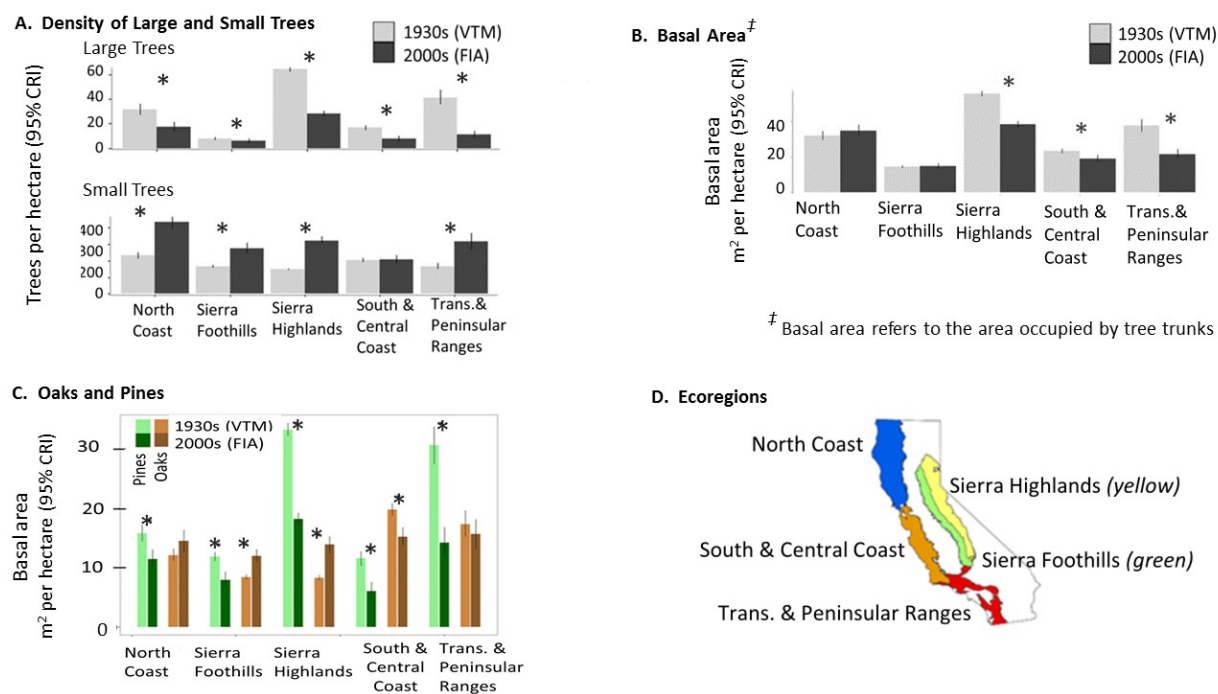


4.3 Changes in Forests and Woodlands Composition

Compared to 80 years ago, California's forests today have more small trees and fewer large trees. The areas occupied by pines have decreased in all regions studied, while the areas occupied by oaks have increased in the Sierra Nevada but have decreased in the South and Central Coast. These changes are associated with decreased water availability driven by warmer temperatures.

About this indicator: This indicator was first presented in OEHHA's 2018 report, titled "Changes in Forests and Woodlands". While the underlying data have not been updated since 2018, we have incorporated more recent findings from scientific literature.

Figure 4.3.1. Changes in Forest Structure and Composition Historical (1929-1936) vs. Contemporary (2000-2010)^a



^a Historical from Wieslander Vegetation Map (VTM); Contemporary from Forest Inventory Analysis (FIA)

* Statistically significant differences

Source: McIntyre et al. (2015)



What does this indicator show?

The structure and composition of California's forests have changed, and this is associated with climate change related water availability. This indicator consists of three metrics tracking changes in the structure and composition of forests across five regions in California. These metrics are based on a comparison of data from a 1930s survey of the state's vegetation (documented in the Wieslander Vegetation Type Map, or VTM) with data from surveys conducted between 2000 to 2010 as part of the US Forest Service's Forest Inventory Analysis, or FIA (McIntyre et al., 2015). Forest structure refers to the distribution of small, medium, and large-sized trees, while species composition refers to the diversity of tree species present.

Figure 4.3.1A displays the first metric, which shows changes in the density of large and small trees. Large trees are defined as greater than (>) 61 centimeters (cm), or >24 inches (in), in diameter at a height of 4.5 feet ("diameter at breast height," or dbh), and small trees are defined as 10–30 cm, or 4–12 in, dbh. Decreases in large tree density were observed in all regions studied. The greatest decrease occurred in the Transverse and Peninsular ranges of Southern California, where large tree density in the contemporary period was less than 30% of the density in the historical dataset—40.8 compared to 10.6 trees per hectare (trees/ha). Declines of about 50% in large tree densities were observed in the Sierra Nevada highlands (64.3 compared to 28.03 trees/ha), the Coast Ranges of Southern and Central California (16.6 compared to 7.5 trees/ha), and Northern California (30.6 compared to 16.7 trees/ha). Declines in large trees were lowest in the Sierra Nevada foothills (7.6 compared to 5.7 trees/ha), the region where large tree densities are lowest.

From the historical to the contemporary period, densities of small trees increased over two-fold within the Sierra Nevada highlands (149 compared to 315 trees/ha), and over 50% in the Sierra Nevada foothills (165 compared to 268 trees/ha), the North Coast region (229 vs. 412 trees/ha) and the Transverse and Peninsular ranges (165 compared to 301 trees/ha) (**Figure 4.3.1C** and **4.3.1D**). The density of small trees was unchanged in the South and Central Coast Region (200 compared to 197 trees/ha). Patterns of



change for intermediate-sized trees (31–60 cm or 12–24 in dbh) were variable across the two time periods (not shown).

Figure 4.3.1B illustrates the second metric, which shows changes in basal area — the amount of area occupied by tree trunks within a given area (expressed in units of square meters per hectare, m^2/ha). Basal area, which reflects biomass, decreased in three of the five regions: up to 40% in the Transverse and Peninsular Ranges Region (37.8 compared to 21.6 m^2/ha , 30% in the Sierra Nevada Highlands Region (55.9 compared to 38.5 m^2/ha), and 18% in the South and Central Coast Region (23.3 compared to 19.0 m^2/ha). In the North Coast and Sierra Nevada Foothills Regions, the reductions in basal area due to large tree declines were balanced by increases in smaller size classes, hence no decline in overall basal area was observed.

The third metric is displayed in **Figure 4.3.1C**, which compares historical and contemporary basal area occupied by pines and oaks. Changes in the relative abundance of these tree species represent changes in forest composition. Pines have declined in all regions, whereas oaks increased in two Sierra Nevada regions but decreased in the South and Central Coastal ranges.

Changes in forest composition and their drivers are not uniform across the state, however. In some areas of California, shrublands are replacing conifer and hardwood forests (Bhoot et al., 2026). 30% of Sierra Nevada’s conifer forest transitioned to non-forest vegetation during 2011–2020, primarily due to the combined effects of wildfires, drought, and drought-associated beetle epidemics (Steel et al., 2022). The increasing pace and intensity of wildfires in California have led to losses in spatial extent of forests between 0.25 and 0.47% per year, leading to deforestation of about 150,000 ha/year in 2021–2023 (Safford and Stewart, 2026). Along California’s central coast, grassland cover declined by 26% over an 80-year period, while shrubland and oak woodland increased by 31% and 16%, respectively, in areas that had not burned (Genua et al., 2024). In the northern Bay Area, woodland and shrub patches were most susceptible to change, with many areas transitioning to denser forest stands, while herbaceous and forest patches showed greater persistence. Wildfires and topographic variables like elevation were identified as important influences on the likelihood of vegetation



persistence in this region, while slope and water availability were not. Unburned, higher-elevation, and Northwest-facing areas were more likely to persist as forest vegetation, whereas higher-elevation and Northwest-facing shrub and woodland sites were more likely to convert to forest (Fertel et al., 2023).

Forest composition in some parts of California has shifted toward increased dominance by oaks relative to pines, a subgroup of conifers (McIntyre et al., 2015). In the Six Rivers National Forest of the Klamath Mountains, however, comparisons between historical inventories (1872–1884) and modern surveys (2008–2017) document declines in oaks alongside increases in pines, Douglas-fir, and small trees across a 36-square-mile study area. These changes were primarily attributed to fire suppression in the 1900s, in which small, low-intensity traditional burns by Native Californian tribes were disrupted and reduced. Densification of contemporary forests in Six Rivers as a result of fire suppression, coupled with a warming climate, likely contributed to unusually large wildfires in recent years. Average hectares (ha) burned in the 2010s was greater than in any other decade between 1908 and 1999. Between 2000 and 2018, over 500,000 ha burned, compared to nearly 200,000 ha during the entire previous century (Knight et al., 2020).

In addition to changes in forest structure and composition, elevational range shifts are also occurring. For example, the lower edge of conifer-dominated forests in the Sierra Nevada has retreated upslope since the 1930s, overlapping with an upslope shift of the winter freezeline (Thorne et al., 2008 and 2015; see also the *Ponderosa Pine Forest Retreat* chapter in OEHHA, 2018 and 2022). In the northern Sierra Nevada, three of twelve tree species—red fir (*Abies magnifica*), western white pine (*Pinus monticola*), and mountain hemlock (*Tsuga mertensiana*)—shifted upward in elevation by an average of 112–119 meters over an 80-year period (Wright et al., 2016). Together with large wildfires that have affected lower-elevation forests, tree mortality events likely contribute to the ongoing upslope retreat of ponderosa pine (Hill et al., 2023).

Why is this indicator important?

California's diverse climate and topography support a wide range of forest ecosystems that cover more than 33 million acres across the state, including some of the largest,



tallest, and oldest trees in the world. California's forests support extensive biodiversity, economic activity, and substantial carbon storage (CAL FIRE, 2018; CARB, 2026). They provide critical ecosystem services, including clean water, clean air, wildlife habitat, and recreation. Forested watersheds in the Sierra Nevada alone supply about 30% of California's total water supply, provide about 60% of water consumed by the state's population, and generate nearly half of the state's hydroelectric power (Soderquist and Luce, 2021).

The pine and oak-dominated forests and woodlands of California provide ecosystem benefits such as erosion control, water provision and carbon sequestration, as well as wildlife habitat, timber, and opportunities for recreation. Changes in forest structure and tree species composition can impact these functions.

This indicator describes how forest conditions have changed relative to historical climate change by comparing the 90-year-old VTM survey with modern-day observations and is bolstered by more recent studies focused on changes in forest structure, composition and extents. It shows that the state's forests are transitioning from one set of species to another. Since these changes may be a natural ecosystem response to warming and drying conditions, monitoring them provides valuable insight into future forest responses to climate change. There is evidence that wildfires at elevations up to about 5,000 feet where pines and oaks grow together can initiate this shift in species dominance by removing the dominant conifers (including pines but also other needle-leafed trees), allowing resident oaks and chaparral to establish and become the dominant vegetation. Another VTM-based study estimates that 13.5 million acres in California are at risk of this conversion (Goforth and Minnich, 2008). Decreases in large coniferous trees, including pines and firs in California montane (mountainous) forests have also been documented in other studies (Dolanc et al., 2013; Lutz et al., 2009; van Mantgem and Stephenson, 2007); furthermore, dieback of trees has been reported on all continents (Allen et al., 2015) and across the western United States (van Mantgem et al., 2009).

Despite a nearly 40% overall increase in tree density, the decline in large trees has resulted in about a 20% decline in basal area and associated biomass (not shown).



What factors influence this indicator?

California Native American tribes have stewarded these lands for thousands of years, and forests remain integral to their cultures and subsistence. For millennia, forests were shaped by frequent fire from both natural ignitions and Indigenous land management practices (CAL FIRE, 2018; Knight et al., 2022). During the twentieth century, widespread fire suppression and a warming climate altered forest structure, resulting in increased tree density and increasingly large wildfires (Klimaszewski-Patterson et al., 2024; Knight et al., 2022). Changes in forest structure are particularly pronounced on private timberlands, where densities of small trees (<10.2 cm diameter) have increased by as much as 400% since 1930 (Easterday et al., 2018). The density of small trees in the subalpine zone (2,300 to 3,400 meters or approximately 7,500 to 11,000 feet elevation) of central Sierra Nevada has increased by 62% since the 1930s while large tree densities decreased by 21%. These shifts are ubiquitous throughout the subalpine zone (Dolanc et al., 2013; also see the *Subalpine Forest Density* chapter in OEHHA, 2018 and 2022). The combined pressures of land-use change, climate change, and their interactions with wildland fire are reshaping the forests of the western United States (Hurteau et al., 2025).

Statewide, the decline in large trees and increases in the relative abundance of oaks compared to pines are associated with climatic water deficit (CWD), while changes in small tree densities are not (McIntyre et al., 2015). CWD is the cumulative annual excess of potential versus actual evapotranspiration of water from plants. Drought, and therefore CWD, can be intensified by unusually warm temperatures. When combined with very low precipitation and snowpack, extreme heat can lead to decreased streamflow, dry soils, and large-scale tree deaths. These conditions create increased potential for extreme wildfires that spread rapidly, burn with more severity, and are costly to suppress (NOAA, 2026).

The ratio of oak to pine basal area was correlated with estimates of CWD in the time periods of both forest surveys (McIntyre et al., 2015). In addition, the contemporary survey shows an increased relative dominance by oaks that was associated with increases in CWD. The paleological record is consistent with this: in the past 150,000



years, oaks dominated in warmer, drier interglacial periods, and pines in colder, more mesic (characterized by moderate or well-balanced supply of moisture) glacial periods (Heusser, 1992).

The changes in forest species composition and basal area described here are occurring in California forest and woodland areas at elevations that are subject to seasonal drought; these areas represent water-limited ecosystems throughout the low to mid-elevations of the state, from the southern coastal and transverse mountains to near the northern end of the foothills of the Sierra Nevada Mountains. Although there are several potential causes for these dynamics at lower elevations, hotter drought conditions are the lead environmental cause.

Other factors potentially contributing to shifts in the oak: pine ratio include fire suppression, wildfires, and logging practices. Widespread fire suppression in the western United States has led to the buildup of forest litter and increased density of small trees, including the establishment of the highly flammable white fir (*Abies concolor*) — changes which have potentially contributed to the more frequent and larger wildfires today. Further, a warming climate is contributing to the increasing frequency and intensity of wildfires in the western United States (Westerling et al., 2006; also see the *Wildfires* chapter).

As noted above, wildfires can initiate the conversion of coniferous to broadleaf forests and woodlands or chaparral by removing dominant conifers. A large stand-replacing fire at Cuyamaca Rancho State Park near San Diego (the Cedar fire, October 24-28, 2003) happened after eight decades of fire suppression. A seedling census four years after the fire found that while various oak species had re-established, few to no conifer seedlings had done so, resulting in the conversion of a mixed conifer-oak forest to one dominated principally by oaks (Goforth and Minnich, 2008). The authors did not examine changes in climatic conditions. The authors predict this transition is to be expected for the ~13.6 million acres of this forest type in California, including large swaths of the Sierra Nevada foothills and most of the forests and woodlands near coastal urban areas. This prediction is also in line with change documented on the western slope of the Sierra Nevada Mountains where lower elevations of coniferous



forests are retracting upslope (Thorne et al., 2008; see also the *Ponderosa Pine Forest Retreat* chapter in OEHHA, 2018 and 2022). This was corroborated by a 2016 study that examined post-fire seedling regeneration after 14 large wildfires in Northern California. Welch et al. (2016) found that in 10 of the 14 fires, conifer regeneration was not high enough to meet US Forest Service stocking standards, indicative of a return of the site to a conifer forest.

Differences among species in postfire recovery may contribute to changes in forest composition. A long history of fire exclusion has created denser conifer stands, and encroachment by Douglas fir (*Pseudotsuga menziesii*) into oak woodlands and shrublands in certain coastal regions of California, has created forests that are now more vulnerable to high-severity wildfire (Polasek et al., 2026). Conifer forests in California generally recover slower than hardwood forests after wildfires, in part because many California hardwood species can resprout after fire, allowing more rapid recovery, while most conifers rely on seed-based regeneration, which can be limited after large, high-severity fires and under hot, dry postfire conditions. In a 32-year remote sensing study of forest recovery after large and severe wildfires in California, Bhoot et al. (2026) found that conifer forests recovered more slowly, on average, than hardwood forests. In addition, conifer forest recovery rates slowed in the second half, during which time overall hardwood forest extents also declined.

As the climate continues to warm and extreme events such as droughts and large wildfires become more frequent, further changes to California forests are expected. Approximately 19.5% of Sierra Nevada conifer forests occur in areas experiencing “vegetation climate mismatch,” where climate conditions have become unsuitable for the current vegetation, but species composition has not yet changed. Nearly 95% of these areas occur below 2,356 meters elevation, and the probability of vegetation type conversion increases by roughly 9.2% for every 10% decline in habitat suitability (Hill et al., 2023).



Technical considerations

Data characteristics

The indicator is based on a study comparing forested plots from the Wieslander Vegetation Type Map (VTM) survey (between 1929 and 1936) with US Forest Service Forest Inventory Analysis (FIA) plots (between 2000 and 2010). Across California, 9,388 VTM plots and 5,198 FIA plots were identified as forested (having at least one tree >10.2 cm dbh, the cutoff for a tree in the VTM data). Only plots occurring within 5 km of a plot from the other time period were selected, resulting in 6,572 VTM and 1,909 FIA focal plots. The plots were similar in slope, aspect, and elevation, as well as location across latitudinal and longitudinal gradients.

A modified version of the Jepson Manual eco-regions of California was used in identifying plots by region, as follows: South and Central Coast; Transverse and Peninsular Ranges; North Coast; Foothills of the Sierra Nevada and southern Cascades; Highlands of the Sierra Nevada and southern Cascades. (The Central Valley and desert regions are not included because they did not have a sufficient number of forested plots). Changes in tree density were compared with changes in CWD between 1910–1940 and 1981–2010 using 30-year averages from each time period. CWD is the seasonally integrated excess in potential evapotranspiration (PET) versus actual evapotranspiration. Details on the methodology are described in McIntyre et al. (2015).

Strengths and limitations of the data

Historical reconstructions, whether of climate or vegetation, are dependent on the quality of the data. In the case of the 1930s historical vegetation survey, the plot areas surveyed were not permanently marked, and this comparison used contemporary US Forest Service plots to compare densities of trees in similar locations as paired plots that had similar slope, aspect and elevation. The VTM survey only classed trees to size classes, so the modern survey, which has actual diameter at breast height values for every tree was re-classed to the same size classes. This reduced some of the precision with regards to tree size. However, the historical VTM was one of the most complete and thorough efforts to document the forests of California, and the use of these data was a unique opportunity to examine shifts statewide.



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References

- Allen CD, Breshears DD and McDowell NG (2015). On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. *Ecosphere* **6**(8): 129.
- Bhoot VN, Kim JE, Randerson JT and Goulden ML (2026). Declines in conifer forest recovery and forest loss from four decades of wildfire in California. *Journal of Geophysical Research: Biogeosciences* **131**: e2025JG009105.
- CAL FIRE (2018). *California's Forests and Rangelands: 2017 Assessment*. California Department of Forestry and Fire Protection. Fire and Resource Assessment Program.
- CARB (2026). [2025 Natural and Working Lands Carbon Inventory](#). Retrieved August 2026.
- Dolanc CR, Thorne JH and Safford HD (2013). Widespread shifts in the demographic structure of subalpine conifer forests over last 80 years in the central Sierra Nevada. *Global Ecology and Biogeography* **22**: 264–276.
- Easterday K, McIntyre P and Kelly M (2018). Land ownership and 20th-century changes to forest structure in California. *Forest Ecology and Management* **422**: 137-146.
- Fertel HM, Collins BM, Lydersen JM and Stephens SL (2023). Vegetation type change in California's Northern Bay Area: A comparison of contemporary and historical aerial imagery. *Forest Ecology and Management* **542**: 121102.
- Goforth BR and Minnich RA (2008). Densification, stand-replacement wildfire, and extirpation of mixed conifer forest in Cuyamaca Rancho State Park, southern California. *Forest Ecology and Management* **256**: 36-45.
- Heusser LE (1992). Pollen stratigraphy and paleoecologic interpretation of the 160-ky record from Santa Barbara Basin, Hole 893A1. Proceedings of the Ocean Drilling Program. *Scientific Results* **146**(2): 265-279.
- Hill AP, Nolan CJ, Hemes KS, Cambron TW and Field CB (2023). Low-elevation conifers in California's Sierra Nevada are out of equilibrium with climate. *PNAS Nexus* **2**(2): pgad004.



Hurteau MD, Baker R, Gonterman K, Granath A, Lopez-Binder J, Taylor MD, et al. (2025). Changing climate and disturbance effects on southwestern US forests. *Forest Ecology and Management* **575**: 122388.

Klimaszewski-Patterson A, Dingemans T, Morgan CT and Mensing SA (2024). Human influence on late Holocene fire history in a mixed-conifer forest, Sierra National Forest, California. *Fire Ecology* **20**(1): 3.

Knight CA, Anderson L, Bunting MJ, Champagne M, Clayburn RM, Crawford JN, et al. (2022). Land management explains major trends in forest structure and composition over the last millennium in California's Klamath Mountains. *Proceedings of the National Academy of Sciences* **119**(12): e2116264119.

Knight CA, Cogbill CV, Potts MD, Wanket JA and Battles JJ (2020). Settlement-era forest structure and composition in the Klamath Mountains: reconstructing a historical baseline. *Ecosphere* **11**(9): e03250.

Lutz JA, Van Wagtendonk JW and Franklin JF (2009). Twentieth-century decline of large-diameter trees in Yosemite National Park, California USA. *Forest Ecology and Management* **257**: 2296–2307.

McIntyre P, Thorne JH, Dolanc CR, Flint A, Flint L, et al. (2015). Twentieth century shifts in forest structure in California: denser forests, smaller trees, and increased dominance of oaks. *Proceedings of the National Academy of Sciences* **112**: 1458–1463.

NOAA (2026). [Drought: Wildfire Management](#). Retrieved April 6, 2026.

OEHHA (2018). *Indicators of Climate Change in California, Third Edition*. California Environmental Protection Agency, OEHHA.

OEHHA (2022). *Indicators of Climate Change in California, Fourth Edition*. California Environmental Protection Agency, OEHHA.

Polasek N, Bruno EM, Stackhouse J, Valachovic Y and Quinn-Davidson L (2026). The Benefits of Oak Woodland Restoration Can Exceed the Costs of Treating Conifer Encroachment. *California Agriculture: The Journal of UC Agriculture and Natural Resources*.

Safford HD and Stewart JAE (2026) Deforestation and reforestation in a world hotspot of fire-driven forest loss: trends in California conifer forests 1991–2023. *Frontiers in Forests and Global Change* **9**: 1764379.

Soderquist BS and Luce CH (2021). *Climate change effects on hydrologic processes and water resources in the Sierra Nevada*. General Technical Report PSW-GTR-272. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Albany, CA.

Steel ZL, Jones GM, Collins BM, Green R, Koltunov A, Purcell KL, et al. (2022). Mega-Disturbances Cause Rapid Decline of Mature Conifer Forest Habitat in California. *Ecological Applications* **33**(2): e2763.

Thorne JH, Morgan BJ, and Kennedy JA (2008). Vegetation change over 60 years in the central Sierra Nevada. *Madroño* **55**: 223-237.

Thorne JH, Boynton RM, Flint LE and Flint AL (2015). Comparing historic and future climate and hydrology for California's watersheds using the Basin Characterization Model. *Ecosphere* **6**(2).

van Mantgem PJ and Stephenson N (2007). Apparent climatically induced increase of tree mortality rates in a temperate forest. *Ecology Letters* **10**(10): 909-916.

van Mantgem PJ, Stephenson NL, Byrne JC, Daniels LD, Franklin JF, et al. (2009). Widespread increase of tree mortality rates in the western United States. *Science* **323**: 521-524.



Wright DH, Nguyen CV and Anderson S (2016). Upward shifts in recruitment of high-elevation tree species in the northern Sierra Nevada, California. *California Fish and Game* **102**: 17-31.

Welch KR, Safford HD and Young TP (2016). Predicting conifer establishment post wildfire in mixed conifer forests of the North American Mediterranean-climate zone. *Ecosphere* **7**(12): e01609.

Westerling AL, Hidalgo HG, Cayan DR, and Swetnam TW (2006). Warming and earlier spring increase western U.S. Forest wildfire activity. *Science* **313**(5789): 940-943.

