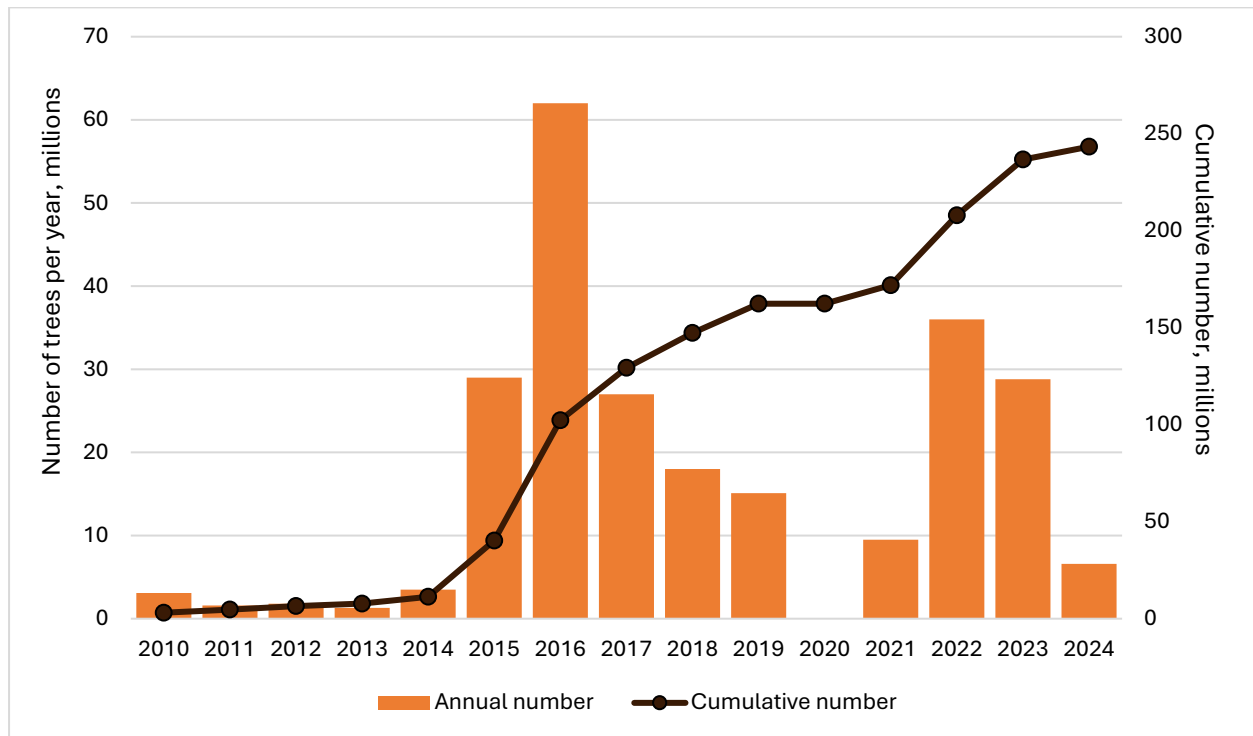


4.2 Forest Tree Mortality

Since the unprecedented 2012–2016 drought, tree deaths in California forest lands have increased dramatically. An estimated 243 million trees in forest lands died between 2010 and 2024. Most of these trees were stressed from higher temperatures and decreased water availability, making them more vulnerable to insects and pathogens.

Figure 4.2.1. Estimated Number of Dead Trees in California.



The figure shows the number of dead trees per year as detected by aerial surveys by the US Forest Service. The estimates include trees killed by a variety of agents including drought and drought-related insect activity, but exclude trees killed by wildfire. Surveys were suspended in 2020 due to the pandemic and stopped in 2025 due to federal budget cuts. The cumulative number of dead trees in forested areas between 2010 and 2024 exceeds an estimated 243 million. Source: USFS (2025)

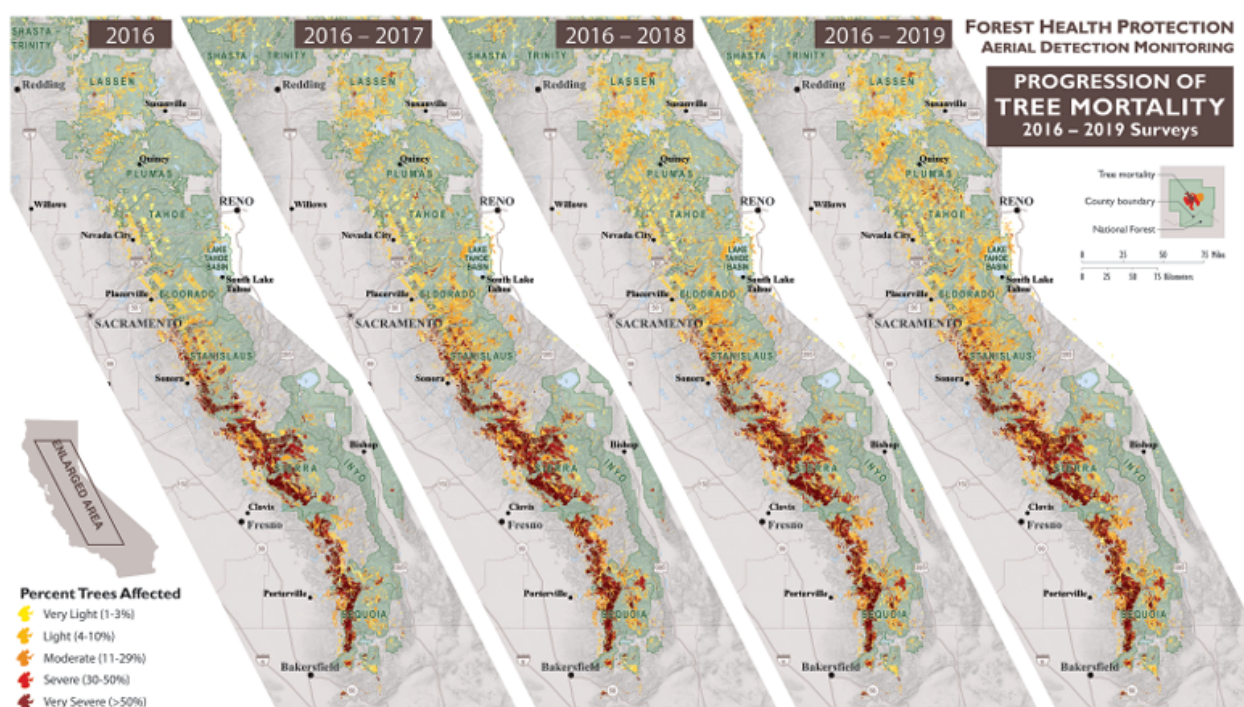
What does the indicator show?

California's forests have experienced persistently high tree mortality since 2015. A sharp rise in tree deaths was first observed during the 2015 survey, coinciding with the



progression of the extreme 2012–2016 drought. The highest recorded tree mortality occurred in 2016, when an estimated 62 million trees died—more than double the number reported the previous year (**Figure 4.2.1**). During this drought, mortality dramatically increased first in the lower-elevation forests of the southern Sierra Nevada, where drought conditions were both most severe and prolonged. By 2016, widespread tree death also became apparent farther north and at higher elevations (**Figure 4.2.2**).

Figure 4.2.2. Tree Mortality in the Sierra Nevada from 2016 to 2019.



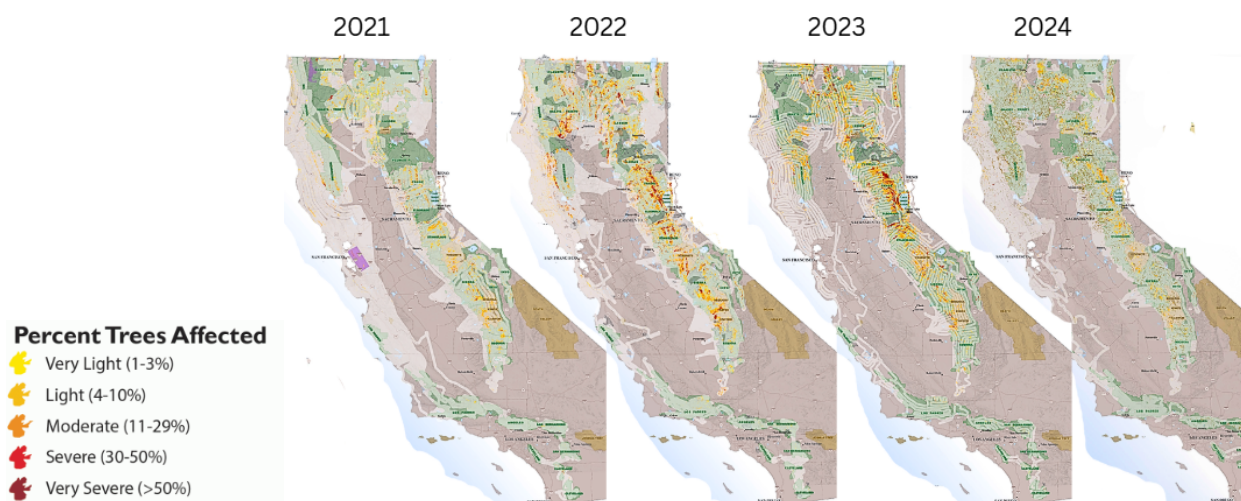
The maps show percent of dead trees recorded in the Sierra Nevada mountains from 2016 to 2019 from aerial surveys. Source: USFS (2025)

Relatively high tree mortality throughout the Sierra Nevada was apparent again in the 2022 and 2023 aerial surveys, to a lesser degree than what was observed during the 2012–2016 drought (**Figure 4.2.3**). The 2020–2022 drought was centered in north-central California, with the highest tree mortality in the central Sierra Nevada and the northern interior (Siskiyou, Shasta, Trinity, Tehama, and Glenn Counties). Also, unlike



the first exceptional drought, where the early mass die-off occurred primarily in low elevation species of pine, mortality primarily affected fir species (USFS, 2025).

Figure 4.2.3. Yearly Tree Mortality in California from 2021 to 2024.



The maps show the percent of dead trees recorded in California forests for each year based on US Forest Service aerial detection surveys. Source: USFS (2025)

The overall increase in tree mortality observed by aerial surveys aligns with satellite-based findings of an upward trend of annual tree cover loss from 1986 to 2019. Tree cover loss rapidly surged later in the study period and appeared to be driven by climate stress and wildfires (Dwomoh et al., 2023). California's pattern of tree mortality also corresponds with global trends: increasing tree mortality has been documented on all vegetated continents and in most bioregions over the past two decades. Tree mortality has been linked to increasingly dry and hot climatic conditions (Allen et al., 2010).

Notably, tree mortality estimates from these surveys may be underestimates: a recent study that mapped individual dead trees in California in 2020 at sub-meter resolution found that the majority of dead trees are isolated or scattered, therefore are likely missed by conventional monitoring methods (Cheng et al. 2024).

As noted in *Impacts on California Tribes*, many tribes have noticed an increase in tree mortality. In 2020 and 2021, OEHHHA co-hosted three regional listening sessions with



the Bishop Paiute Tribe, the Pala Band of Mission Indians, the Santa Ynez Band of Chumash Indians, the Big Valley Band of Pomo Indians, and the Middletown Rancheria of Pomo Indians of California. Tribes participating in the [Eastern Sierra](#) and [Southern California](#) listening sessions including Bishop, Big Pine, Mono Lake Kootzaduka’a, Santa Ynez, Pala, Barona, and others have witnessed increased tree mortality of conifers, oaks as well as pinyon pines and other conifer species. During the [Lake, Sonoma and Mendocino listening session](#), the Middletown Rancheria shared this image of local trees (**Figure 4.2.4**) that are dead or dying. The Kashia Band of Pomo Indians are also experiencing tree mortality and now refer to these stands or dead and dying trees as “match sticks”.

Figure 4.2.4. Dead and Dying Trees at Middletown Rancheria.



Photo credit: Mike Shaver, Water Resources Manager, Potter Valley Tribe

Why is this indicator important?

Forests occupy almost one-third of California and are a vital resource for the state, providing important ecosystem services, including water and air purification, carbon sequestration, building materials, renewable energy, cultural resources, wildlife habitat,



and recreational opportunities (CNRA, 2016). Accelerating tree mortality and the increasing frequency of large-scale and high mortality events (known as forest dieback) could have profound effects on these ecosystem services. The loss of large trees represents a significant reduction in the capacity of forests to store carbon, further exacerbating climate change. The unprecedented scale of tree mortality and the increased fuel load present increased risks of large, severe fires in the coming decades (Stephens et al., 2018).

Tribal Connection 4.2.1

Pinyon pine nuts and acorns from a variety of oaks are culturally important foods for Tribal Nations across the state. One impact of climate change that tribes have observed is that drought weakens these trees' defenses, making them more susceptible to invasive insect pests and/or pathogens. For example, the Mono Lake Kootzaduka'a Tribe has observed higher mortality of pinyon trees, lower pinyon nut production and size, and less pinyon sap which is an important cultural medicine (Mono Lake Kootzaduka'a Tribe of California and Nevada, 2026). Similar observations of pinyon mortality have been made by other tribes in the Eastern Sierra, including the Big Pine Paiute Tribe and Bishop Paiute Tribe (Big Pine Paiute Tribe, 2026; Bishop Paiute Tribe, 2026), and the Big Valley Band of Pomo Indians in northern California (Big Valley Band of Pomo Indians, 2026). Likewise, the Big Valley Band of Pomo Indians, Big Pine Paiute Tribe, Bishop Paiute Tribe, and Pala Band of Mission Indians (Pala Band of Mission Indians, 2026) have all reported increased oak death and reduction in acorn availability and quality.



Examples of how increased tree mortality is impacting different tribes:

Tribe: region	Tree: pest	Driver	Cultural impact
Big Pine Paiute Tribe: Owens Valley	• Pinyon pine: Mountain pine beetle • Oaks	• Drought • Drought	• Decreased pine nut yield and size • Fewer acorns, stronger acorn tannins
Big Valley Band of Pomo Indians: Clear Lake	• Ponderosa pine: western pine beetle • Pinyon pine: Ips pine bark beetle • Valley oaks: Mediterranean oak borer	• Drought • Drought • Drought	• Wildfire fuel hazard • Decreased pine nut yield and size • Fewer acorns for Tribe and animals; fire fuels hazard; loss of habitat and cultural landscape
Bishop Paiute Tribe: Bishop	• Pinyon pine: Mountain pine beetle • Oaks	• Drought • Drought	• Decreased pine nut yield and size • Fewer acorns, change in taste
Karuk Tribe: mid-Klamath River	• Tanoak: Sudden Oak pathogen • Black oak: Sudden Oak pathogen • Sugar pine: fungal pathogen	• Drought • Warming temperatures • Warming temperatures	• Fewer acorns and tanoak mushrooms • Fewer acorns • Fewer pine nuts (Karuk Tribe, 2026)
Mono Lake Kootzaduka'a Tribe: Mono Lake	• Pinyon pine: Mountain pine beetle	• Drought	• Decreased pine nut yield and size • Less sap for medicine • Loss of critical habitat
Pala Band of Mission Indians: Pala	• Oaks: Gold spotted oak borer	• Drought	• Fewer acorns for Tribe and animals; fire fuels hazard; loss of habitat and cultural landscape
Wiyot Tribe: <i>Wigi</i> (Humboldt Bay)	• Sitka spruce: green spruce aphid	• Flooding, saturated soil	• Reduced critical habitat type (Wiyot Tribe, 2026)

There is also evidence that increased tree mortality amplifies other climate change-related phenomena such as forest type conversion (a change in tree species or group of species present, for example, from conifers to hardwood; see the *Changes in Forests and Woodlands Composition* chapter) and increased wildfire risk (see the *Wildfires*



chapter). Shifts in dominant tree species can alter ecosystem structure and function, including water use and availability, carbon storage, habitat suitability for wildlife, and fuel characteristics that influence fire behavior. If high tree mortality persists, California's forests may shift in species composition, convert to less forested vegetation, or disappear altogether (Larvie et al., 2019; Lenihan et al., 2003; Millar and Stephenson, 2015; Thorne et al., 2008).

What factors influence this indicator?

Tree mortality in California reflects the complex interplay of wildfire, rising temperatures, prolonged drought, and pest outbreaks (Dwomoh et al., 2023; Young et al., 2023).

Decades of fire suppression have led to unnaturally dense forests, intensifying competition for water and other resources and leaving trees increasingly vulnerable to drought stress, pest infestations, and a surge of large and severe wildfires (Harrison et al., 2024; McIntyre et al., 2015; Stephens et al., 2018; Young et al., 2017). Recovery is threatened by habitat loss, conversion to different dominant species in response to changing environmental conditions, poor tree regeneration, and rising moisture deficits (Davis et al., 2023).

The extreme 2012–2016 drought, part of a larger “megadrought” from 2000 to at least 2021 in the U.S. southwest, was an example of the increasingly common “hot droughts”, when anomalously high temperatures coincide with very dry conditions. The broader megadrought was the driest in over 1,200 years, with up to 42% of its severity linked to climate change (Williams et al., 2022). Using tree ring data from California, researchers estimated 2014 to be the worst single drought year in at least the last 1,200 years in the state, as seen in the tree rings of blue oak — the result of unusually low (but not unprecedented) precipitation and record high temperatures (Griffin and Anchukaitis, 2014). Hot droughts increase the physiological stress in trees (Diffenbaugh et al., 2015; Young et al., 2017). In fact, rising global temperatures have contributed to droughts of a severity that is unprecedented in the last century (Millar and Stephenson, 2015).

Regional warming and drought change the hydrology at landscape scales (Thorne et al. 2015). Less precipitation falling as snow, declining snowpack water content, and earlier spring snowmelt and runoff have impacted old growth western forests (van Mantgem et



al., 2009). The 2012–2016 drought occurred at a time of record warmth — 2014 was, at that time, the warmest year on record, followed by 2015 — and was accompanied by record low snowpack (DWR, 2017; also see the *Air Temperature, Drought, and Snow-Water Content* chapters).

The 2012–2016 drought triggered widespread tree dieback in the Sierra Nevada, driven by pests thriving in dense, fire-suppressed forests. Meanwhile, rising precipitation variability—including record wet years—has amplified disease outbreaks linked to moisture, also increasing tree mortality (Harrison et al., 2024). Tree mortality during drought is linked to rising climatic water deficit (CWD), a measure of plant water stress that increases with warming, reduced precipitation, and earlier snowmelt. High CWD impairs water transport in trees, a key driver of drought-induced mortality (Flint et al., 2013; Thorne et al., 2015). Prolonged depletion of soil moisture, compounded by high tree density and warm temperatures, substantially increased tree mortality in the Sierra Nevada during the 2012–2016 drought (Goulden and Bales, 2019). Statewide, approximately 10.6 million hectares (ha) of forest containing up to 888 million large trees in California experienced measurable loss in canopy water content during this drought (Asner et al., 2016).

Notably, hot droughts may be beneficial for some tree species growing at high elevations. Tree growth of *Pinus jeffreyi*, *P. lambertiana*, and *P. contorta* in the San Jacinto Mountains from 2000 to 2020 fared better with warmer temperatures and lower precipitation. Warmer temperatures in these historically cooler elevations may be extending growing season while remaining within the temperature range needed for growth (Knapp et al., 2023).

Large scale, drought-induced tree mortality events create feedbacks that exacerbate the threat of wildfires (Stephens et al., 2018). Across the west, drier conditions have also amplified the occurrence and extent of wildfires (Abatzoglou and Williams, 2016) that directly kill trees and also burn trees that previously died due to other factors. Longer fire seasons—due to reduced snowpack, earlier melt, and rising temperatures—are pushing wildfires into higher elevations. In northern montane forests, climate’s influence on fire size and area burned has increased by two- to four-times over the past century.



At lower elevations, hotter, drier conditions fuel more destructive, wind-driven autumn fires (Goss et al., 2020). Since 1985, forest cover has declined nearly 7%, largely due to fire (Wang et al., 2022). Another study found yearly statewide forest spatial loss to fire in 2021–2023 averaged about 150 km²/year (Safford and Stewart, 2026).

Warming temperatures favor pest growth, heightening risks of tree infestations and disease (van Mantgem et al., 2009). Most conifer deaths result from drought-weakened trees succumbing to beetle attacks rather than direct drought stress (Moore et al., 2016). Recent decades have seen widespread forest dieback and mortality across western North America as warmer winters fueled insect outbreaks (Bentz et al., 2010). Pathogens are also expanding, for example, the range of white pine blister rust has shifted upslope with warming, so that high-elevation white pines may face greater risk (Dudney et al., 2021).

Some of the predominant pests and diseases affecting California's forests are:

Fir engraver beetle (*Scolytus ventralis*). Fir engraver beetle is a native insect significantly impacting California red fir and white fir and caused most of the detected mortality in California in 2022 and 2023 (USFS, 2025). Drought is a primary stressor that weakens the trees and makes them susceptible to infestations.

Western pine beetle (*Dendroctonus brevicomis*). The western pine beetle, a native bark beetle, has caused severe ponderosa pine mortality in California's Sierra Nevada, especially during drought. Significant tree mortality of low-elevation ponderosa pines was attributed to the western pine beetle during the 2012–2015 drought based on an analysis of 11.3-m fixed-radius plots installed within three elevation bands on the Eldorado, Stanislaus, Sierra and Sequoia National Forests (914–1219, 1220–1524 and 1525–1829 m), two elevation bands on the Eldorado, Stanislaus, and Sierra National Forests (1219–1524, 1525–1829) and one elevation band on Sequoia National Forest (1830–2134 m), where tree mortality was most severe (Fettig et al., 2019). A study encompassing the Eldorado, Stanislaus, Sierra, and Sequoia National Forests, Kings Canyon, Sequoia, and Yosemite National Parks, and adjoining areas of the Sierra Nevada found that during the 2012–2015 drought, warmer temperatures increased beetle-caused mortality by 30% (Robbins



et al., 2022) by accelerating beetle development and reducing winter die-off (Bentz et al., 2023; Robbins et al., 2022). The resulting beetle outbreaks, combined with drought stress, have boosted wildfire fuel loads and subsequent tree mortality (Wayman and Safford, 2021).

Sudden oak death (*Phytophthora ramorum*). In coastal northern California, sudden oak death (SOD) is the leading cause of tree mortality. First detected around 1990, this invasive pathogen infects over 130 plant species (Cobb et al., 2020). It kills tanoak (*Notholithocarpus densiflorus*), coast live oak (*Quercus agrifolia*), and California black oak (*Q. kelloggii*); while California bay laurel (*Umbellularia californica*) serves as a carrier. The SOD pathogen thrives in warm, wet conditions, and although a direct link is unconfirmed, winter temperatures in California's north coast have warmed by about 1.3°F (0.72°C) since 1951 (Flint et al. 2021; analysis by Thorne, personal communication).

Shothole Borers (*Euwallacea* spp.). Some urban and natural forests in southern California have been severely affected by beetle-related tree mortality. Invasive shothole borers are two closely related species of small, non-native, beetles that bore into trees and introduce fungi that cause a tree disease called Fusarium dieback (UCANR, 2026). These beetles have killed thousands of trees in Southern California, and can impact riparian, agricultural and urban tree species (Boland 2018; Eskalen et al., 2018). They have also moved into riparian systems in Southern California, including the Tijuana River and the Santa Clara River riparian forests (Bennett, 2020).

Goldspotted Oak Borer (*Agrilus auroguttatus*). Also in Southern California, the invasive goldspotted oak borer, introduced from Arizona, kills oaks such as coast live oak and black oak (Coleman et al., 2017). For example, the Lipay Nation of Santa Ysabel and the Barona Band of Mission Indians, the Pala Band of Mission Indians (and others) have reported widespread oak deaths on their reservations.



Technical considerations

Data characteristics

The aerial tree mortality surveys were based on annual small plane reconnaissance over California's forested lands. Forested areas were mapped on a one-acre basis, and the following were recorded: (a) damage type, (b) number of trees affected, and (c) affected tree species. Generally, areas with <1 tree per acre of mortality were considered to have "background" or "normal" levels of mortality and were not usually mapped during the flight. If low levels of mortality were indicative of a localized pest-related event, the areas were supposed to be mapped; however, it is usually not possible to systematically discern the cause of such low-level mortality using visual aerial surveys.

For the aerial surveys, lands dominated by hardwood and conifer tree species were considered forest lands. Affected trees were recorded to species level, when possible (sugar pine and white fir), or to genus level (pine, fir). In areas where two or more tree species were affected, the surveyor designated the proportion of damage affecting each species (e.g., 25% sugar pine, 75% white fir), or preferably, an estimate of trees per acre for each species affected was recorded. Lands characterized as urban, orchards, and windbreaks were not mapped. Tree injuries that were recorded were typically defoliation, discoloration, dieback or more commonly death.

Survey results provide a reasonable estimate of dead trees that aid in the understanding of the mortality event (USFS, 2019). There will be some level of error in the density estimates, however, over large areas, the results should show the correct trends.

Strengths and limitations of the data

Aerial surveys cannot detect mortality until the trees have been dead some months and the foliage has dried out and faded from green to a red or yellow color. Thus, currently infested, still-living trees that still look healthy from a distance may not be counted in the aerial survey. The aerial detection survey program was suspended in 2020 due to the COVID-19 pandemic and no estimates are available that year. Aside from 2020, aerial surveys covered most of California forests every year up to 2024 (J. Moore, personal



communication, March 2024). The 2021 Aerial Detection Survey (ADS) did not include all areas covered by past aerial survey operations; instead remote sensing was used to analyze some of the areas.

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