, **climate-driven changes in wildfire regimes** may increase injury and mortality of black oaks, particularly for seedlings and saplings that are more vulnerable to intense wildfire compared to mature trees (Swiecki & Bernhardt 2002; Holmes et al. 2008, 2011). Repeated high-severity fires, in particular, may negatively impact the persistence of black oak in areas where post-fire seedlings and sprouted trees are unable to mature and produce acorns before the next fire (Holmes et al. 2008). Over time, repeated high-severity fire can result in conversion of black oak-dominated systems to chaparral or grasslands (George & Alonso 2008; Cocking et al. 2012; Davis et al. 2016b; Stephens et al. 2023). These impacts are more likely to occur where fire suppression has allowed encroachment of shrubs and conifers into open woodlands, increasing fuel loads that drive intense fires (Cocking 2011).
- **Increased disease** may be expected as changes in temperature and moisture impact pathogen production and transmission, as well as black oak defenses and susceptibility (Kliejunas 2011; Cobb et al. 2020). The greatest disease concern currently is sudden oak death (caused by the introduced pathogen *Phytophthora ramorum*), to which California black oak is susceptible (Rizzo et al. 2002; Kliejunas 2011). Sudden oak death causes high rates of injury and mortality in black oak and several other *Quercus* species, with the highest mortality rates occurring among large trees (McPherson et al. 2010; Kliejunas 2011; Cobb et al. 2012; Haas et al. 2016). Beetle attacks in infected trees can also speed mortality, reducing life expectancy by 65–70% (McPherson et al. 2010). Transmission and infection by *P. ramorum* is associated with warmer, wetter winter and spring conditions that optimize growth and spread of this pathogen (Davidson et al. 2003; Kozanitas et al. 2022). Climate projections that model warmer, wetter futures support an increase of occurrence and intensity of this disease in California (Kliejunas 2011).

Dependency on habitat and/or other species → Moderate *(moderate confidence)*

Black oaks are distributed across a fairly wide range of elevations and vegetative communities (McDonald 1990), though they tend to be associated with wetter and cooler conditions compared to other oaks (Davis et al. 2016b, 2016a). Birds and small mammals are considered particularly important to the caching and redistribution of seeds away from the parent plant, which may play an important role in seedling recruitment following disturbances such as fire (Borchert & Tyler 2010) and which may make black oak vulnerable to climate-driven changes that impact caching species. Black oaks are also highly dependent on indigenous stewardship management practices, including frequent low-intensity burning, nurturing, and other traditional ecological knowledge approaches, particularly in areas where they would not otherwise be maintained by natural factors. These practices were used for thousands of years prior to European contact, favoring the development of black oak-dominated stands, dominated by older, larger-diameter trees with full crowns and abundant acorn crops, (Anderson 2005; Mensing 2006; Davis et al. 2016b; Long et al. 2016). Those relationships were largely decimated by colonialism and genocide beginning in the 19th century and continuing through today, with the additions of modern threats to oak woodlands including urbanization, fire suppression, and disease (Davis & Borchert 2006; Ortiz & McCreary 2008; Davis et al. 2016b). Recently there has been increasing work by indigenous groups and allies to restore and reconnect with this species using traditional ecological knowledge pathways (Long et al. 2016; O'Gorman et al. 2022; Stephens et al. 2023).

Sensitivity and current exposure to non-climate stressors → High *(high confidence)*

Non-climate stressors can exacerbate ecosystem sensitivity to changes in climate factors and disturbance regimes, and/or can be exacerbated by these changes.

- **Residential and commercial development** has led to loss and fragmentation of black oak populations, particularly in the Coast Range foothills in the GGB region (Gaman & Firman 2006; Davis et al. 2016b; Vuln. Assessment Worksheets, pers. comm., 2022). Many of the current black oak woodlands in the region, particularly in San Mateo County, are not protected by open space designation and are potentially vulnerable to urban and suburban development (Gaman & Firman 2006; Vuln. Assessment Worksheets, pers. comm., 2022). Development has been associated with reduced oak tree recruitment and genetic exchange in fragmented oak populations, shifts in plant and wildlife composition, and decreases in biodiversity (Merenlender et al. 1998; Sork et al. 2002). Development may also lead to the drawdown of groundwater tables that can reduce water availability for young oaks, leading to reduced recruitment and establishment (McLaughlin et al. 2017). Finally, humans can disperse *P. ramorum* (the fungus that causes sudden oak death) into stands lacking local sources of the pathogen by carrying it with them as they recreate in natural areas (Cushman & Meentemeyer 2008).
- **Invasive and problematic species** influence many aspects of oak woodland ecology, impacting the health and survival of black oak. Invasive annual grasses, in particular, alter species composition within oak woodland understories, displacing native species such as bunchgrasses and competing for the shallow soil moisture and light needed for successful establishment and growth of oak seedlings (Gordon et al. 1989; Tyler et al. 2006; Holmes et al. 2011). Although many wildlife species feed on oak acorns (Tyler et al. 2006), high abundances of introduced

species can have outsized impacts. Wild turkeys (*Meleagris gallopavo)* can impact oaks through high rates of acorn predation and soil disturbance (Fehring et al. 2007). Acorn predation by feral pigs (*Sus scrofa*) can be significant, and their rooting can also disturb soils and damage oak seedlings and saplings (Peart & Patten 1994; Sweitzer & Vuren 2002).

- **Agriculture** and **livestock grazing** has occurred in and around oak woodlands since European settlement, and significant loss of black oak and other oak species has occurred as trees were thinned and removed for row crops and orchards, particularly in the Bay Area (Davis et al. 2016b). Historic and ongoing impacts of grazing on oaks include soil compaction, acorn and seedling destruction, and shifts in plant composition, but these impacts vary depending on grazing intensity, timing, and type of vegetative community (Hall et al. 1992; Davis et al. 2016b). In some cases, grazing has been shown to have positive indirect effects on oak recruitment by reducing growth of competing grasses (Tyler et al. 2006); however, livestock can also introduce invasive annual grasses that compete with oak seedlings for moisture and contribute to changes in fire frequency and behavior (Brooks et al. 2016; Davis et al. 2016b). Grazing has also been shown to slow post-fire recovery of oak woodlands (Callaway & Davis 1993; George & Alonso 2008).
- **Fire exclusion and suppression** has altered historical wildfire regimes in oak woodlands, increasing fire return intervals in the GGB region from every few years (prior to European settlement) to several decades, especially in areas where fire suppression to protect human property and lives is a management priority (Davis & Borchert 2006; Davis et al. 2016b). Reduction in wildfire frequency within these low-intensity, short interval fire-adapted communities has resulted in shifts in species composition and habitat structure, notably in terms of invasion by conifer species such as fire-sensitive Douglas fir (*Pseudotsuga menziesii*; Cocking 2011; Hammett et al. 2017). Loss of fire in forested ecosystems may also play a role in increasing incidence of *P. ramorum*, though the intersection between disease and fire is complex and a causative relationship has not been clearly established (Kliejunas 2010).

Adaptive Capacity → Moderate *(moderate confidence)*

Adaptive capacity *is the ability of a species to respond to or cope with climate change impacts with minimal disruption. High adaptive capacity corresponds to lower overall climate change vulnerability, while low adaptive capacity means that the species will be less likely to cope with the adverse effects of climate change, thus increasing the vulnerability of the species.*

Species extent, status, connectivity, and dispersal ability → Moderate (moderate confidence)

California black oak are found on well-drained soils throughout a wide range of elevations in central coastal California, at elevations from 60 m (200 ft) in the Napa Valley to 1,500 m (5,000 ft) in the Coast Range (McDonald 1990; Niemiec et al. 1995). Black oak tends to be restricted to cooler, wetter sites compared to other oak species in the region (Davis et al. 2016a). Although black oaks sprout vigorously after topkill following disturbances such as fire (Ritchie et al. 2023), their primary mode of dispersal is through acorns which either germinate near the adult tree or are cached farther away by small mammals and birds that later may not retrieve them (Borchert & Tyler 2010). Indigenous management practices such as frequent cultural burning shaped black oak persistence and distribution throughout central coastal California, a process that was largely disrupted following Euro-American settlement two centuries ago (Davis & Borchert 2006; O'Gorman et al. 2022; Stephens et al. 2023). As a result, increasing understanding of how indigenous people dispersed oaks historically and what those reconnections can look like are important for contemporary oak management (Long et al. 2016; Vuln. Assessment Worksheets, pers. comm., 2022).

Black oak has declined significantly over the past century due to anthropogenic factors including agriculture and urbanization (Davis et al. 2016b; Easterday et al. 2016). As a result, remaining black oak stands in the region are highly fragmented and at risk of further decline, particularly in lowlands proximate to the San Francisco Bay Area where development pressure is high (Davis et al. 2016b; Vuln. Assessment Worksheets, pers. comm., 2022). Diseases such as sudden oak death have caused additional dieback of black oak in multiple areas of the GGB region (Davis et al. 2016b; Panorama Environmental 2019). The State of California currently lists most black oak and its vegetative associates at a global (G) and state (S) ranking of 4, which is just below the 1-3 rankings that are considered sensitive species assemblages. However, the black oak – pacific madrone – coast live oak (*Q. kellogii, Arbutus menzesii, Quercus agrifolia*) association is ranked as sensitive (G3,S3; CDFW 2023).

Intraspecific/life history diversity → High (moderate confidence)

California black oak exhibits multiple methods of reproduction, including sprouting and gravity- and animal-facilitated acorn dispersal (McDonald 1969; Borchert & Tyler 2010). Black oaks are at least 30 years of age before they produce viable seed, and are most productive after 80 to 100 years of age; their life span can extend to 500 years (McDonald 1990; Niemiec et al. 1995). Black oak will hybridize with *Q. agrifolia* (known as *Quercus x gander*) and with interior live oak, *Q. wislizeni* (known as *Quercus morehus*) as well as with Shreve oak (*Q. parvula* var. *shrevei*; Niemiec et al. 1995; Dodd & Kashani 2003). Black oak is phenotypically diverse, with forms ranging from scrubby on marginal sites, to tall and straight with clear boles and thin crowns on more enclosed sites, to multi-stemmed, broad-crowned trees in open areas (McDonald 1990).

Resistance and recovery → Moderate (moderate confidence)

Mature black oaks are generally resilient to disturbances including drought and wildfire (Long et al. 2016). The long life span 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 (Davis et al. 2011). Mast seeding strategies that produce large volumes of acorns every few years also increase the chances of successful oak recruitment (McDonald 1990; Koenig et al. 1996). Black oak is a vigorous re-sprouter and shows high rates of survival and recovery by resprouting, even after severe fire (Ritchie et al. 2023). However, black oak is a slow-growing species that takes decades to mature before acorn production, and acorns, seedlings, and saplings are particularly sensitive to climate-driven changes in precipitation and temperature that may reduce recruitment and recovery. Rapid climatic change and ongoing non-climate stressors (e.g., fire suppression, grazing, invasive species, habitat fragmentation) may increase vulnerability disturbances by limiting regeneration and increasing stress and mortality in black oak (Gaman & Firman 2006; Easterday et al. 2016; Vuln. Assessment Worksheets, pers. comm., 2022).

Management potential → Moderate (high confidence)

Black oak is considered to be of high value for its aesthetic, economic, ecological, and cultural values (Davis et al. 2016b; Easterday et al. 2016; Long et al. 2016). In particular, it is critically important to California tribes, who use cultural burning and other practices to maintain the species (Mensing 2006; Long et al. 2016; Stephens et al. 2023). Black oak is also used for timber and especially for fuel wood, which has led to historic and ongoing removal (McDonald 1990; Niemiec et al. 1995). Societal support for oak woodlands is increasing as a result of regulatory protection, and additional attention and resources are now being dedicated to research on sudden oak death (McCreary 2004; Bartolome & Huntsinger 2015; McPherson et al. 2015). There are cities and counties that are moving to protect oaks (e.g., Dagit 2015), though this is not always backed by financial and regulatory support (Vuln. Assessment Worksheets, pers. comm., 2022) and often individual trees are the focus of such regulations to the detriment of landscape-scale protection of oak woodlands (Light & Pedroni 2002).

Successful restoration efforts support climate adaptation by creating favorable conditions for black oak germination and growth. Because frequent fire is required for persistence of black oak within the landscape, reintroduction of frequent, low-intensity fire through a return to cultural burning practices and/or implementation of other prescribed burns or managed wildfire is widely considered a critical restoration strategy, and there is growing interest in the use of these practices to restore and maintain black oak stands across the state (Jewell & Vilsack 2014; Long et al. 2016; Nemens et al. 2018; Karuk Tribe 2019; Stephens et al. 2020, 2023). However, prescribed burning can pose political and economic challenges at the wildland-urban interface (Stephens et al. 2020). Thinning of encroaching shrubs and conifers is often necessary prior to the use of fire as a management tool, which reduces competition for water and fuel loading that can contribute to more severe wildfires (Cocking et al. 2012; Stephens et al. 2020; Ritchie et al. 2023). Protection efforts should focus on landscape-scale conservation of oak woodlands, particularly in areas likely to remain climatically suitable for black oak, such as high-moisture microclimates that may function as refugia for this species (Davis et al. 2016a; Thorne et al. 2020). Protection and restoration of oaks within more urban and residential areas may also have significant ecological benefits, as these trees can increase genetic connectivity in addition to providing wildlife habitat and shade (Whipple et al. 2011; Easterday et al. 2016). Additional management strategies that may support black oak adaptation to future climate changes includes removing invasive grasses and restoring native grass and perennial forbs (Panorama Environmental 2019), climate-informed grazing management (e.g., adapting grazing intensity and timing to respond to changing climate conditions), and increased harvest of high-abundance predators such as feral pigs (Sweitzer & Vuren 2002).

Recommended Citation

EcoAdapt. 2024. California black oak (*Quercus kelloggii*): Climate change vulnerability assessment summary for the Golden Gate Biosphere region. EcoAdapt, Bainbridge Island, WA.

Further information on the Golden Gate Biosphere Region Climate Adaptation Project is available on the project page (www.ecoadapt.org/goto/GGBRClimateProject).

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