Mixed Evergreen/Montane Hardwood Forest

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 mixed evergreen/montane hardwood forest 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

Mixed evergreen/montane hardwood forests are comprised of a mix of hardwoods and conifers including Pacific madrone (*Arbutus menziesii*), tanoak (*Notholithocarpus densiflorus*), Douglas-fir (*Pseudostuga menziesii*), canyon live oak (*Quercus chrysopelis*), interior live oak (*Q. wislizenni*), California black oak (*Q. kelloggii*), coast redwood (*Sequoiadendron sempervirens*), and California buckeye (*Aesculus californica*)[1–3]. California bay laurel (*Umbellularia californica*), white alder (*Alnus rhombifolia*), and western sycamore (*Platanus racemosa*) are also common in riparian areas[1,3]. The understory typically includes shrubs such as California nutmeg (*Torreya californica*), evergreen huckleberry (*Vaccinium ovatum*), and manzanita (*Arctostaphylos* spp.; in disturbed areas and near forest edges)[1]. Forest structure and composition can vary widely across sites depending on moisture balance, disturbance history, soil conditions, and topography[2,4–6].

Vulnerability Ranking

Moderate Vulnerability

Low → High

Mod Confidence

Mixed evergreen/montane hardwood forests are sensitive to changes in climate factors that increase water demand (e.g., air temperature) or decrease water availability (e.g., precipitation, soil moisture, coastal fog, drought). These changes are likely to alter patterns of tree growth and mortality, resulting in shifts in species composition, forest structure, and regeneration. Changes in the frequency, timing, and/or intensity of disturbances (e.g., wildfire, storms, disease) may cause more extensive mortality, especially in stands where increased competition for soil moisture has reduced tree vigor. Non-climate stressors (e.g., timber harvest, fire suppression, invasive plants, roads/highways/trails, and development) can exacerbate habitat sensitivity by reducing forest extent and altering forest structure, species composition, ecosystem functioning, and connectivity.

Mixed evergreen/montane hardwood forests are extensive within the Santa Cruz Mountains region. However, historical logging, land-use conversion, road construction, and other human activities have fragmented and degraded forests, reducing structural integrity and increasing vulnerability to disturbances such as uncharacteristically severe wildfires and drought. Resistance to climate stressors and altered disturbance regimes is supported by high landscape heterogeneity, and high structural and species diversity may support shifts in forest composition towards species adapted to warmer, drier conditions. However, climate change may also slow forest recovery following disturbances. Management activities designed to increase forest resilience to climate change are likely to focus on promoting spatial heterogeneity and structural complexity as well as protecting forests from anthropogenic stressors.

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 mixed evergreen/montane hardwood forests, they found highly variable trends across landscape units, though Douglas fir forest was consistently stable or increased in all areas; similarly, tanoak forest was projected to remain stable or undergo declines across all landscape units.

Vegetation Type	San Francisco	Santa Clara Valley	Santa Cruz Mtns. North	Santa Cruz	Sierra Azul
Douglas fir forest	△	—	△	—	—
Montane hardwoods	▽	△	▽	—	▽
California bay forest	▽▽	△	▽	▽	▽
Tanoak forest	▽	—	—	▽▽	▽▽

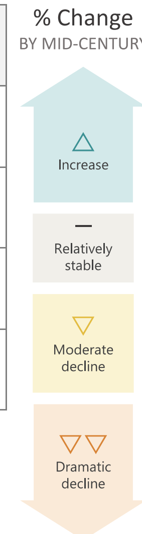

Table 1. Projected trends in vegetation distribution (increase, relatively stable, moderate decline, or dramatic decline) by mid-century within five landscape units of the Santa Cruz Mountains region.

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

Mixed evergreen/montane hardwood forests are sensitive to climate stressors that change the water balance (e.g., increasing demand or decreasing availability), which alters patterns of tree growth and mortality and are likely to contribute to shifts in species composition, forest structure, and regeneration.

Climate Stressor	Trend Direction	Projected Future Changes
Precipitation	▲ ▼	• Shorter winters and longer, drier summers likely, with higher interannual variability[7,8]
Coastal fog	▼	• Possible 12–20% decline in the frequency of days with coastal fog and low clouds[9]

[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).

Soil moisture	▼	• Reduced soil moisture likely due to increased evaporative demand[7,10]
Air temperature	▲	• 1.5–3.1°C (2.7–5.6°F) increase in annual mean temperature[11,12]
Drought	▲	• Increased frequency of drought years, including periods of prolonged and/or severe drought[7,13]

- **Changes in precipitation amount and timing**, **coastal fog**, and **soil moisture** are likely to alter tree recruitment, growth, and mortality rates[14–17], potentially leading to shifts in forest structure and species composition[14,18–21]. Water stress is most likely to limit growth and increase mortality on drier sites and at the southern edge of a species' range[16,19,22]. Species that are sensitive to site-specific conditions (e.g., coast redwoods, riparian trees) may be particularly vulnerable to overall drier conditions, especially if coastal fog also becomes less frequent[1,23].

  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[24,25]. By contrast, dry conditions and low soil moisture could limit the spread and severity of this disease[26,27].
- **Warmer air temperatures** are likely to enhance water stress within mixed evergreen/montane hardwood forests due to increased evaporative demand[12,15]. However, warmer temperatures may also increase productivity and seedling recruitment in some hardwood species (e.g., Pacific madrone, California bay), enhancing competition with conifers and potentially contributing to shifts in species composition towards a greater proportion of hardwoods[14,21].
- **More frequent and/or severe future droughts** may cause significant tree mortality[17,28–32], especially in large trees and on sites with higher competition for soil moisture[17,30,31]. Mortality rates typically increase as drought progresses over multiple years[31], and the effects of severe drought (e.g., growth declines, high tree mortality rates) can persist for several years after the drought is over[32,33]. Under future climate conditions, prolonged and/or severe droughts may cause large-scale forest dieback, with higher rates of mortality occurring where trees have already been stressed by climate-driven increases in wildfire, insect outbreaks, disease, and previous droughts[17,30,31,34,35].

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

Mixed evergreen/montane hardwood forests are sensitive to disturbances that alter forest structure and contribute to major shifts in species composition, which may ultimately impact ecosystem function.

Disturbance Regimes	Trend Direction	Projected Future Changes
Disease	▲	• Likely increases in spore production and infection risk of *Phytophthora ramorum*[36,37]
Wildfire	▲	• Slight to moderate increase in wildfire risk, particularly in areas of higher rainfall[11,12]
Storms	▲	• Increased storm intensity and duration[7,38,39]

- **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[26,35,40,41]. 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 tanoak and true oaks (e.g., coast live oak), particularly for large trees[26,42–44]. Beetle attacks in infected trees can also speed mortality, reducing life expectancy by 65–70%[42]. Because the impacts of sudden oak death are species-specific, patterns of mortality can significantly alter forest structure and species composition[43–45]. For instance, significant losses of large tanoak trees is likely[42,43], which may shift overstory composition towards species with lower susceptibility to infection[46]. High rates of tree mortality and resulting shifts in species composition may also change patterns of fuel composition and availability, potentially altering fire behavior[47–50].
- Mixed evergreen/montane hardwood forests are well-adapted to low- to moderate-intensity surface fires[2,51]. However, climate-driven **increases in the frequency and/or severity of wildfires** may increase tree mortality and cause substantial modifications in forest structure and composition by favoring post-fire dominance of sprouting hardwoods and shrubs[52–55]. These changes are particularly likely within the interior of larger high-severity patches, where conifer recovery may be delayed due to lack of seed sources in combination with warmer, drier conditions that limit seedling establishment[56,57]. Repeated high-severity fire can also alter forest structure and prevent the development of later-successional stages by killing seedlings and sprouting stems before trees have matured and developed more fire-resistant characteristics[58,59].
- **Increased frequency and/or severity of storms** may cause more frequent tree mortality due to windthrow and landslides, particularly in burned areas[1,2].

Sensitivity and current exposure to non-climate stressors

Non-climate stressors can exacerbate habitat sensitivity to changes in climate factors and disturbance regimes by altering forest structure, species composition, ecosystem functioning, and connectivity.

- **Fire exclusion and suppression** has altered historical wildfire regimes in mixed evergreen/montane hardwood forests, increasing fire return intervals within the Santa Cruz Mountains region to over 150 years (compared to 8–12 years prior to Euro-American settlement)[51,60]. Reductions in fire frequency as a result of fire exclusion has contributed to shifts in fuel structure and increased fuel loading, increasing the risk that fires will be uncharacteristically intense when they do occur[61]. This is of particular concern in second-growth forests, where increased tree and understory density already enhances the likelihood of intense fires[61].

- **Timber harvest** has resulted in the loss and fragmentation of many old-growth mixed evergreen/montane hardwood forests in the Santa Cruz Mountains region[51]. Historical logging followed by decades of fire suppression has also resulted in significant shifts in forest structure due to higher stem densities and low structural diversity in second-growth forests, which reduces forest heterogeneity at the landscape scale[6,62,63].
- **Invasive plants** compete with or degrade native vegetation and alter soil properties, affecting forest structure, species composition, and ecosystem processes[64,65]. Within the Santa Cruz Mountains region, slender false brome (*Brachypodium sylvaticum*) is of increasing concern[66]. This aggressive perennial bunchgrass invades forest understories where it displaces native species, limits tree seedling recruitment, and increases fire risk by enhancing fine fuel availability[67,68].
- **Roads, highways, and recreational trails** increase habitat fragmentation and alter ecosystem dynamics in mixed evergreen/montane hardwood forests[69,70]. For example, transportation corridors contribute to the introduction and spread of invasive plants[69,70] and are associated with increased fire ignitions[71]. Roads and trails also provide enhanced opportunities for the spread of sudden oak death, both because of greater air movement that increases spore dispersal and because spores within the soil can be transported on vehicles, footwear, and equipment[72,73].
- **Residential development** has resulted in significant forest loss and fragmentation, particularly in and around the growing wildland-urban interface[1].

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

Mixed evergreen/montane hardwood forests are widespread within the Santa Cruz Mountains region, which is located at the heart of this habitat's distribution within the state[1,60]. However, historical logging, land-use conversion, road construction, fuelbreak creation, and other human activities have fragmented and degraded many forest areas in the region[1], reducing structural integrity and increasing vulnerability to disturbances such as uncharacteristically severe wildfires and severe drought[31,34]. Large areas of forest affected by severe fire or sudden oak death may also experience very slow regeneration, reducing habitat continuity[1]. Sudden oak death may create barriers to gene dispersal[1], if the distance between increasingly fragmented tanoak patches exceeds the range of insect pollinators[74].

Habitat diversity

Mixed evergreen/montane hardwood forests in the Santa Cruz Mountains region occupy topographically diverse areas with varied site conditions (e.g., substrate, water balance, disturbance history)[1,75]. These factors contribute to high structural and species diversity across the landscape, which may support shifts in forest composition towards species adapted to warmer, drier conditions[76].

Mixed evergreen/montane hardwood forests are home to many sensitive plant and wildlife species, including the Kings Mountain manzanita (*Arctostaphylos regismontana*), California red-legged frog (*Rana draytonii*), and dusty-footed woodrat (*Neotoma fuscipes*)[1].

Resistance and recovery

Resistance to climate stressors and altered disturbance regimes in mixed evergreen/montane hardwood forests is supported by high landscape heterogeneity, which provides varied microsites and areas of refugia from thermal stress, increasing climatic water deficit, and wildfire[56,77,78]. These refugia may include north-facing slopes, valley bottoms and riparian areas, sites with relatively high precipitation, and areas surrounding seeps, springs, and wetlands[12,77,79]. Stands of mature and old-growth forest with dense, closed canopies may also provide microrefugia that could protect vulnerable plant and animal species from thermal and moisture stress[77,78,80].

Where structural diversity remains relatively high, a mosaic of forest patches at various successional stages limits the impact of disturbances at large spatial scales and supports relatively rapid recovery from disturbances[53,81,82]. However, the combined impacts of historical logging and fire suppression has decreased forest heterogeneity, reducing the ability of the forest to recover from future stressors and large-scale disturbances[6,34,56]. Warmer, drier conditions and altered fire regimes over the coming century are likely to further alter recovery rate and successional patterns, favoring increased dominance of shrubs and hardwoods compared to conifers[21,55,56,83].

Management potential

Mixed evergreen/montane hardwood forests in the Santa Cruz Mountains region are highly valued by the public for birding and hiking opportunities[1]. Because this forest type is highly productive, it also plays a particularly critical role in carbon storage and maintaining hydrological function across the landscape, especially in old-growth stands[80,84]. However, public and societal support for management of mixed evergreen/montane hardwood forests is lower than for the region's iconic redwood forests, and land use conflicts can occur with the timber industry[1].

Changing climate conditions are likely to make the management of mixed evergreen/montane hardwood forests more complex due to the increased potential for stressed forests to experience drastic shifts in species composition and/or large-scale dieback[31,56,62]. In forests that have been degraded and/or are threatened by climatic and anthropogenic stressors, management strategies may include reducing stem density[85], reintroducing fire onto the landscape[86–89], and supporting forest regeneration[55]. These strategies are designed to enhance forest resilience by increasing spatial heterogeneity and structural complexity[6,31,86,87], which reduces vulnerability to large-scale disturbances such as uncharacteristically severe wildfire, insects, and disease[87,90]. For instance, the use of thinning from below and prescribed fire can increase tree vigor and encourage the development of larger, more fire-resistant trees within mature, structurally diverse forests[91–94]. Protecting existing late-successional forests and increasing connectivity between these forest patches is also critical, as they may exhibit higher resistance to changing climate conditions and are likely to provide refugia for sensitive species[77,95,96]. Protection efforts could also include mid-seral and complex early-seral habitats that exhibit high structural diversity and the potential to develop old-growth characteristics over time[95,96].

Management efforts are unlikely to stop the spread of sudden oak death, but monitoring networks have allowed early detection of newly-infected areas[97]. Other efforts have involved surveying the area to determine whether naturally-occurring resistance to sudden oak death can be leveraged to aid conservation benefits[98]. Seed banks and living collections may also provide a way to preserve genetic diversity and allow the future reintroduction of tanoak into infected areas[99].

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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