2023 Aerial Detection Survey Results: California

State & Private Forestry, Region 5
Forest Health Monitoring Program • 1323 Club Dr, Vallejo, CA 94592
www.fs.usda.gov/detail/r5/forest-grasslandhealth

COVER PHOTO
Severe mostly fir mortality in the Warner Mountains near Bald Mountain, Modoc NF.
Photo by J.Moore USDA Forest Service

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USDA Forest Service, Region 5

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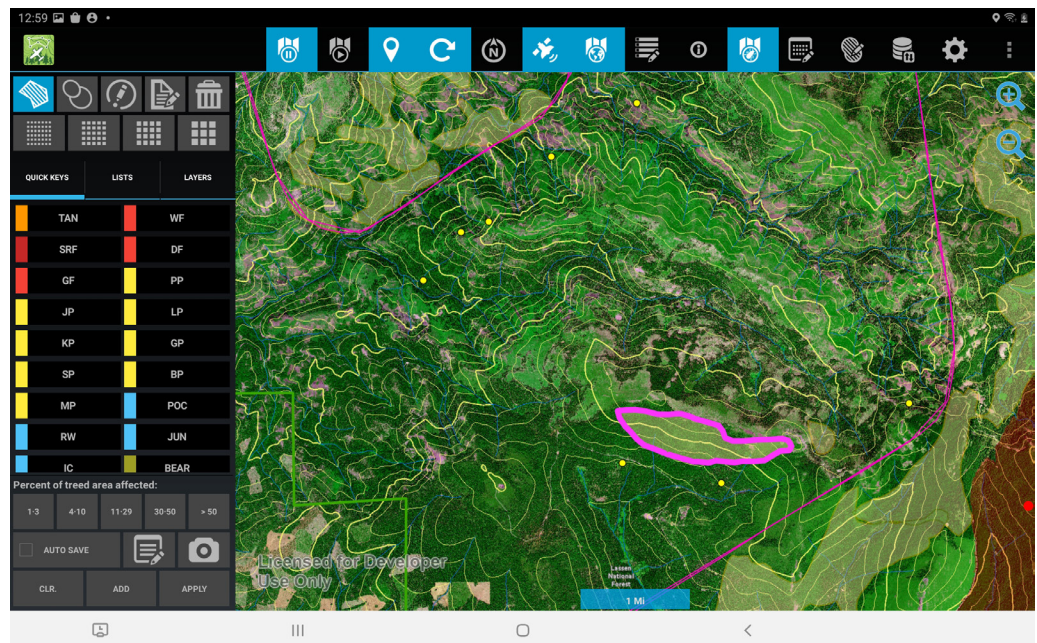Nicholas Stevens, USFS

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Screenshot of the Digital Mobile Sketchmapping System (DMSM) used to record tree mortality and damage data

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FOREST HEALTH PROTECTION
AERIAL DETECTION MONITORING

2023 SURVEY

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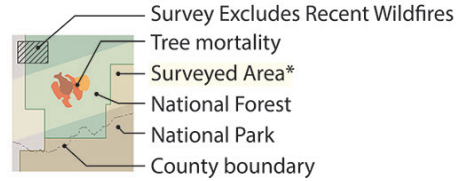
*This map depicts tree mortality **only** within the surveyed area.

Percent Trees Affected

- Very Light (1-3%)
- Light (4-10%)
- Moderate (11-29%)
- Severe (30-50%)
- Very Severe (>50%)

Map only depicts dead trees surveyed in 2023.
Areas of tree mortality are for visualization purposes only.

2022 Tree Mortality

Figure 1. Statewide damage mapped via aerial detection survey in 2023.

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Overview

The USDA Forest Service (USFS), Pacific Southwest Region, State and Private Forestry staff conduct annual aerial detection surveys (ADS) throughout forested areas of Califo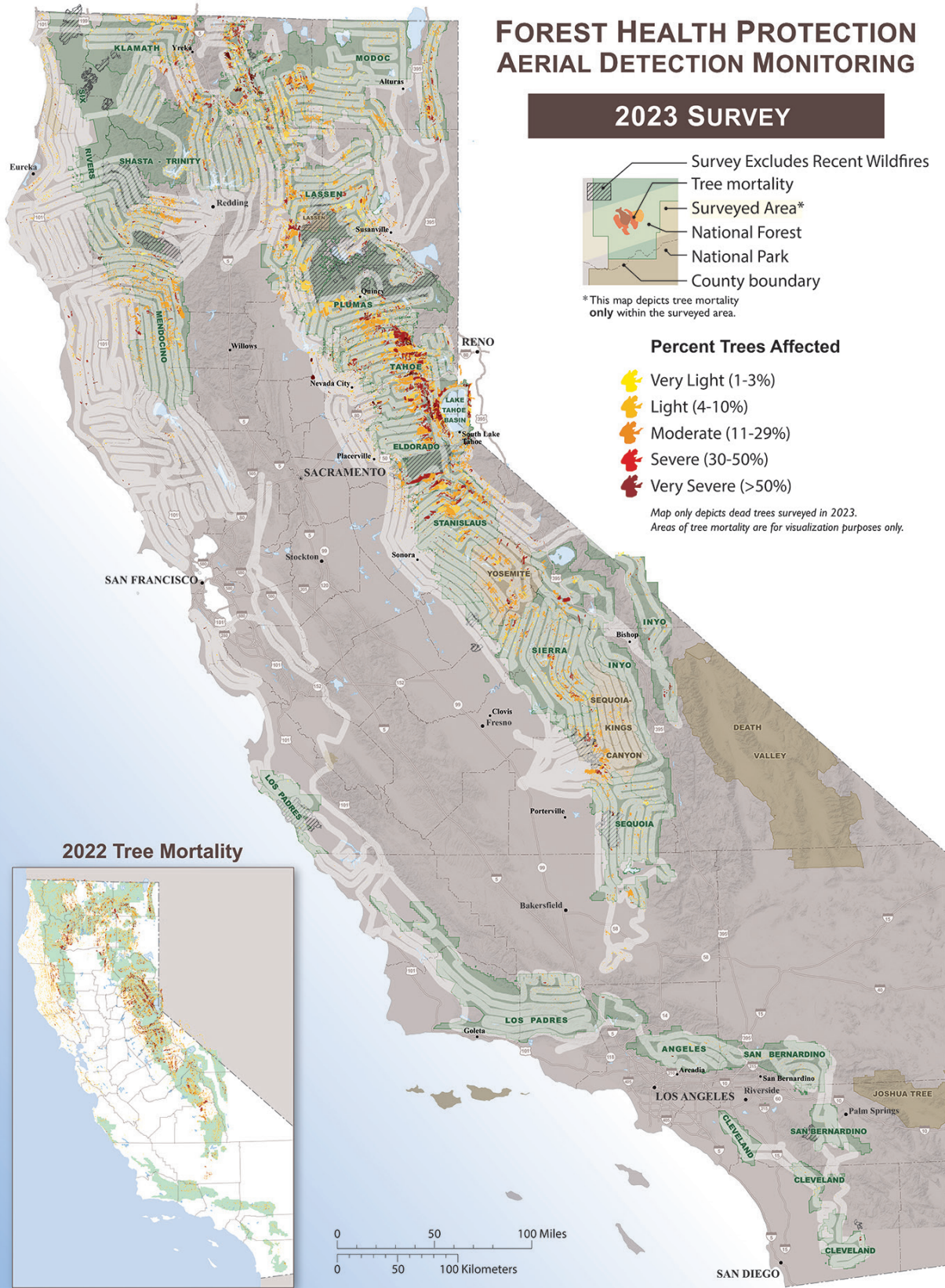rnia to detect tree mortality and tree damage such as defoliation or dead/dying branches. Surveys are flown in small, fixed-wing aircraft on a 4–5-mile grid pattern with two observers recording from opposite sides of the plane. Most National Forests (NF) and National Parks (NP) in California are surveyed, along with other federal, state, and private forested lands. The objective of this report is to summarize observations from the 2023 aerial detection survey.

Approximately 38.2 million acres were surveyed during the 2023 flight season (June – September). Several large areas were excluded from surveys in 2023 due to large wildfires that occurred within the previous three years. Insect and disease activity is difficult to discern in forests that have burned recently (Figure 1). Active large fires late in the 2023 season prevented survey in parts of the northern Coastal Range.

Elevated levels of tree mortality (i.e. more than 1% of forested area affected) were recorded on more than 2.4 million acres, totaling an estimated 28.8 million dead trees. Most of the trees killed were recorded as fir (*Abies* spp.), followed by ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii*) (Figure 2). Mortality was particularly severe and widespread in the central Sierra Nevada Range and northern interior California (Figure 1). Elevated levels of tree mortality can be attributed in part to the ongoing effects of long-term, intermittent, exceptional drought conditions and subsequent successful bark and engraver beetle attacks that have resulted in an estimated 239 million trees killed since 2010 (Figure 3).

Note: no survey was flown in 2020 due to Covid-19 considerations
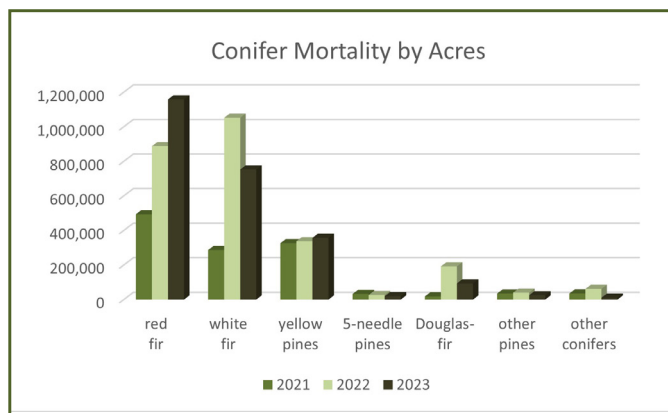
Figure 2. Chart compares the number of acres with conifer mortality from 2021 through 2023.
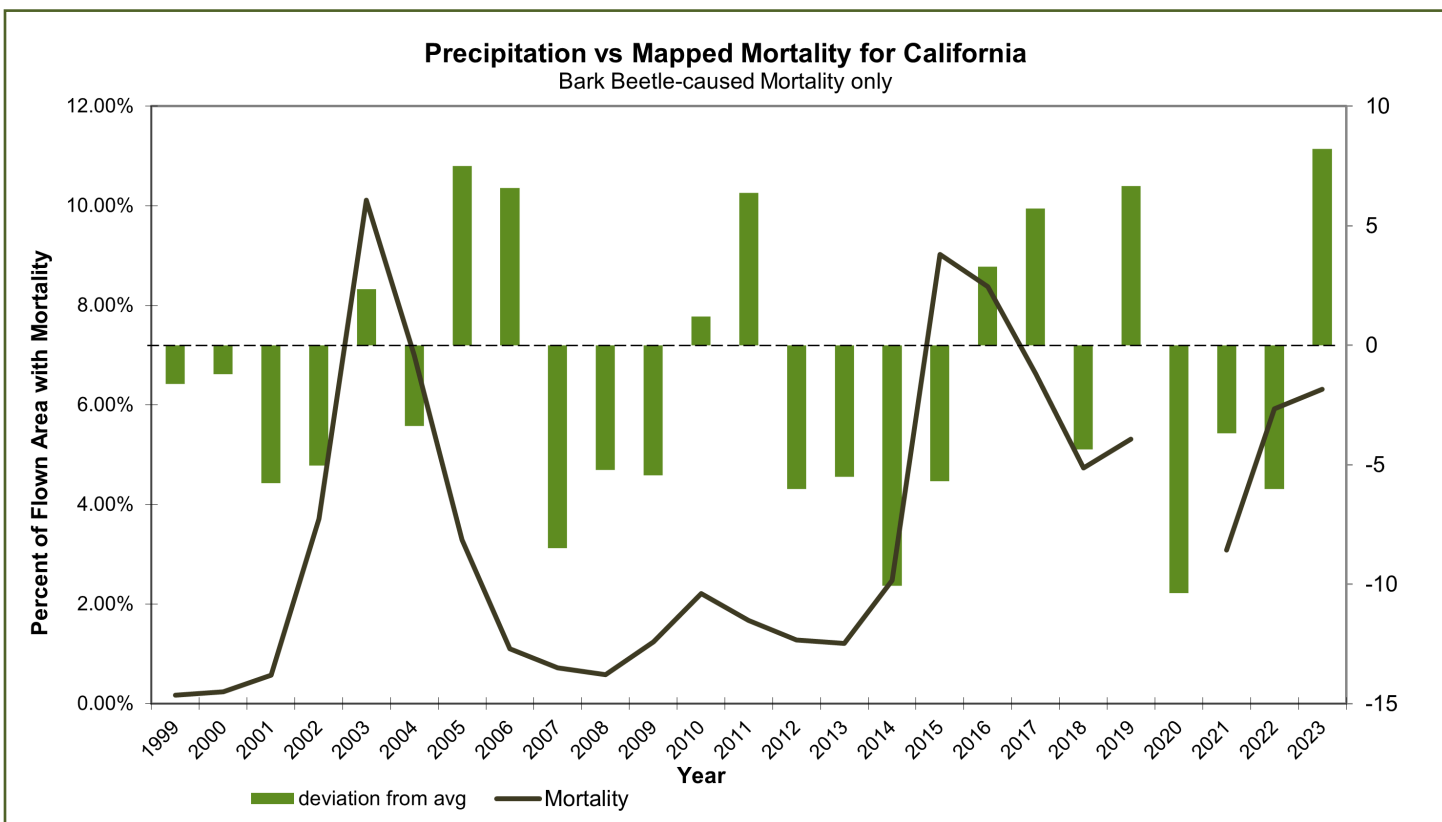

Figure 3. This chart shows the long-term trends in tree mortality and precipitation variability in California since 1999. There is a break in tree mortality data for 2020 because aerial survey was not flown that year due to COVID-19 restrictions.

U.S. Drought Monitor—California

2018 2019 2020 2021 2022 2023

Intensity

D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. For more information: DroughtMonitor.unl.edu/
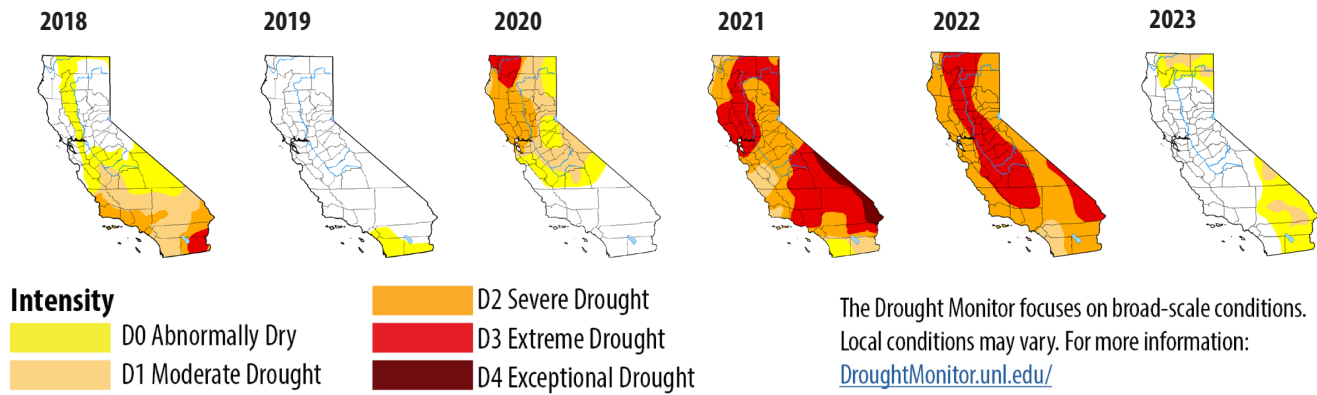
Figure 4. The U.S. Drought Monitor maps of 2018 through 2023 illustrate the severity, range, and ebb and flow of drought in California over the past six years. Maps are presented from the report date in April of each year. D1 is the least intense drought level and D4 the most intense; D0 areas are not in drought. A full description of each drought severity classification is available from the U.S. Drought Monitor. Source: U.S. Drought Monitor

Drought Conditions

The drought of 2011 to 2017 was concentrated in central California and most tree mortality occurred in the southern Sierra Nevada Range. In contrast, the 2020 - 2022 drought was concentrated in north central California and recent mortality has been most intense and widespread in the central Sierra Nevada Range and the northern interior of the state (primarily Siskiyou, Shasta, Trinity, Tehama and Glenn Counties). Unlike the first exceptional drought, where the early mass die-off occurred primarily in low elevation pine, mortality has primarily affected fir since 2018.

2020 - 2022 was the hottest, driest three-year period in California since at least 1895 (National Center for Environmental Information) and was primarily responsible for and closely correlated with the recent mass mortality conditions (Figure 4).

However, in what the California Department of Water Resources (CDWR) coined as a "weather whiplash", the 2022-2023 water year was well above average for all but the northern fringe of the State. Overall, California received 141% of its average precipitation in 2022 - 2023 and snowpack ranked among the highest on record, especially in the Southern Sierra Nevada Range where it approached 300% of normal. The 2022 – 2023 water year should greatly improve the overall health of forests statewide. Though much of the Region's forests have been weakened by chronic drought, bark beetle populations that are at outbreak levels, and other stressors, mortality levels should continue to decline.

Methodology

Recent tree mortality and damage was mapped on a mobile device by aerial observers flying in a small, fixed wing aircraft at ≈1000' above ground level (AGL). Aerial observers searched for visibly dried and discolored foliage, typically yellow to reddish brown. The following information was collected for each area with tree mortality or damage: a) damage type (mortality, top kill, defoliation, branch flagging, die back or discoloration), b) percent of area affected (see below for severity scale), c) affected tree species or genus and d) probable damage agent (root disease, bark beetles, etc.). Not all trees in reported acres are dead or damaged. Tree mortality and damage was recorded on a severity scale based on the percent of trees affected within a given area (Figure 5). Severity of mortality and damage was classified as follows:

Very Light (1-3% of mapped area affected), Light (4-10%), Moderate (11-29%), Severe (30-50%) and Very Severe (>50%).

Surveyors visually detect current tree damage such as defoliation via the red coloring of chewed, dried foliage and, most often, recent mortality by the red or yellow color of
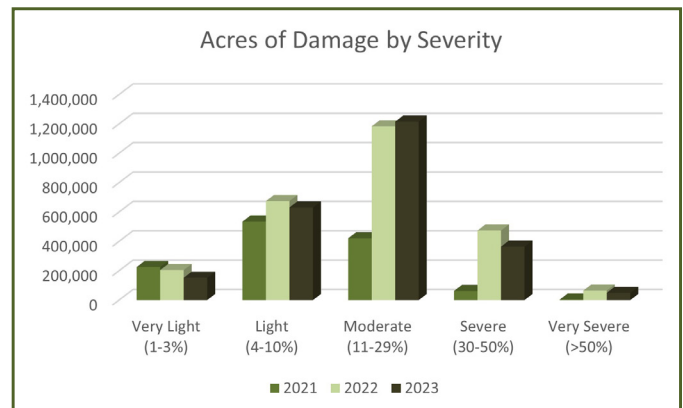

Figure 5. Chart compares the number of acres observed in each severity category from 2021 through 2023.

the foliage still mostly intact on the tree. When a tree dies, it typically appears green and healthy until dry hot conditions ensue. This is known as a "lag effect" and mortality recorded in 2023 likely occurred in 2022 when the drought was at its peak. Mortality is not recorded once foliage fades to gray or falls off the tree.

ADS is a systematic overview survey accomplished over 2-3 months in the summer, often in difficult mountainous terrain. Damage is sometimes missed.

Below we report the estimated number of acres affected, the severity of mortality or damage, and estimated number of trees affected within those areas (rounded as appropriate).

Acres of mortality or damage may be noted in more than one point as multiple damage types and/or species affected can occur in the same location.

State Highlights

In 2023, the number of trees killed, acreage with mortality, and average severity of that mortality all decreased compared to 2022 (Figure 5). Both years, however, were greatly elevated both in intensity and range compared to non-drought conditions. Tree mortality was common throughout the Sierra Nevada Range but was particularly concentrated in the central Sierra Nevada Range and northern interior where the recent drought was most intense. Additionally, fir mortality shifted to higher elevations and to more northern areas of the state (Figure 1).

Bark Beetles and Wood Borers

Fir mortality attributed to fir engraver beetle (*Scolytus ventralis*):
California/Shasta red fir (*A. magnifica*, *A. shastensis*), white fir (*A. concolor*), and grand fir (*A. grandis*) mortality attributed to fir engraver beetle was common throughout the region, often at moderate to severe intensities. This was the second largest tally ever recorded by ADS, surpassed only by 2022 estimates. Approximately 24.3 million recently killed trees across 1.9 million acres were recorded compared to ~28.1 million dead trees across 1.9 million acres in 2022. Both years, mortality was most severe and widespread throughout the central Sierra Nevada Range. Additionally, live trees with dead tops (top killed trees) were uncommon in 2023 unlike the two years prior. Fir engraver beetle often top or strip kills trees before successive generations kill them outright, so mortality should ameliorate.

- California and Shasta red fir mortality occurred at generally higher severities than other conifers. An estimated 18.3 million dead trees across 1.2 million acres were recorded, an increase from ~15 million dead trees across 890,000 acres in 2022. Mortality typically occurred in high-elevation mature monodominant stands.
- White fir mortality was widespread but generally light to moderate in severity and associated with dense mixed conifer stands. White fir mortality decreased to ~6 million dead trees across 750,000 acres in 2023 from ~13 million dead trees across 1.1 million acres in 2022.
- Grand fir mortality was light to moderate in severity, and decreased from ~8,400 dead trees across 2,000 acres in 2022 to ~1,100 dead trees across 220 acres in 2023 in northwestern portions of California.

Note: Red and white fir often occur together in mixed conifer mid-elevation stands and can be difficult to differentiate from the air.

Conifer mortality attributed to flatheaded fir borer (*Phaenops drummondi* prev. *Melanophila*):
Tree mortality attributed to flatheaded fir borer, while still elevated, decreased in all host species. The second highest level of tree mortality caused by this agent in California was recorded by ADS in 2023, second only to 2022.

- Douglas-fir mortality (not attributed to damage by bears in pole- sized plantations) caused by flatheaded fir borer in 2023 decreased substantially to an estimated 800,000 dead trees across 93,000 acres, compared to an estimated 3 million dead trees across 190,000 acres in 2022. Mortality was common throughout the northern interior but particularly severe and widespread in the greater Redding area. Additionally, there was a significant reduction of mortality in the Coast Range, especially in Lake County.
- Santa Lucia fir (*A. bracteata*) mortality occurred within the Monterey District of the Los Padres NF. Mortality decreased to an estimated 210 dead trees across 180 acres, compared to ~3,500 dead trees across 380 acres in 2022.
- Bigcone Douglas-fir (*P. macrocarpa*) mortality decreased from ~105 dead trees in 2022 to approximately 60 dead trees in 2023 and occurred as single trees or small groups within the Transverse and Peninsula Mountain Ranges.

Pine mortality attributed to western pine beetle (*Dendroctonus brevicomis*):
- Ponderosa pine mortality caused by western pine beetle remained elevated but decreased to ~2.9 million dead trees across 330,000 acres in 2023 from an estimated 3.5 million dead trees across 280,000 acres in 2022 and

occurred throughout its range. Mortality was most widespread in the northern interior, north and west of the greater Redding area (Shasta County), and was detected in large, high-severity pockets in the northern Sierra Nevada Range.

- Coulter pine (*P. coulteri*) mortality increased from ~330 trees across 110 acres in 2022 to ~410 trees across 1,200 acres in 2023. Mortality occurred in small pockets throughout the central Coast and southern California.

Pine mortality attributed to mountain pine beetle (*D. ponderosae*):

Mountain pine beetle-caused tree mortality remained elevated but decreased to an estimated 270,000 dead trees across 36,000 acres in 2023 compared to ~390,000 dead trees across 40,000 acres in 2022 and was most prevalent in far eastern CA and the southern Warner Mountains.

- Limber pine (*P. flexilis*) mortality increased from ~86,000 trees across 2,900 acres in 2022 to an estimated 98,000 trees across 4,300 acres in 2023. Mortality was concentrated east of the Chagoopa Plateau (or Kern Canyon) and in the White Mountains.
- Lodgepole pine (*P. contorta*) mortality increased from an estimated 65,000 trees across 13,000 acres in 2022 to ~95,000 trees across 17,000 acres in 2023. Mortality occurred along the Sierra Nevada and Klamath mountain ranges.
- Sugar pine (*P. lambertiana*) mortality decreased from ~20,000 trees across 800 acres in 2022 to an estimated 2,900 trees across 370 acres in 2023. Mortality was scattered throughout the state, excluding the Central Coast and Southern California.
- Western white pine (*P. monticola*) mortality decreased to approximately 4,400 trees across 1,200 acres in 2023 from ~5,200 trees across 1,200 acres in 2022. Mortality occurred primarily north of and around Lake Tahoe.
- Whitebark pine (*P. albicaulis*) mortality decreased to an estimated 71,000 trees across 13,000 acres in 2023 from ~220,000 trees across 22,000 acres in 2022. Mortality occurred throughout the range of whitebark pine in the eastern Sierra Nevada Range.

Jeffrey pine mortality:

Jeffrey pine (*P. jeffreyi*) mortality attributed to Jeffrey pine beetle (*D. jeffreyi*) decreased to ~170,000 dead trees across 27,000 acres in 2023 from an estimated 270,000 dead trees across 40,000 acres in 2022. Mortality occurred primarily in higher elevations of the Sierra Nevada Range.

Jeffrey pine mortality attributed to ips engraver beetles (*Ips* spp.) decreased to ~44,000 dead trees across 2,600 acres in 2023 from approximately 80,000 dead trees across 12,000 acres in 2022. Mortality was concentrated within the Mt. Pinos Ranger District on the Los Padres NF and, to a lesser degree, west of Grasshopper Valley bordering both Modoc and Lassen NFs.

Pinyon pine mortality:

Pinyon pine (*P. monophyla*) attributed to Ips spp. decreased to an estimated 77,000 dead trees across 5,700 acres in 2023 from ~220,000 dead trees across 16,000 acres in 2022. Mortality was concentrated primarily in the White Mountains and in the Mt. Pinos Ranger District of the Los Padres NF.

Knobcone pine mortality:

Knobcone pine (*P. attenuata*) mortality attributed to California flatheaded borer (*Melanophila californica*) decreased to an estimated 4,400 dead trees across 840 acres in 2023 from ~8,200 dead trees across 960 acres in 2022 and occurred primarily within the Klamath NF.

Knobcone pine mortality attributed to *Ips* spp. was not reported prior to 2022, however an estimated at 250,000 dead trees across 9,000 acres in 2022. Subsequent field observations along the northern coast and north interior indicate this is the primary causal agent in these areas. In 2023, knobcone pine mortality attributed to *Ips* spp. decreased to an estimated 5,500 dead trees across ~930 acres.

Gray pine mortality:

Gray pine (*P. sabiniana*) mortality decreased substantially to an estimated 790 dead trees across 58 acres in 2023 from ~2,300 dead trees across 250 acres in 2022. The causal agent for gray pine mortality is not well understood and therefore assigned to an unknown agent or drought.

Oak mortality:
Goldspotted oak borer (*Agrilus auroguttatus*)-caused oak (*Quercus* spp.) mortality decreased to approximately 4,300 dead trees across 1,400 acres in 2023 from ~8,000 dead trees across 1,600 acres in 2022. Most mortality detected via aerial surveys occurred in and near the Palomar Ranger District Cleveland NF.

Mortality Due to Diseases
Tanoak (*Notholithocarpus densiflorus*) mortality attributed to sudden oak death (SOD) (*Phytophthora ramorum*) decreased to ~2,300 dead trees across 620 acres in 2023 from an estimated 36,000 dead trees across 7,300 acres in 2022. The spread and impact of SOD is diminished in times of drought (Figure 6).

Figure 6. Chart compares the acres with oak mortality caused by various damage causing agents between 2021 and 2023.

Monterey pine (*P. radiata*) mortality decreased to an estimated 1,200 dead trees across 32 acres in 2023 from ~1,700 dead trees across 95 acres in 2022. Mortality that occurred in the Half Moon Bay area was attributed to pitch canker but was likely caused by other diseases interacting with drought.

Damage Other than Mortality
White fir defoliation caused by Douglas-fir tussock moth (*Orgyia pseudotsugata*) increased from ~800 acres in 2022 to approximately 9,600 acres in 2023 and was observed southwest of Quincy on the Plumas NF.

Defoliation of lodgepole pine by lodgepole needleminer (*Coleotechnites milleri*) was recorded on ~9,700 acres within Yosemite NP and Inyo NF.

Defoliation of Sitka spruce (*Picea sitchensis*) attributed to a complex of pathogens was recorded on approximately 1,700 acres in 2023 in several areas along the north coast. Click here for more details.

Defoliation of true fir attributed to balsam wooly adelgid (*Adelges piceae*) was documented on ~1,300 acres along the northern border, mostly on the Rogue River NF.

Defoliation of quaking aspen (*Populus tremuloides*) was observed across more than 1,200 acres and attributed to several damage causing agents: Defoliation attributed to *Cytospora* spp. was detected across ~460 acres located north of Mono Lake (Mono County), ~630 acres of satin moth (*Leucoma salicis*) defoliation located in the southern Warner Mountains (Lassen County), and ~110 acres of defoliation attributed to frost damage was observed in the Bodie Hills area near the Nevada State line (Mono County).

Approximately 1,200 acres of ponderosa pine defoliation were detected east of Garberville along the Humboldt-Trinity County line in the north coast. Similarly in 2022, approximately 1,200 acres were recorded and attributed to Dothistroma needle blight (*Dothistroma septosporum*).

Defoliation of pinyon pine by pinyon needle scale (*Matsucoccus acalyptus*) was recorded on approximately 1,100 acres in the central White Mountains (Mono and Inyo Counties).
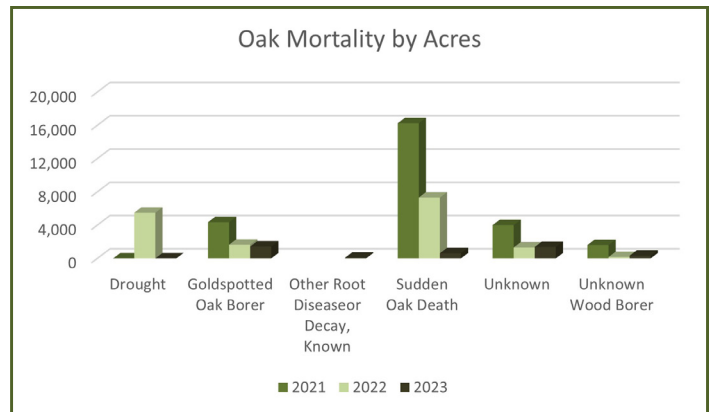
Forest Highlights

Note: Tables for each National Forest show trends of conifer mortality during the past five years, both in estimated trees killed and area affected. Broadleaved trees especially tanoak and other oaks are not included. Note that 2020 is omitted since surveys were not flown that year due to Covid-19 concerns.
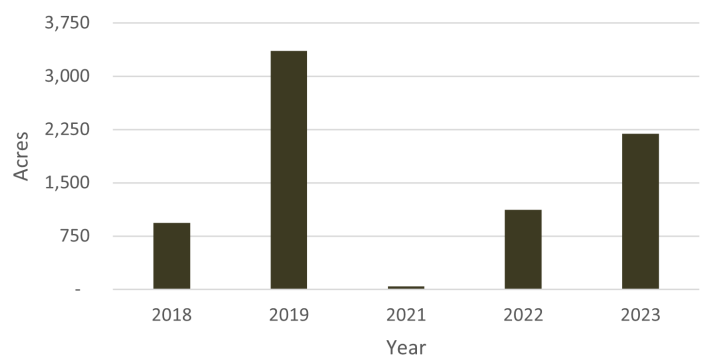
Angeles

Tree mortality increased to ~12,000 dead trees across 2,200 acres in 2023 from an estimated 10,000 dead trees across 1,100 acres in 2022.

- White fir mortality increased to an estimated 10,000 dead trees across 1,600 acres in 2023 from ~8,800 dead trees across 930 acres in 2022. Several areas of moderate severity were recorded in northeastern areas of the Forest.
- Jeffrey pine mortality increased to an estimated 1,300 dead trees over 560 acres in 2023 from ~810 dead trees across 170 acres in 2022, most notably in Cooper Canyon (Los Angeles County).
- An area of severe pine defoliation was detected in the Upper Big Tujunga Canyon area (Los Angeles County)

Dead Conifers 2018-2023: Angeles NF
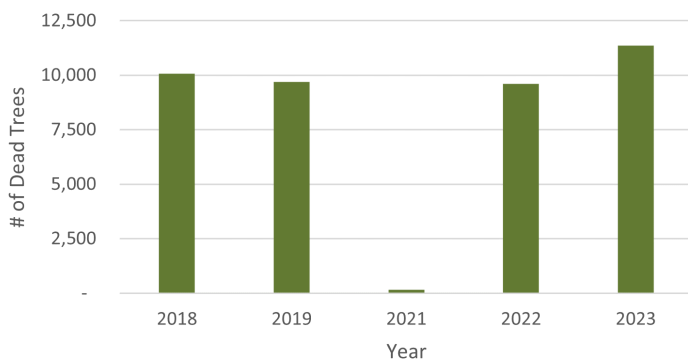
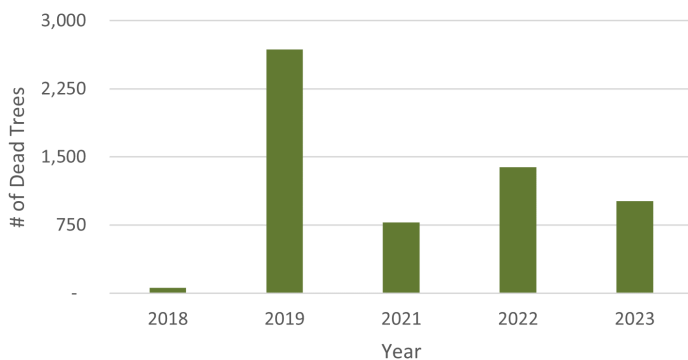Acres with Conifer Mortality 2018-2023: Angeles NF

Cleveland

Tree mortality decreased to ~5,000 dead trees across 1,500 acres in 2023 from an estimated 8,000 dead trees across 1,500 acres in 2022. Mortality was particularly severe in areas near Palomar Mountain (San Diego County).

- Detected oak mortality attributed to goldspotted oak borer decreased to ~3,900 dead trees across 1,400 acres in 2023 from ~6,400 trees across 1,400 acres in 2022.
- Areas of moderate white fir mortality were detected in the Mendenhall Valley (San Diego County).

Dead Conifers 2018-2023: Cleveland NF

Acres with Conifer Mortality 2018-2023: Cleveland NF
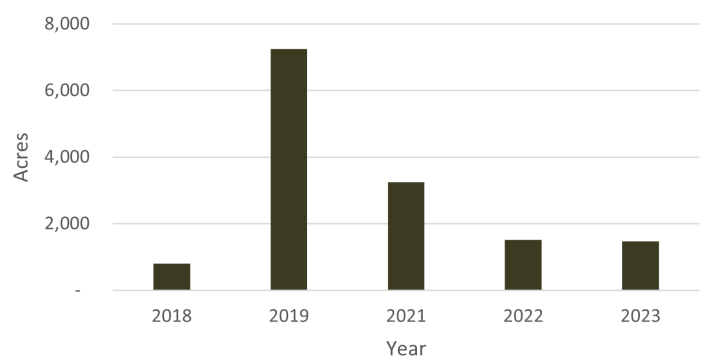
Eldorado

Mortality increased to an estimated 2.2 million dead trees across 150,000 acres in 2023 from ~1.3 million dead trees across 91,000 acres in 2022. Mortality was widespread throughout much of the Forest and was particularly severe at higher elevations.
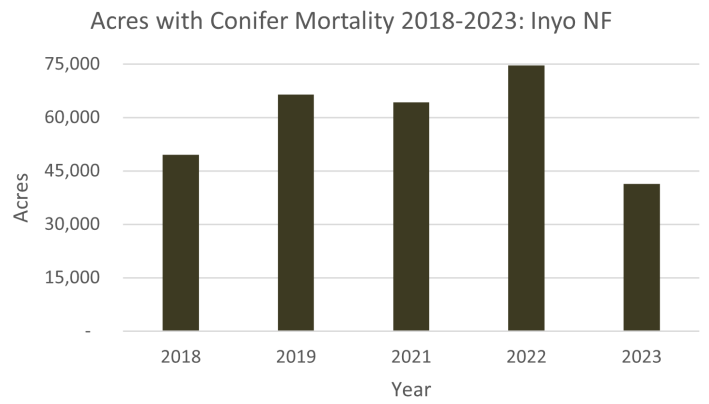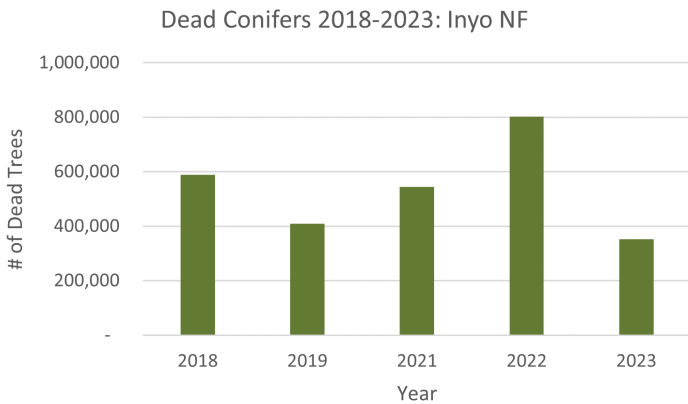
- California red fir mortality increased to an estimated 2.1 million dead trees across 120,000 acres in 2023 from ~1 million dead trees across 66,000 acres in 2022 and was located primarily in the Pacific Ranger District.
- White fir mortality decreased to approximately 66,000 dead trees but increased in spread over 23,000 acres in 2023 from ~180,000 dead trees across 20,000 acres in 2022.
- Ponderosa pine mortality decreased to an estimated 24,000 dead trees across 2,900 acres in 2023 from ~42,000 dead trees across 3,000 acres in 2022.

Dead Conifers 2018-2023: Eldorado NF

Acres with Conifer Mortality 2018-2023: Eldorado NF
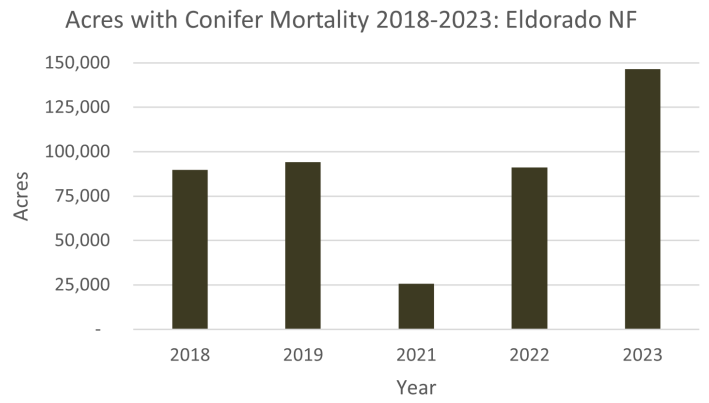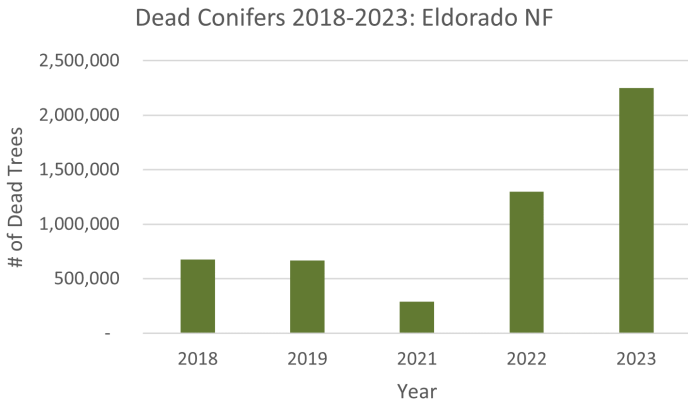
Inyo

Mortality decreased to an estimated 350,000 dead trees over 41,000 acres in 2023 from ~820,000 dead trees across 76,000 acres in 2022.

- California red fir mortality attributed to fir engraver beetle decreased to approximately 100,000 dead trees across 17,000 acres in 2023 compared to ~300,000 trees across 35,000 acres in 2022.
- Pinyon pine mortality decreased to an estimated 78,000 dead trees across 5,000 acres in 2023 from ~200,000 dead trees across 13,000 acres in 2022.
- Approximately 1,800 acres of severe pine defoliation attributed to lodgepole needleminer were detected in Yosemite NP and Inyo NF Tuolumne and Inyo Counties.

Dead Conifers 2018-2023: Inyo NF

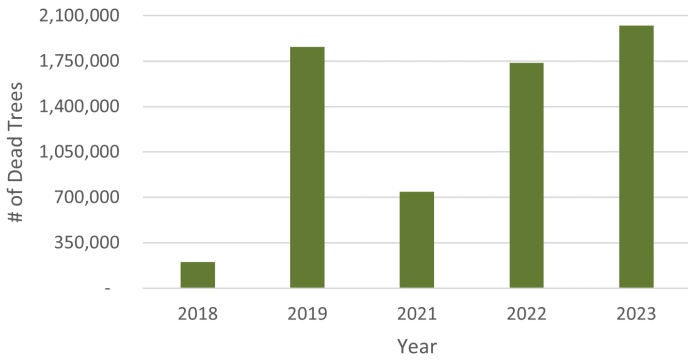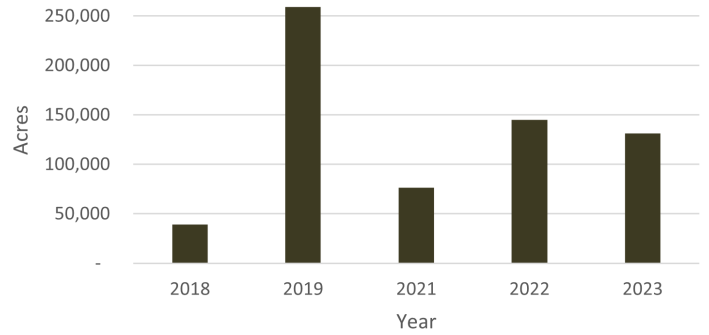Acres with Conifer Mortality 2018-2023: Inyo NF

Klamath

Mortality increased to an estimated 2 million dead trees but decreased in spread across 132,000 acres in 2023 from ~1.8 million trees across 150,000 acres in 2022. Widespread mortality was light to moderate in intensity, especially in northern areas. Mortality was particularly severe in western areas of the Goose Nest Ranger District.

- Shasta red fir mortality increased to approximately 990,000 dead trees across 51,000 acres in 2023 from ~340,000 dead trees across 21,000 acres in 2022.
- White fir mortality decreased to approximately 770,000 dead trees across 56,000 acres in 2023 from ~1.3 million dead trees across 96,000 acres in 2022.

Dead Conifers 2018-2023: Klamath NF

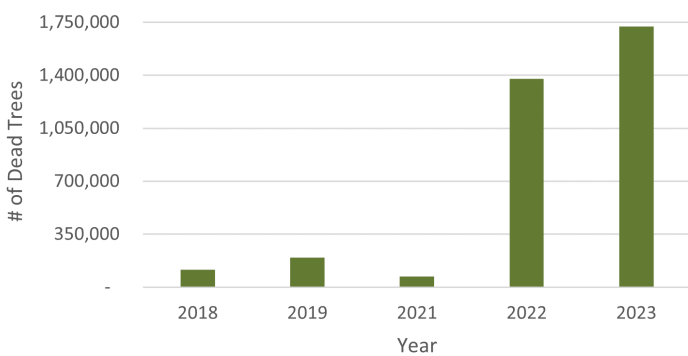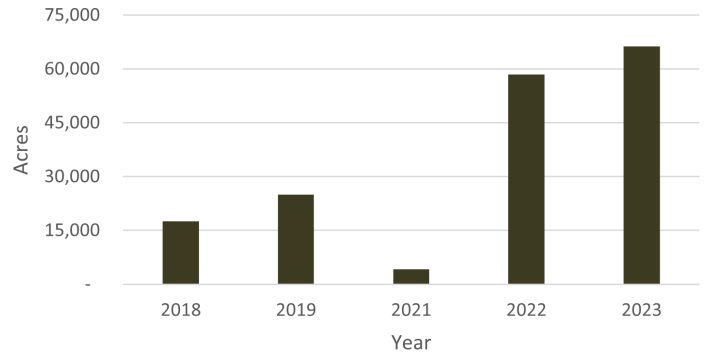Acres with Conifer Mortality 2018-2023: Klamath NF

Lake Tahoe Basin

Mortality increased to an estimated 1.7 million dead trees across 66,000 acres in 2023 from ~1.4 million dead trees across 58,000 acres in 2022. Although mortality was widespread in eastern and northern areas it was most intense west of Lake Tahoe.

- California red fir mortality increased to approximately 1.6 million dead trees across 63,000 acres in 2023 from ~1.3 million dead trees across 54,000 acres in 2022.
- In 2023, white fir mortality decreased to 6 dead trees from an estimated 14,000 dead trees across 1,500 acres in 2022.

Dead Conifers 2018-2023: Lake Tahoe Basin

Acres with Conifer Mortality 2018-2023: Lake Tahoe Basin

Lassen

Mortality increased to an estimated 1.7 million dead trees across 200,000 acres in 2023 from ~2 million dead trees across 170,000 acres in 2022. Mortality was generally more widespread in western areas and on the Eagle Lake Ranger District.
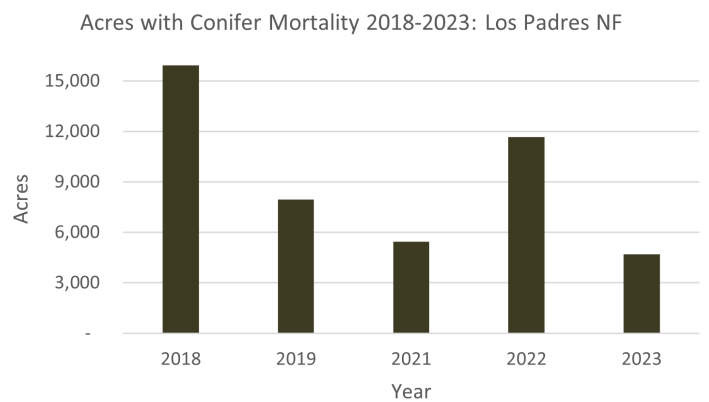
- White fir mortality decreased to approximately 760,000 dead trees across 30,000 acres in 2023 from ~1.3 million dead trees across 120,000 acres in 2022.
- California red fir mortality increased to approximately 720,000 dead trees across 67,000 acres in 2023 from ~310,000 dead trees across 28,000 acres in 2022.

Dead Conifers 2018-2023: Lassen NF

Acres with Conifer Mortality 2018-2023: Lassen NF
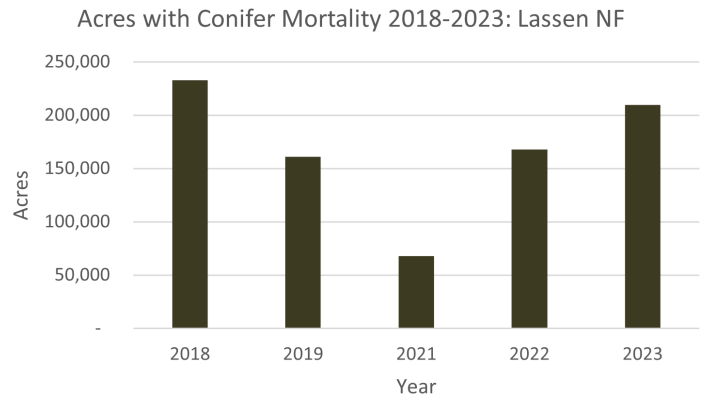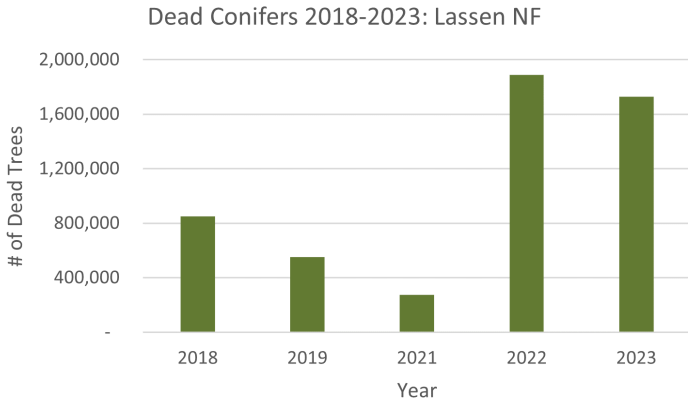
Los Padres

Mortality decreased to an estimated 37,000 dead trees across 4,700 acres in 2023 from ~60,000 dead trees across 12,000 acres in 2022. Most of the mortality occurred in northern areas of the Forest and Ventura and Kern Counties.

- Jeffrey pine mortality decreased to approximately 23,000 dead trees across 1,900 acres in 2023 from ~44,000 dead trees across 8,600 acres in 2022.
- Pinyon pine mortality decreased to approximately 1,900 dead trees across 11,000 acres in 2023 from ~4,900 dead trees across 1,400 acres in 2022.

Dead Conifers 2018-2023: Los Padres NF

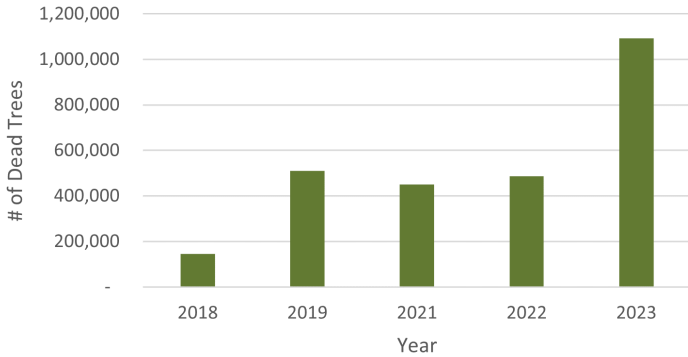Acres with Conifer Mortality 2018-2023: Los Padres NF

Mendocino

Mortality increased to 1.1 million dead trees across 130,000 acres in 2023 from ~490,000 dead trees across 40,000 acres in 2022. Mortality was more severe and widespread in eastern and northern areas of the Forest.

- White fir mortality increased to approximately 260,000 dead trees across 36,000 acres in 2023 from ~220,000 dead trees across 21,000 acres in 2022.
- Ponderosa pine mortality increased to approximately 650,000 dead trees across 72,000 acres in 2023 from ~160,000 dead trees across 12,000 acres in 2022.

Dead Conifers 2018-2023: Mendocino NF

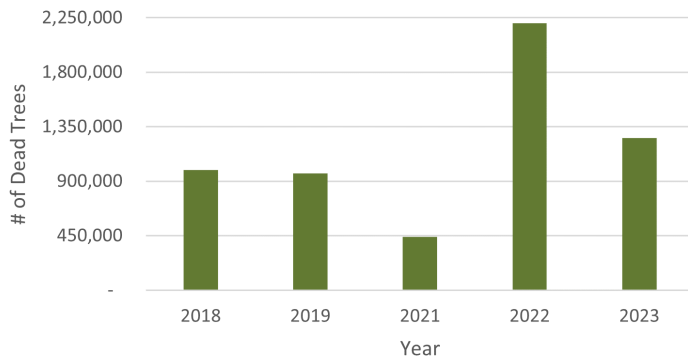Acres with Conifer Mortality 2018-2023: Mendocino NF
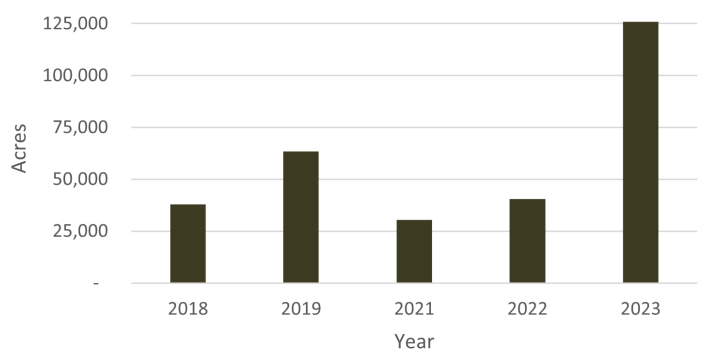
Modoc

Mortality decreased to an estimated 1.3 million dead trees across 140,000 acres in 2023 from ~2.2 million dead trees across 180,000 acres in 2022 and was widespread at light to moderate intensities in the Black and Manzanita Mountain areas. However, there was moderate to severe mortality throughout much of the Warner Mountains.

- White fir mortality decreased to approximately 940,000 dead trees across 96,000 acres in 2023 from ~1.8 million dead trees across 130,000 acres in 2022.
- Ponderosa pine mortality decreased to approximately 100,000 dead trees across 24,000 acres in 2023 from ~260,000 dead trees across 40,000 acres in 2022.

Dead Conifers 2018-2023: Modoc NF

Acres with Conifer Mortality 2018-2023: Modoc NF
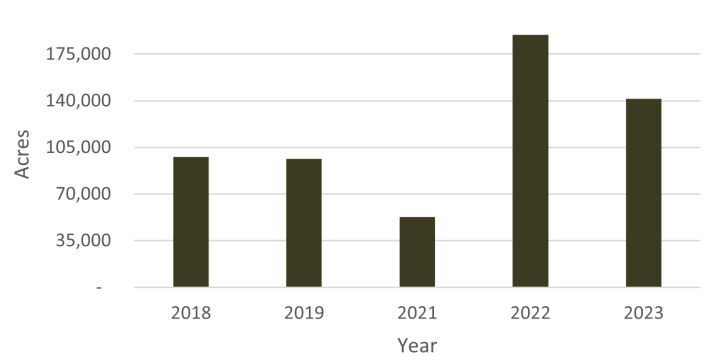
Plumas

Mortality increased to an estimated 1.6 million dead trees across 130,000 acres in 2023 from ~1.5 million dead trees across 110,000 acres in 2022. Mortality was most widespread and intense in southern areas of the Forest.
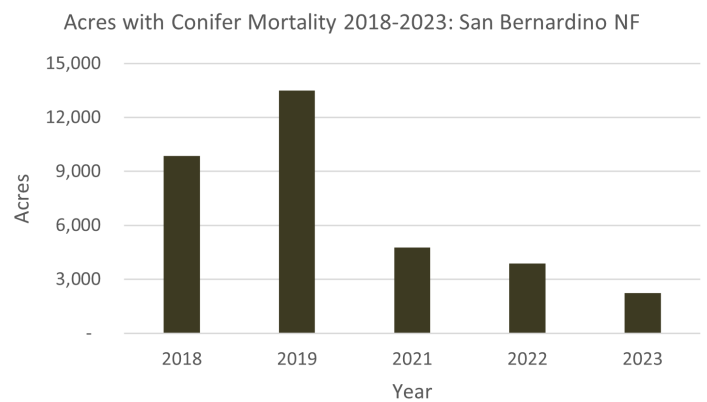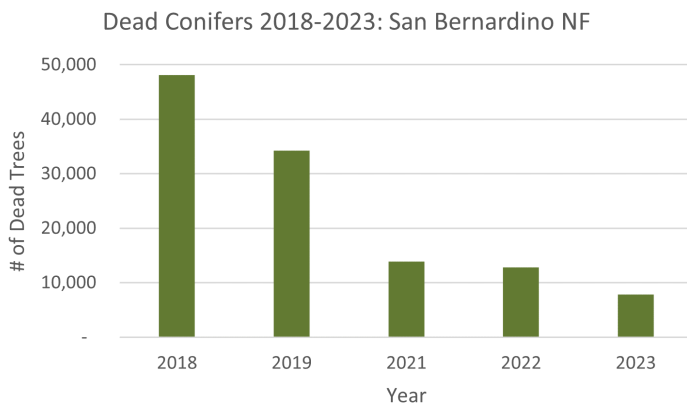
- White fir mortality decreased to approximately 370,000 dead trees across 53,000 acres in 2023 from ~870,000 dead trees across 81,000 acres in 2022.
- California red fir mortality increased to approximately 1.1 million dead trees across 70,000 acres in 2023 from ~620,000 dead trees across 24,000 acres in 2022.

Dead Conifers 2018-2023: Plumas NF

Acres with Conifer Mortality 2018-2023: Plumas NF
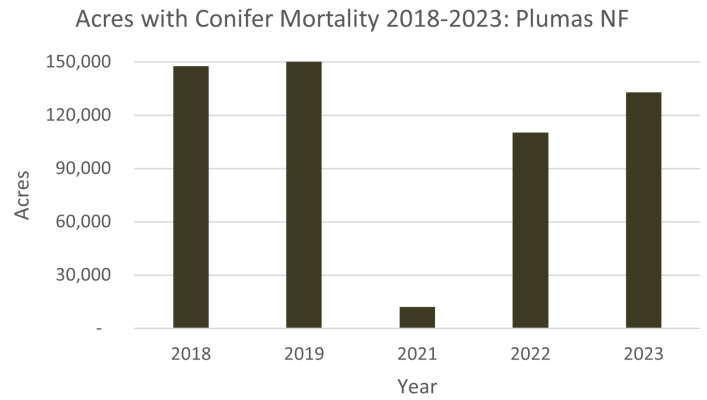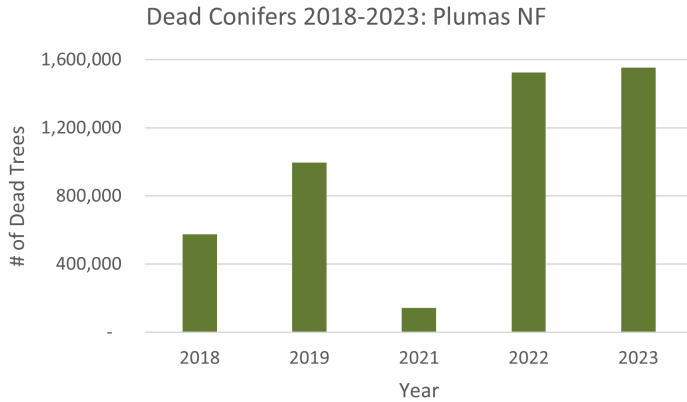
San Bernardino

Mortality decreased to an estimated 8,400 dead trees across 2,200 acres in 2023 from ~13,000 dead trees across 3,900 acres in 2022. Mortality was typically light in severity however notable areas of moderate intensity were recorded in the Valley of Enchantment and south of Big Bear Lake.

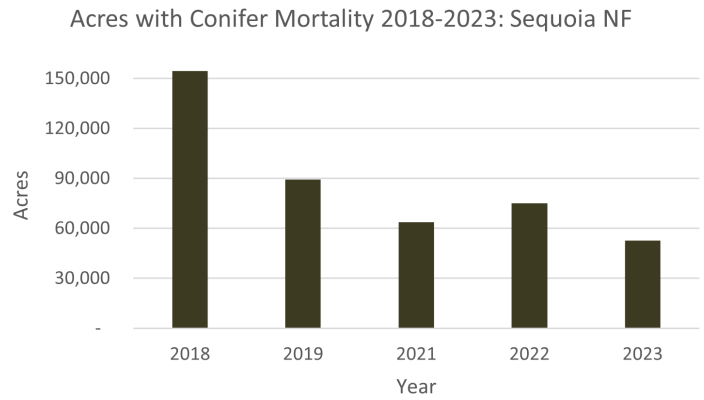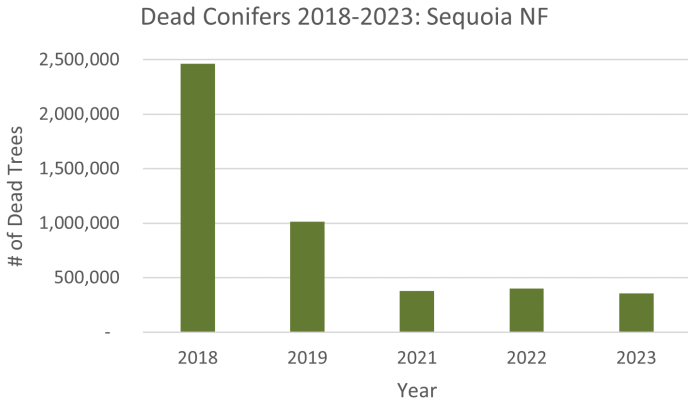- White fir mortality decreased from approximately 5,300 dead trees across 1,100 acres in 2023 from ~6,900 dead trees across 1,300 acres in 2022.
- Jeffrey pine mortality decreased to approximately 1,200 dead trees across 430 acres in 2023 from ~5,300 dead trees across 1,900 acres in 2022.

Dead Conifers 2018-2023: San Bernardino NF

Acres with Conifer Mortality 2018-2023: San Bernardino NF

Sequoia

Mortality decreased from an estimated 360,000 dead trees across 53,000 acres in 2023 from ~410,000 dead trees across 75,000 acres in 2022. Most of the mortality was light in severity, however very severe mortality was detected around Slate Mountain Tulare County.
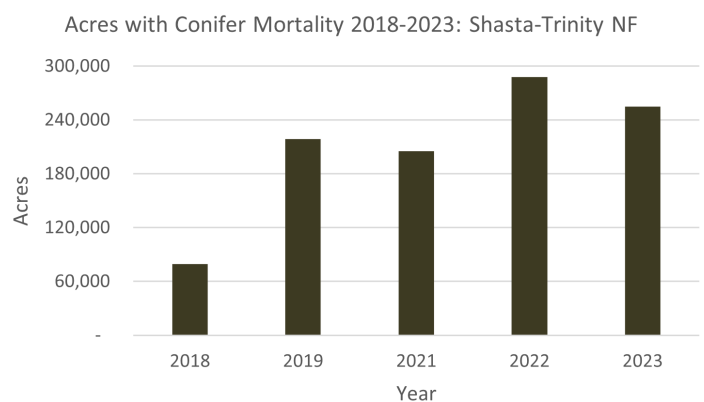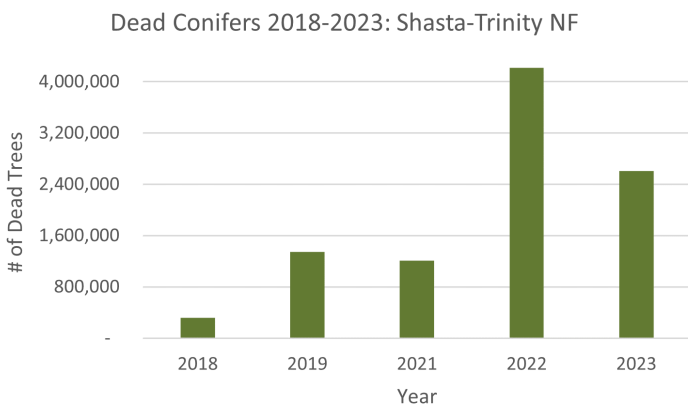
- California red fir mortality decreased to approximately 140,000 dead trees across 27,000 acres in 2023 from ~200,000 dead trees across 35,000 acres in 2022.
- White fir mortality increased to approximately 130,000 dead trees across 11,000 acres in 2023 from ~110,000 dead trees across 19,000 acres in 2022.

Dead Conifers 2018-2023: Sequoia NF

Acres with Conifer Mortality 2018-2023: Sequoia NF

Shasta-Trinity

Mortality decreased to an estimated 2.6 million dead trees across 260,000 acres in 2023 from ~4.3 million dead trees across 290,000 acres in 2022. Mortality was more extensive and severe in northeastern areas of the Forest.

- White fir mortality increased from approximately 400,000 dead trees across 80,000 acres in 2022 to ~570 dead trees across 89,000 acres in 2023.
- Ponderosa pine mortality decreased to approximately 360,000 dead trees but increased in spread across 57,000 acres in 2023 from ~570,000 dead trees across 49,000 acres in 2022.

Dead Conifers 2018-2023: Shasta-Trinity NF

Acres with Conifer Mortality 2018-2023: Shasta-Trinity NF

Sierra

Mortality decreased to an estimated 970,000 dead trees across 110,000 acres in 2023 from ~1.7 million dead trees across 180,000 acres in 2022 and was mixed severity from light to severe.

- California red fir mortality decreased to approximately 850,000 dead trees across 92,000 acres in 2023 from ~1.5 million dead trees across 150,000 acres in 2022.
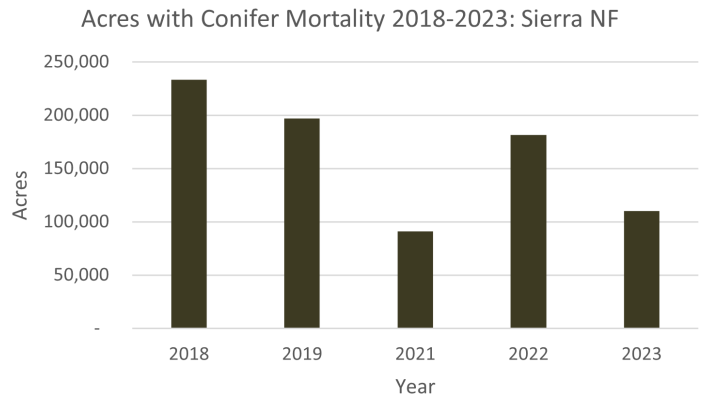- White fir mortality decreased to approximately 31,000 dead trees across 8,100 acres in 2023 from ~130,000 dead trees across 26,000 acres in 2022.

Dead Conifers 2018-2023: Sierra NF

Acres with Conifer Mortality 2018-2023: Sierra NF

Six Rivers

Mortality decreased to an estimated 67,000 dead trees across 11,000 acres in 2023 from ~150,000 dead trees across 24,000 acres in 2022. Mortality was common at light to moderate severities in southern areas of the Forest.
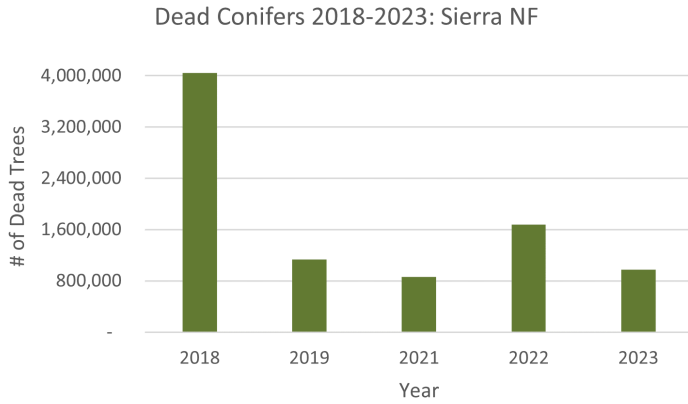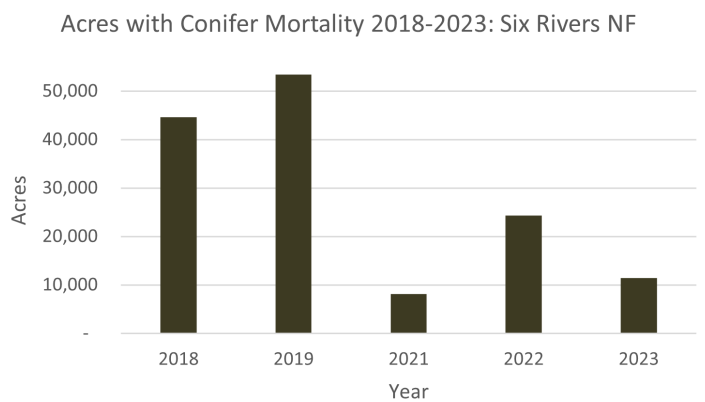
- White fir mortality decreased to approximately 19,000 dead trees across 4,000 acres in 2023 from ~100,000 dead trees across 16,000 acres in 2022.
- Ponderosa pine mortality increased to approximately 33,000 dead trees across 5,000 acres in 2023 from ~7,000 dead trees across 2,200 acres in 2022.
- Douglas fir mortality decreased to ~10,000 dead trees across 1,600 acres in 2023 to approximately 18,000 trees across 2,900 acres in 2022.

Dead Conifers 2018-2023: Six Rivers NF

Acres with Conifer Mortality 2018-2023: Six Rivers NF

Stanislaus

Mortality decreased to an estimated 1.6 million dead trees across 150,000 acres in 2023 from ~2.6 million dead trees across 140,000 acres in 2022. Mortality was most widespread and severe from central to northern regions of the Forest.

- California red fir mortality decreased to approximately 1.2 million dead trees but increased in area across 110,000 acres in 2023 from ~2.1 million dead trees across 93,000 acres in 2022.
- White fir mortality decreased to approximately 300,000 dead trees across 39,000 acres in 2023 from ~390,000 dead trees across 43,000 acres in 2022.

Dead Conifers 2018-2023: Stanislaus NF

Acres with Conifer Mortality 2018-2023: Stanislaus NF

Tahoe

Mortality increased to an estimated 6.5 million dead trees across 330,000 acres in 2023 from ~5 million dead trees across 260,000 acres in 2022. Mortality occurred at moderate to severe levels over many areas, particularly along central, high-elevation areas of the Forest.
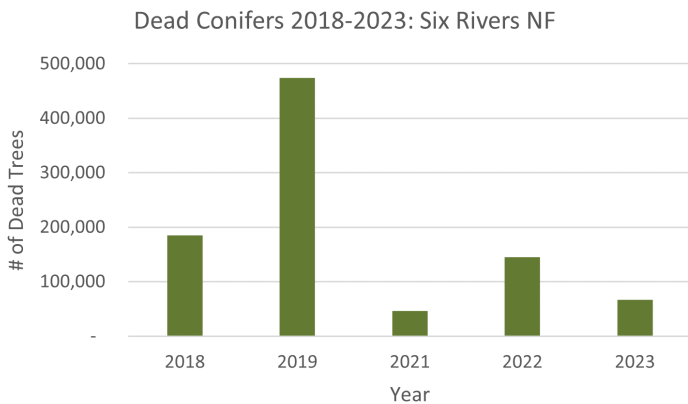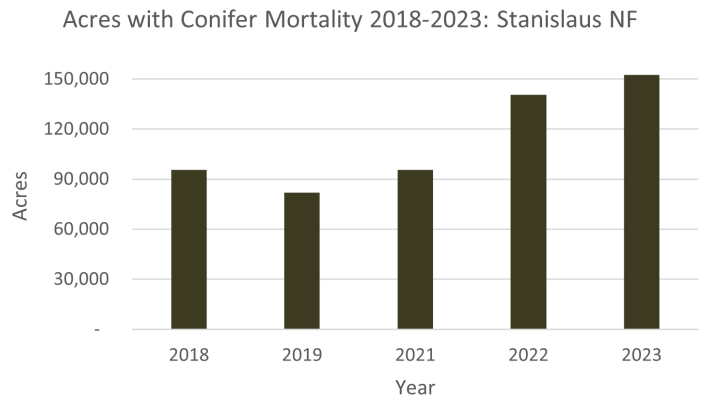
- California red fir mortality increased to approximately 6 million dead trees across 290,000 acres in 2023 from ~3.8 million dead trees across 170,000 acres in 2022.
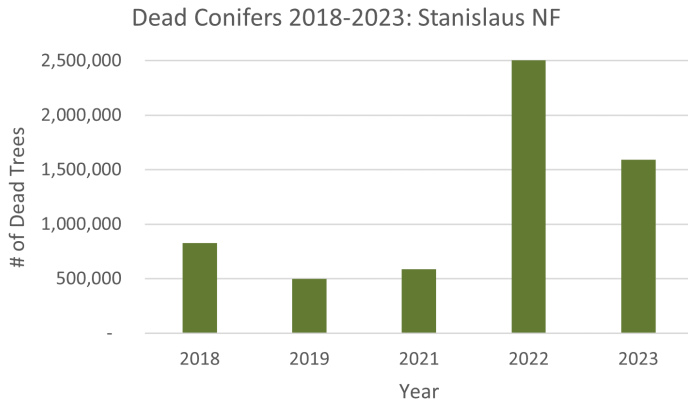- White fir mortality decreased to approximately 160,000 dead trees across 22,000 acres in 2023 from ~890,000 dead trees across 74,000 acres in 2022.

Dead Conifers 2018-2023: Tahoe NF

Acres with Conifer Mortality 2018-2023: Tahoe NF
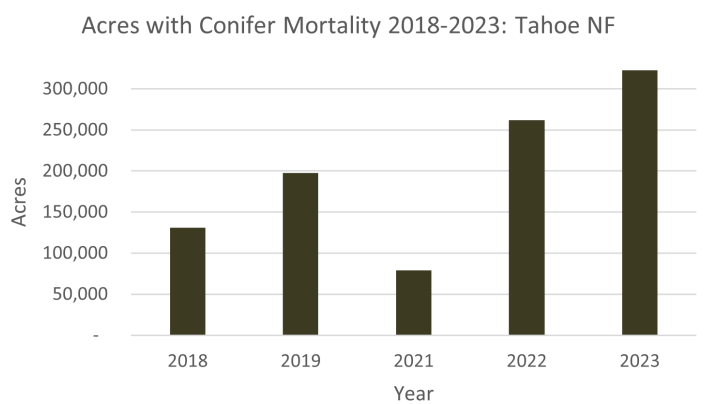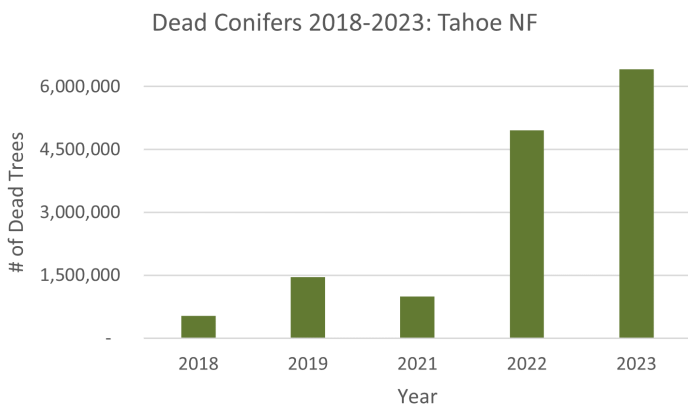
Acres with Mortality and Estimated Number of Dead Trees by Forest (2023)

National Forest	Acres	Dead Trees
Angeles National Forest	2,200	12,000
Cleveland National Forest	1,500	4,900
Eldorado National Forest	150,000	2,200,000
Humboldt-Toiyabe National Forest	47,000	540,000
Inyo National Forest	41,000	350,000
Klamath National Forest	130,000	2,000,000
Lake Tahoe Basin Management Unit	66,000	1,700,000
Lassen National Forest	200,000	1,700,000
Los Padres National Forest	4,700	37,000
Mendocino National Forest	130,000	1,100,000
Modoc National Forest	140,000	1,300,000
Plumas National Forest	130,000	1,600,000
Rogue River-Siskiyou National Forests	24,000	260,000
San Bernardino National Forest	2,200	8,400
Sequoia National Forest	53,000	360,000
Shasta-Trinity National Forest	260,000	2,600,000
Sierra National Forest	110,000	970,000
Six Rivers National Forest	11,000	67,000
Stanislaus National Forest	150,000	1,600,000
Tahoe National Forest	330,000	6,500,000

The numbers of acres and trees throughout this report have been rounded as appropriate.

* Includes acreages outside of California, but within the National Forest boundary.

Acres with Mortality and Estimated Number of Dead Trees by County (2023)

County	Acres	Dead Trees
Alameda	1	3
Alpine	83,000	930,000
Amador	33,000	520,000
Butte	34,000	130,000
Calaveras	23,000	420,000
Colusa	1,700	7,800
Contra Costa	1	11
Del Norte	2,800	9,300
El Dorado	130,000	2,200,000
Fresno	99,000	820,000
Glenn	31,000	250,000
Humboldt	5,000	14,000
Inyo	7,000	160,000
Kern	21,000	130,000
Lake	13,000	79,000
Lassen	110,000	820,000
Los Angeles	1,900	9,400
Madera	45,000	360,000

County	Acres	Dead Trees
Marin	1	23
Mariposa	34,000	340,000
Mendocino	43,000	390,000
Modoc	110,000	960,000
Mono	30,000	180,000
Monterey	740	2,200
Napa	330	880
Nevada	91,000	1,500,000
Orange	27	290
Placer	140,000	3,300,000
Plumas	110,000	1,200,000
Riverside	27	520
San Benito	1	6
San Bernardino	2,500	11,000
San Diego	1,500	5,000
San Joaquin	1	2
San Luis Obispo	230	5,800
San Mateo	560	24,000
Santa Barbara	25	220
Santa Clara	47	81
Santa Cruz	170	530
Shasta	190,000	1,500,000
Sierra	170,000	3,200,000
Siskiyou	400,000	5,600,000
Solano	1	9
Sonoma	390	1,400
Stanislaus	1	18
Tehama	120,000	1,100,000
Trinity	140,000	860,000
Tulare	84,000	800,000
Tuolumne	120,000	890,000
Ventura	1,700	11,000
Yolo	1	24
Yuba	3,200	34,000

The numbers of acres and trees throughout this report have been rounded as appropriate.
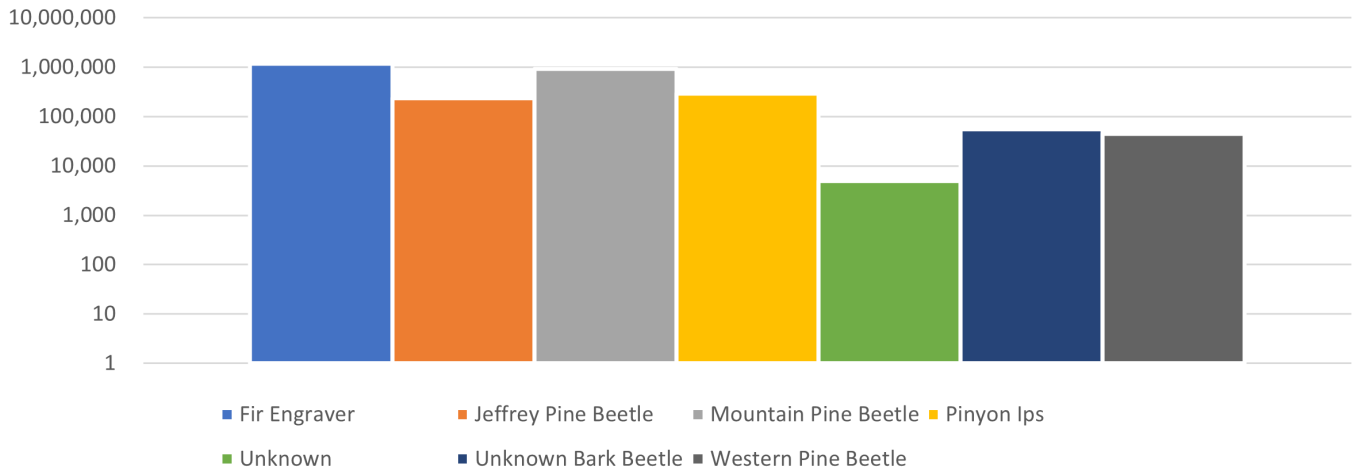
Citatation

Williams, A.P., Cook, B.I. & Smerdon, J.E. Rapid intensification of the emerging southwestern North American mega-drought in 2020–2021. *Nat. Clim. Chang*. 12, 232–234 (2022). https://doi.org/10.1038/s41558-022-01290-z

Appendix A: Conifers killed by Damage Causing Agents between 2018 -2023

Trees Killed by Damage Causing Agent, 2018-2023: Angeles NF

Legend: Fir Engraver | Flatheaded Fir Borer | Jeffrey Pine Beetle | Western Pine Beetle

Trees Killed by Damage Causing Agent, 2018-2023: Cleveland NF

Legend: Fir Engraver | Ips Engraver Beetles | Jeffrey Pine Beetle

Trees Killed by Damage Causing Agent, 2018-2023: Eldorado NF

Legend: California Flatheaded Borer | Fir Engraver | Flatheaded Fir Borer | Jeffrey Pine Beetle | Mountain Pine Beetle | Unknown | Western Pine Beetle

Trees Killed by Damage Causing Agent, 2018-2023, 2018-2023: Inyo NF

Legend:
- Fir Engraver
- Jeffrey Pine Beetle
- Mountain Pine Beetle
- Pinyon Ips
- Unknown
- Unknown Bark Beetle
- Western Pine Beetle

Trees Killed by Damage Causing Agent, 2018-2023: Klamath NF
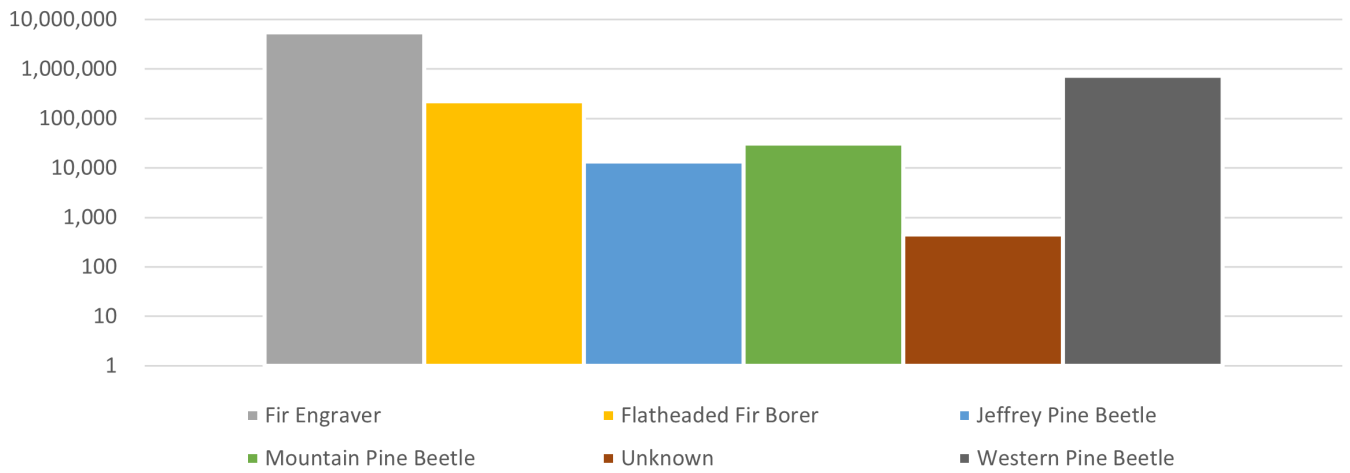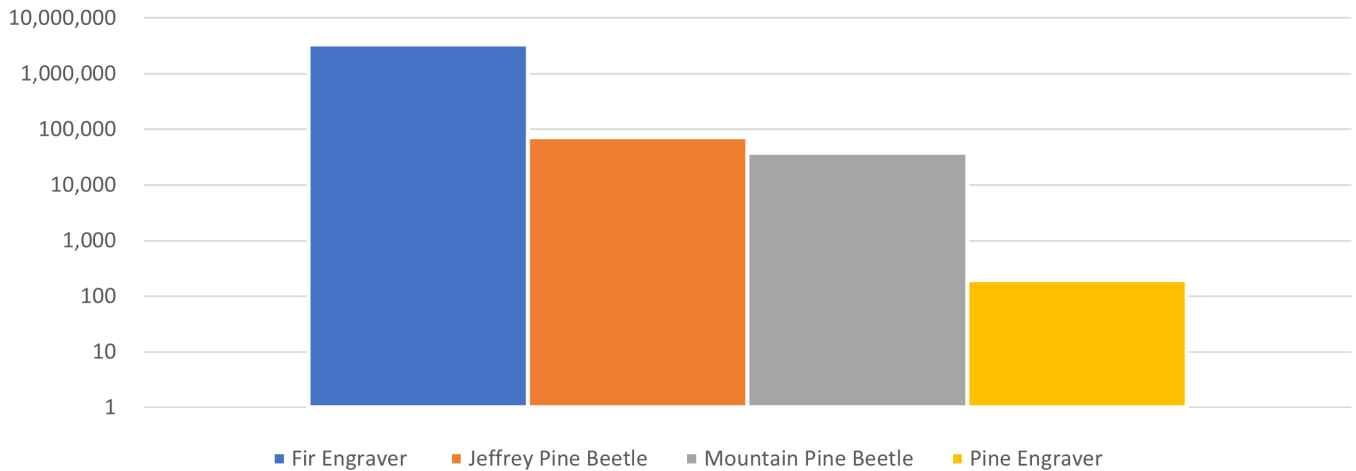
Legend:
- Fir Engraver
- Flatheaded Fir Borer
- Jeffrey Pine Beetle
- Mountain Pine Beetle
- Unknown
- Western Pine Beetle

Trees Killed by Damage Causing Agent, 2018-2023: Lake Tahoe Basin

Legend:
- Fir Engraver
- Jeffrey Pine Beetle
- Mountain Pine Beetle
- Pine Engraver

Trees Killed by Damage Causing Agent, 2018-2023: Lassen NF

Legend: California Flatheaded Borer, Fir Engraver, Flatheaded Fir Borer, Ips Engraver Beetles, Jeffrey Pine Beetle, Mountain Pine Beetle, Unknown, Western Pine Beetle
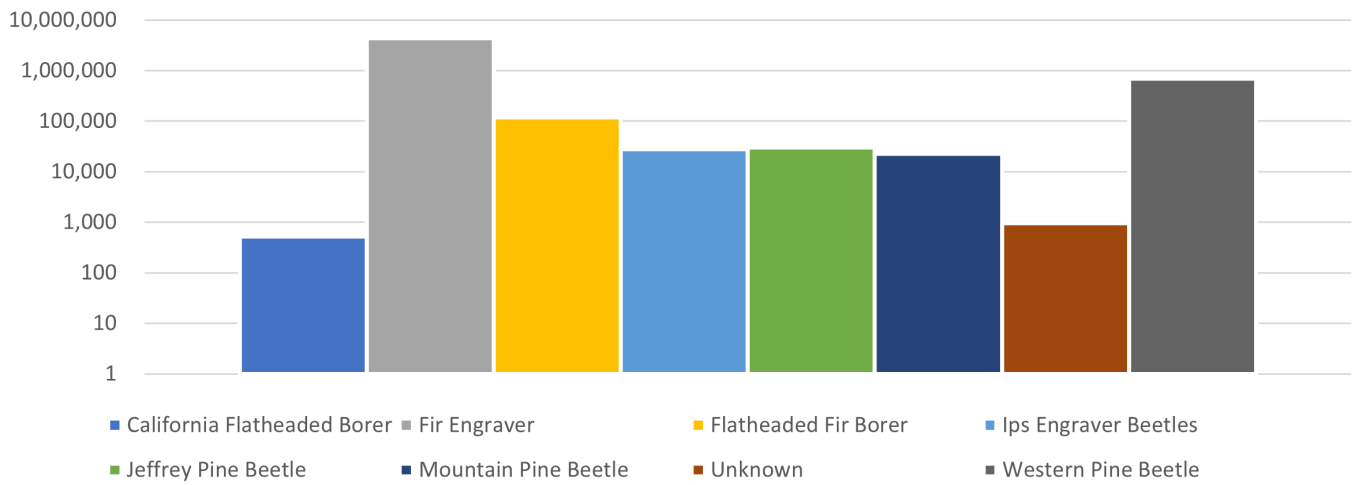
Trees Killed by Damage Causing Agent, 2018-2023: Los Padres NF

Legend: California Flatheaded Borer, Fir Engraver, Flatheaded Fir Borer, Ips Engraver Beetles, Jeffrey Pine Beetle, Pinyon Ips, Unknown Bark Beetle, Western Pine Beetle
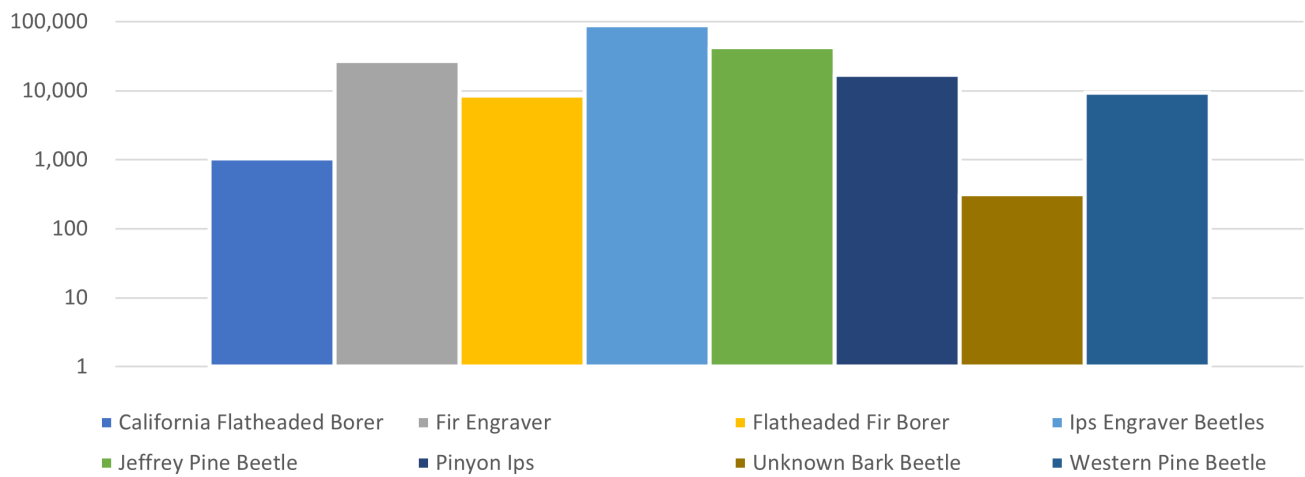
Trees Killed by Damage Causing Agent, 2018-2023: Mendocino NF

Legend: California Flatheaded Borer, Drought, Fir Engraver, Flatheaded Fir Borer, Ips Engraver Beetles, Jeffrey Pine Beetle, Mountain Pine Beetle, Unknown, Western Pine Beetle
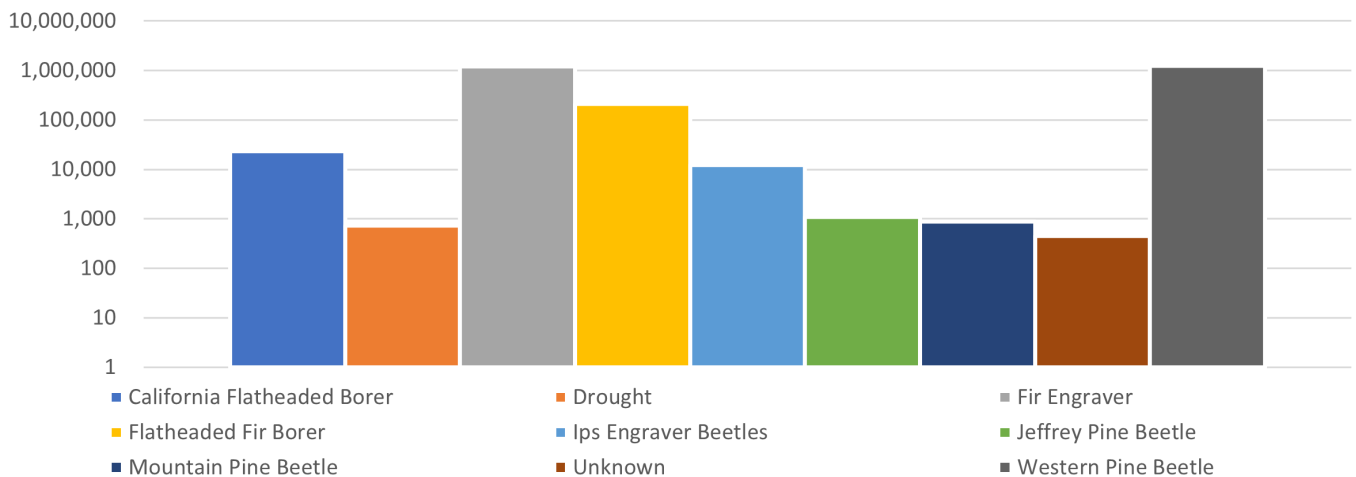
Trees Killed by Damage Causing Agent, 2018-2023: Modoc NF

Legend: California Flatheaded Borer, Fir Engraver, Ips Engraver Beetles, Jeffrey Pine Beetle, Mountain Pine Beetle, Western Pine Beetle
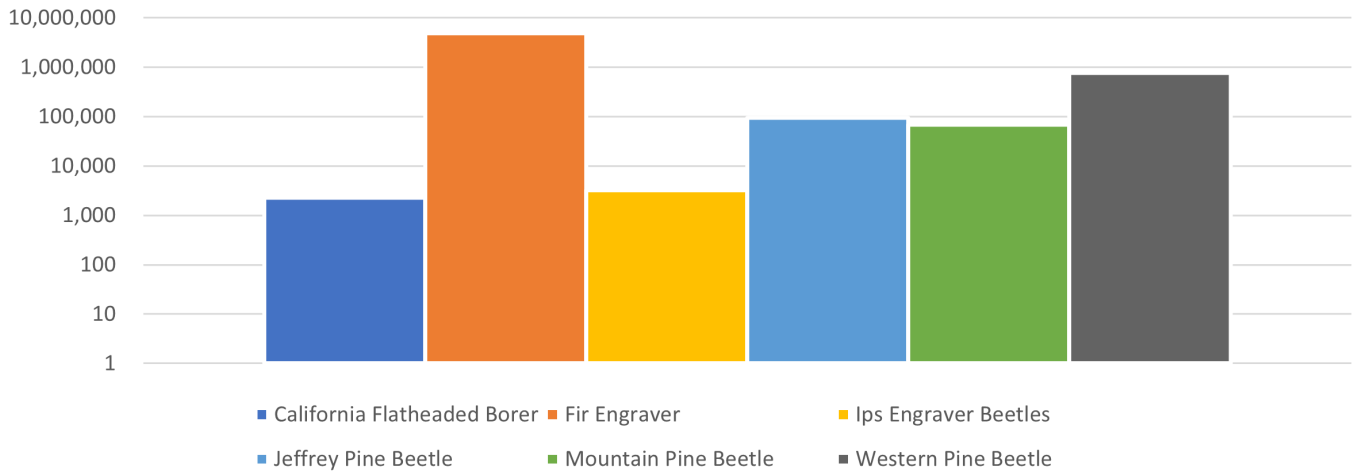
Trees Killed by Damage Causing Agent, 2018-2023: Plumas NF

Legend: Drought, Fir Engraver, Flatheaded Fir Borer, Ips Engraver Beetles, Jeffrey Pine Beetle, Mountain Pine Beetle, Western Pine Beetle
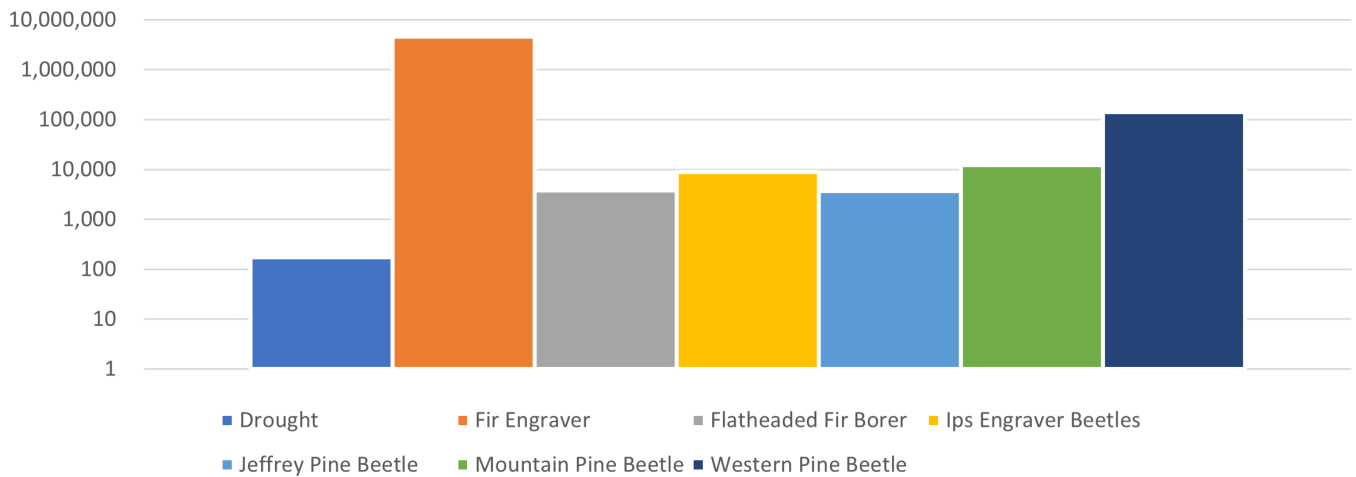
Trees Killed by Damage Causing Agent, 2018-2023: San Bernardino

Legend: California Flatheaded Borer, Fir Engraver, Flatheaded Fir Borer, Ips Engraver Beetles, Jeffrey Pine Beetle, Mountain Pine Beetle, Pinyon Ips, Unknown Bark Beetle, Western Pine Beetle
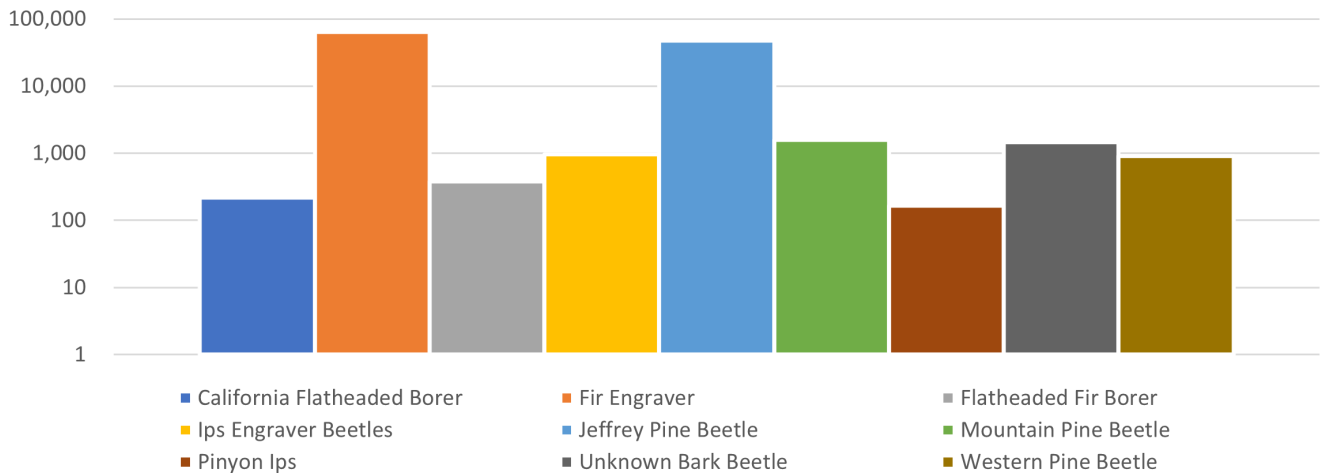
Trees Killed by Damage Causing Agent, 2018-2023: Sequoia NF

Legend: Fir Engraver, Jeffrey Pine Beetle, Mountain Pine Beetle, Pinyon Ips, Unknown Bark Beetle, Unknown Wood Borer, Western Pine Beetle
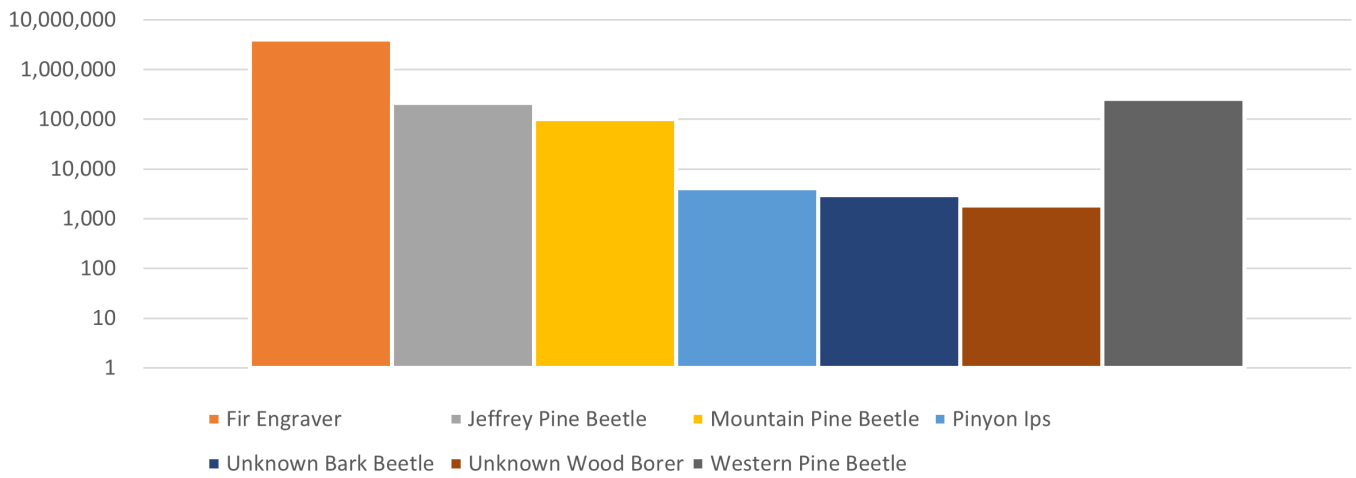
Trees Killed by Damage Causing Agent, 2018-2023: Shasta-Trinity NF
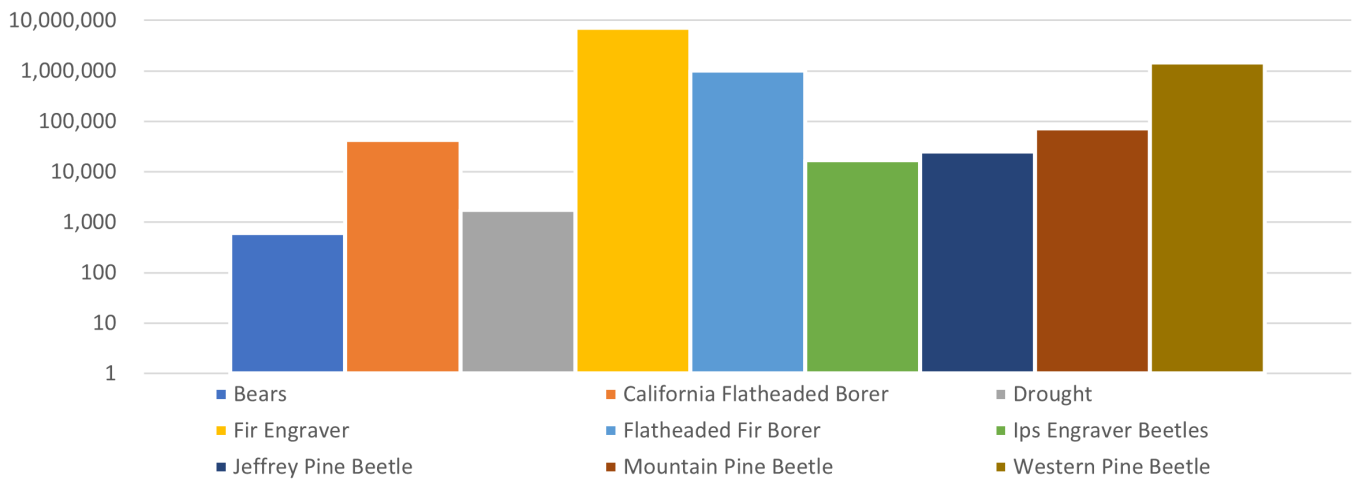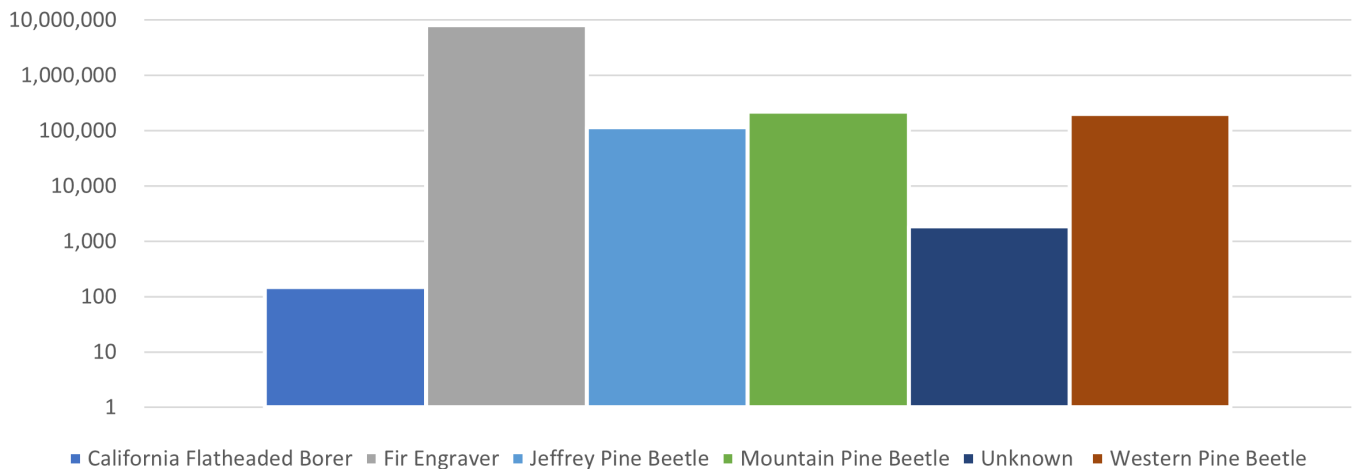
Legend: Bears, California Flatheaded Borer, Drought, Fir Engraver, Flatheaded Fir Borer, Ips Engraver Beetles, Jeffrey Pine Beetle, Mountain Pine Beetle, Western Pine Beetle

Trees Killed by Damage Causing Agent, 2018-2023: Sierra NF

Legend: California Flatheaded Borer, Fir Engraver, Jeffrey Pine Beetle, Mountain Pine Beetle, Unknown, Western Pine Beetle
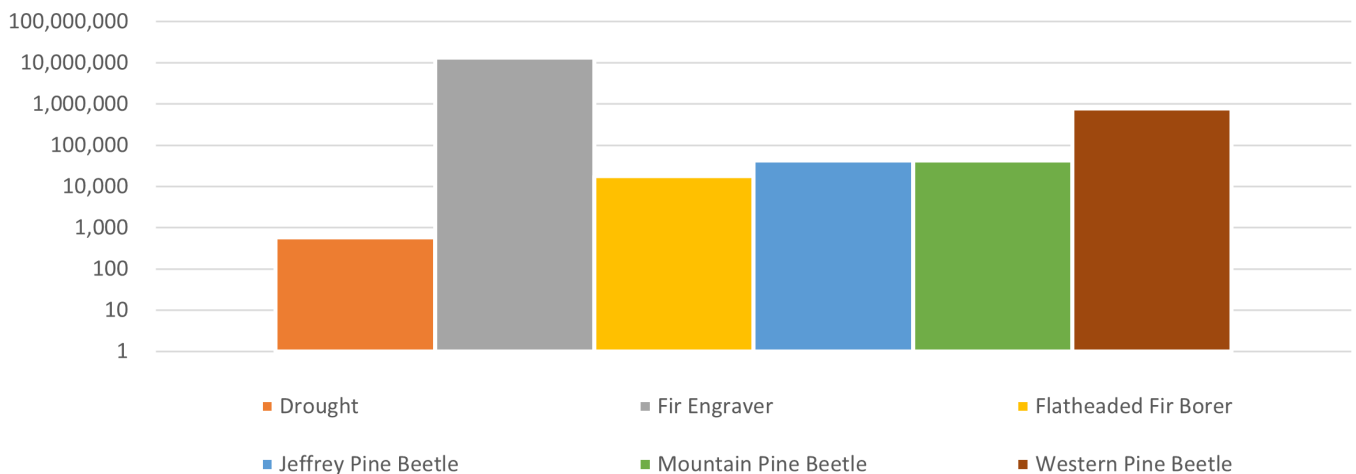
Trees Killed by Damage Causing Agent, 2018-2023: Six Rivers NF

Legend:
- Bears
- California Flatheaded Borer
- Fir Engraver
- Flatheaded Fir Borer
- Ips Engraver Beetles
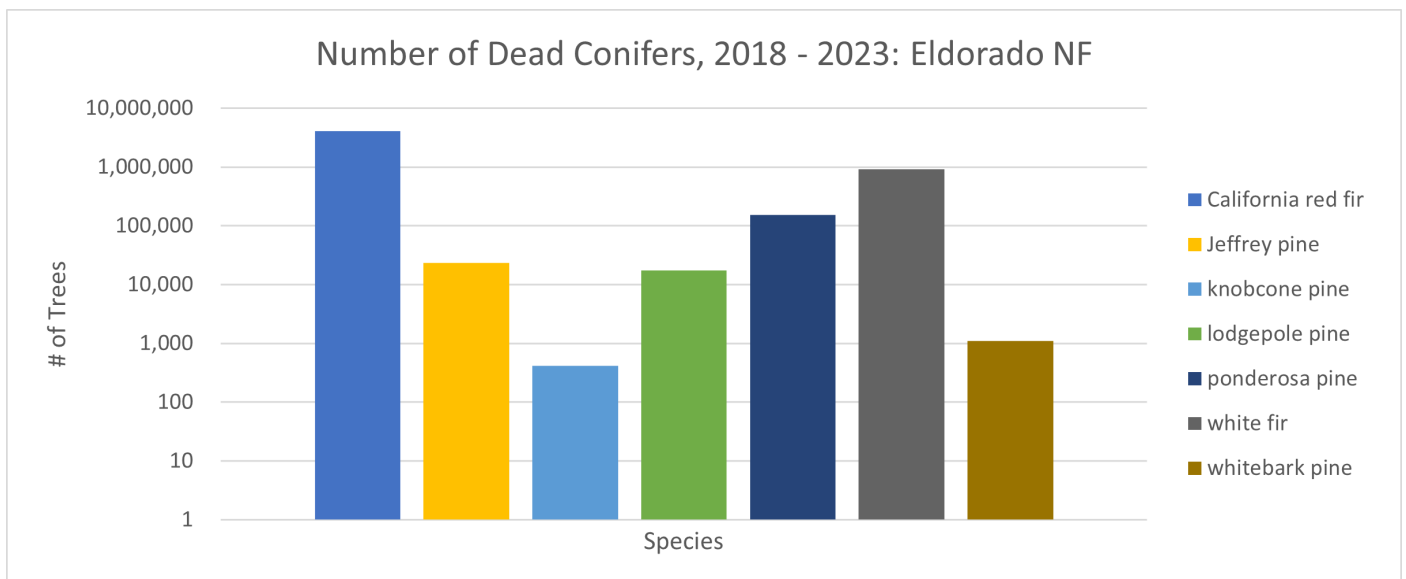- Jeffrey Pine Beetle
- Mountain Pine Beetle
- Western Pine Beetle
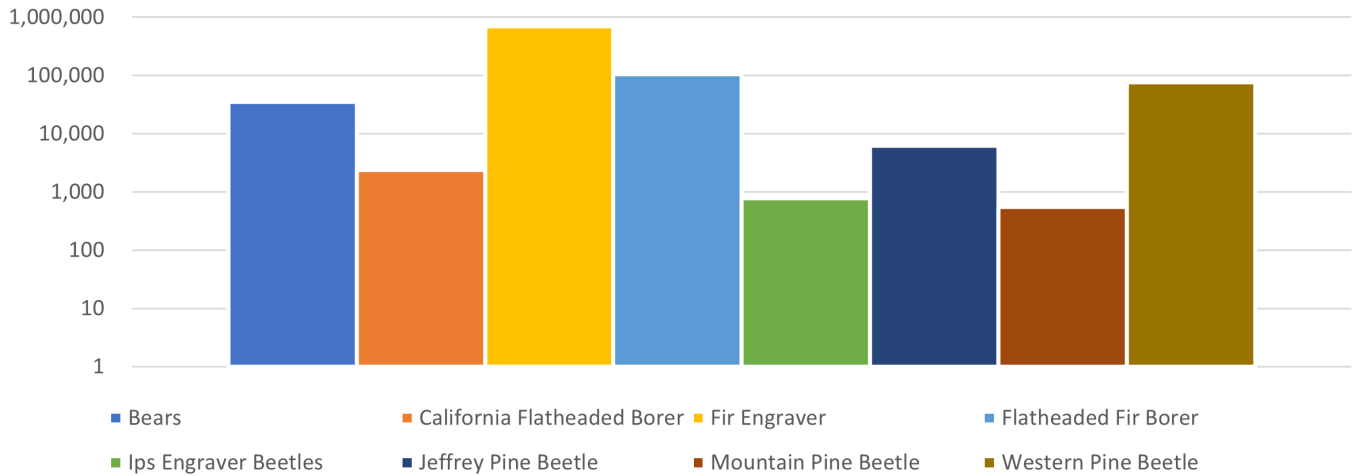
Trees Killed by Damage Causing Agent, 2018-2023: Stanislaus NF

Legend:
- California Flatheaded Borer
- Drought
- Fir Engraver
- Flatheaded Fir Borer
- Jeffrey Pine Beetle
- Mountain Pine Beetle
- Pine Engraver
- Western Pine Beetle
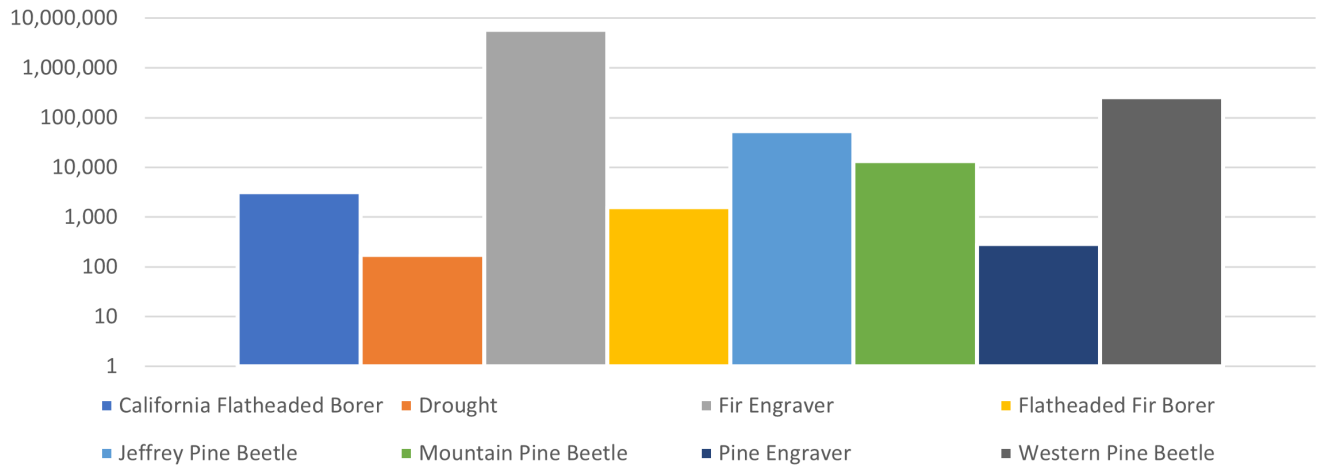
Trees Killed by Damage Causing Agent, 2018-2023: Tahoe NF

Legend:
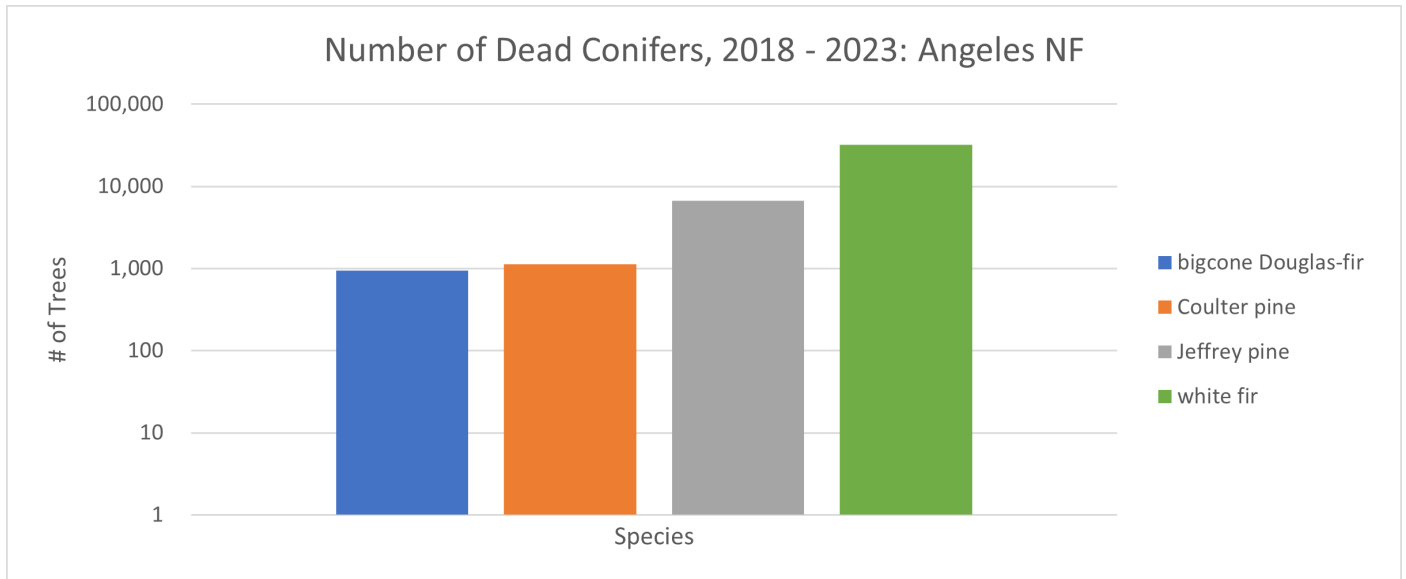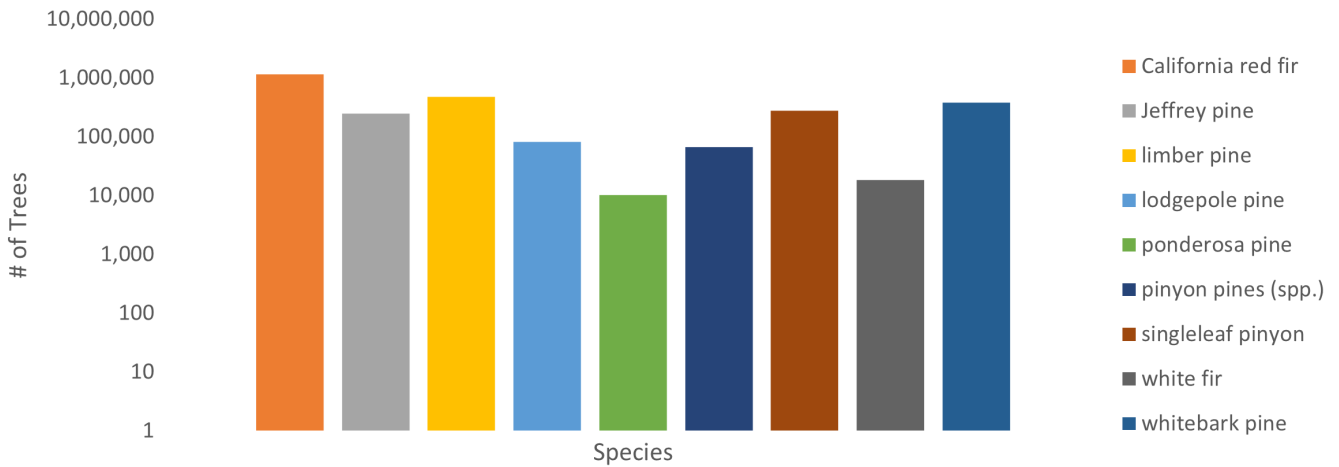- Drought
- Fir Engraver
- Flatheaded Fir Borer
- Jeffrey Pine Beetle
- Mountain Pine Beetle
- Western Pine Beetle

Appendix B: Conifers killed by Host Species between 2018 -2023

Number of Dead Conifers, 2018 - 2023: Angeles NF

Legend:
- bigcone Douglas-fir
- Coulter pine
- Jeffrey pine
- white fir

Y-axis: # of Trees
X-axis: Species

Number of Dead Conifers, 2018 - 2023: Cleveland NF

Legend:
- Jeffrey pine
- ponderosa pine
- white fir

Y-axis: # of Trees
X-axis: Species

Number of Dead Conifers, 2018 - 2023: Eldorado NF

Legend:
- California red fir
- Jeffrey pine
- knobcone pine
- lodgepole pine
- ponderosa pine
- white fir
- whitebark pine

Y-axis: # of Trees
X-axis: Species

Number of Dead Conifers, 2018 - 2023: Inyo NF

Legend:
- California red fir
- Jeffrey pine
- limber pine
- lodgepole pine
- ponderosa pine
- pinyon pines (spp.)
- singleleaf pinyon
- white fir
- whitebark pine

Number of Dead Conifers, 2018 - 2023: Klamath NF

Legend:
- California red fir
- Douglas-fir
- Jeffrey pine
- lodgepole pine
- ponderosa pine
- Shasta red fir
- sugar pine
- white fir

Number of Dead Conifers, 2018 - 2023: Lake Tahoe Basin

Legend:
- California red fir
- Jeffrey pine
- lodgepole pine
- ponderosa pine
- white fir
- whitebark pine

Number of Dead Trees by Host: Lassen NF

Legend:
- California red fir
- Douglas-fir
- incensecedar
- Jeffrey pine
- lodgepole pine
- ponderosa pine
- sugar pine
- white fir
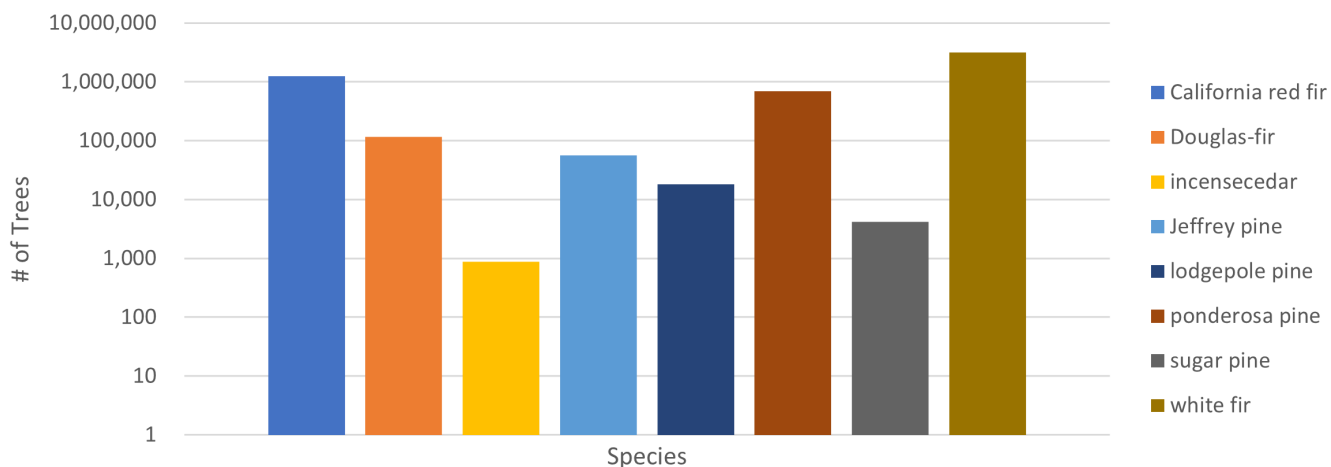
Number of Dead Trees by Host: Los Padres NF

Legend:
- bigcone Douglas-fir
- Coulter pine
- Douglas-fir
- Jeffrey pine
- knobcone pine
- ponderosa pine
- Santa Lucia or bristlecone fir
- pinyon pines (spp.)
- singleleaf pinyon
- white fir

Number of Dead Conifers, 2018 - 2023: Mendocino NF

Legend:
- California red fir
- Douglas-fir
- gray or California foothill pine
- Jeffrey pine
- knobcone pine
- ponderosa pine
- sugar pine
- white fir

Number of Dead Conifers, 2018 - 2023: Modoc NF

Legend:
- California red fir
- Jeffrey pine
- knobcone pine
- lodgepole pine
- ponderosa pine
- Shasta red fir
- western white pine
- white fir
- whitebark pine

Number of Dead Conifers, 2018 - 2023: Plumas NF

Legend:
- California red fir
- Douglas-fir
- Jeffrey pine
- lodgepole pine
- ponderosa pine
- sugar pine
- white fir

Number of Dead Conifers, 2018 - 2023: San Bernardino NF

Legend:
- bigcone Douglas-fir
- Jeffrey pine
- limber pine
- lodgepole pine
- ponderosa pine
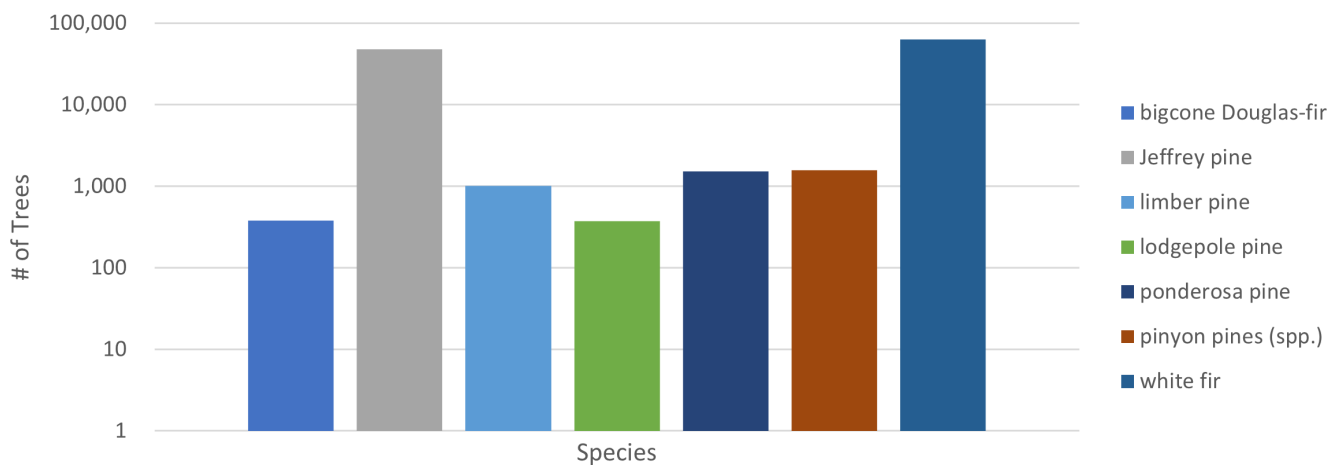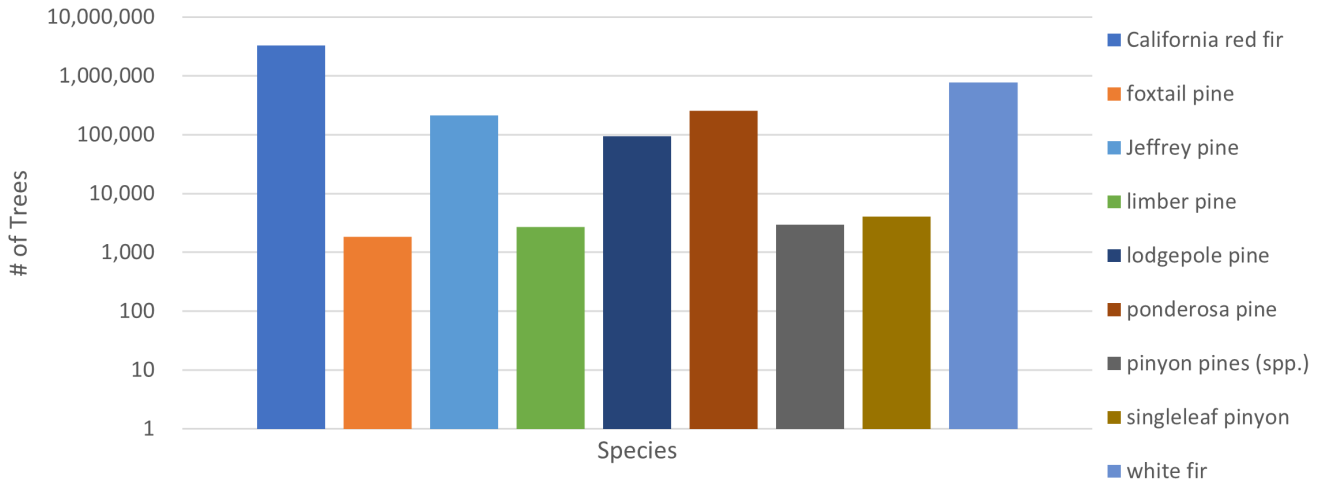- pinyon pines (spp.)
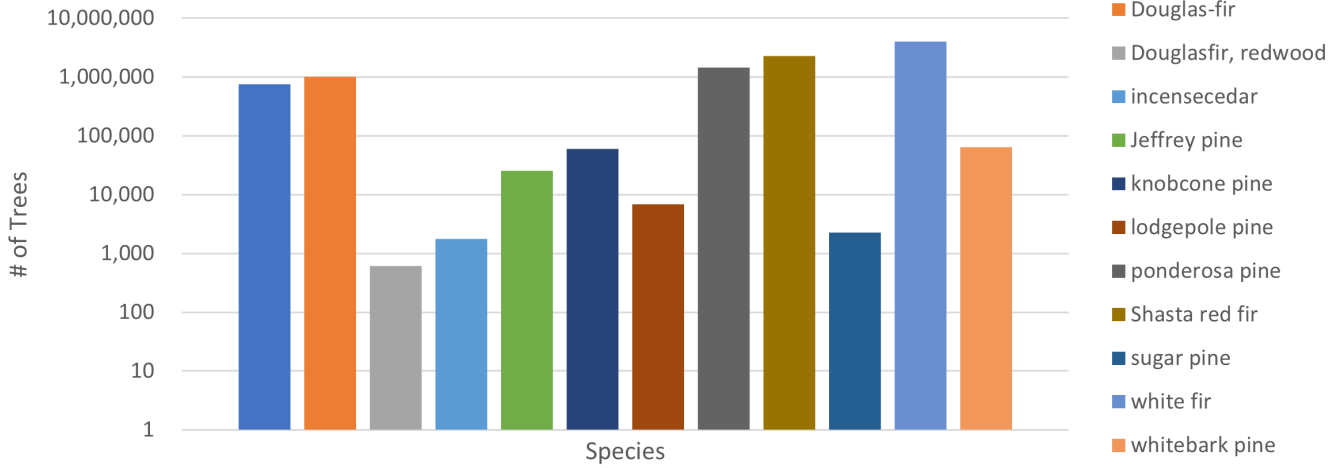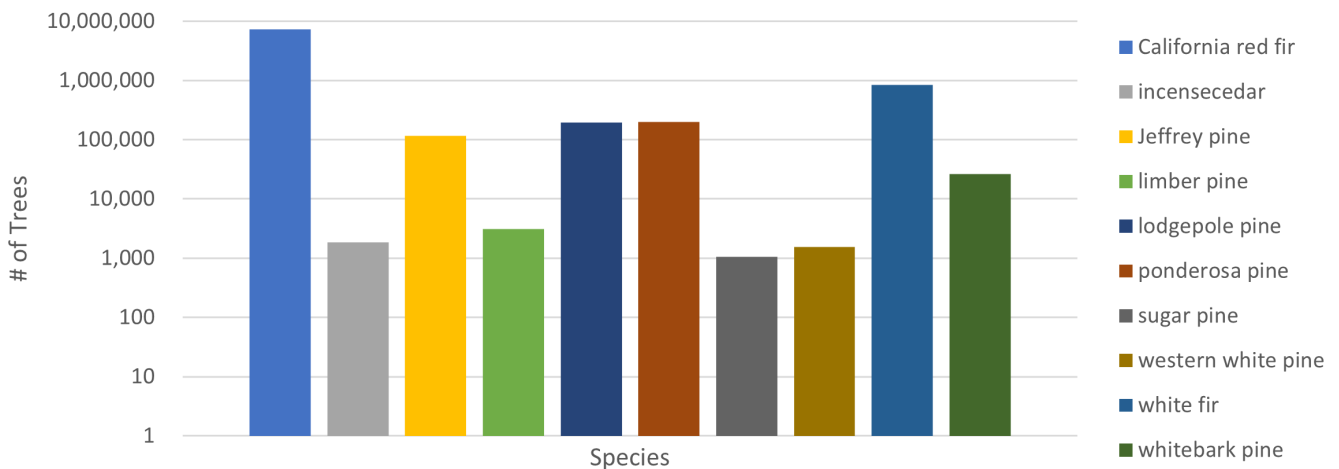- white fir

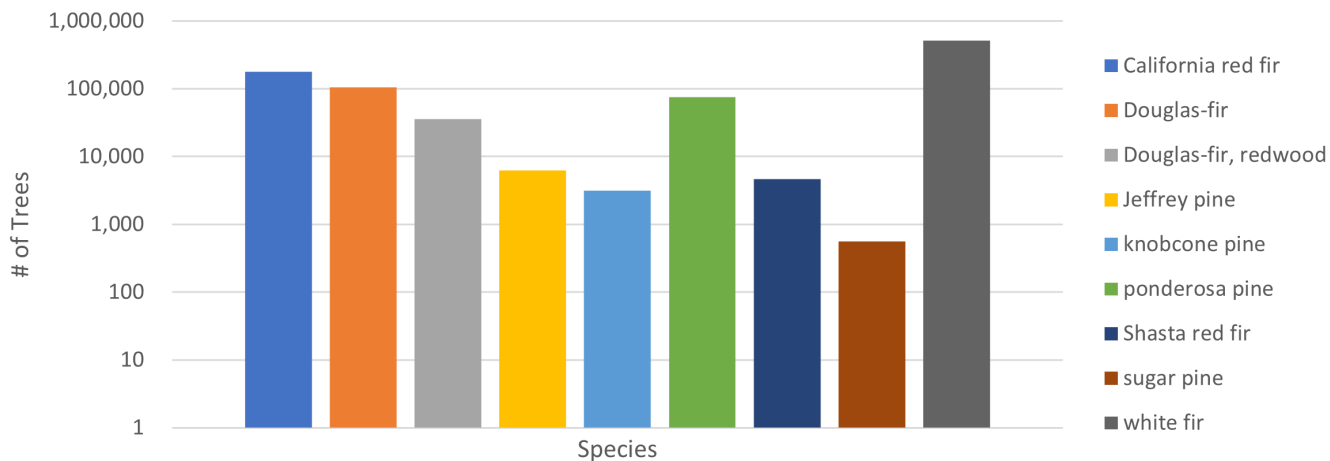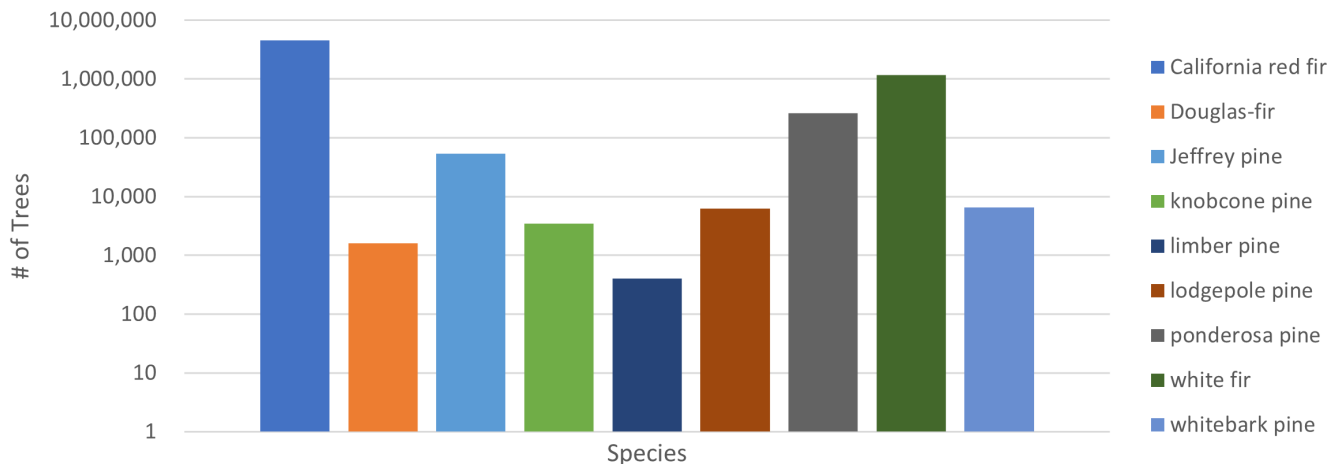Number of Dead Conifers, 2018 - 2023: Sequoia NF

Number of Dead Conifers, 2018 - 2023: Shasta-Trinity NF

Number of Dead Conifers, 2018 - 2023: Sierra NF

Number of Dead Conifers, 2018 - 2023: Six Rivers NF

Legend:
- California red fir
- Douglas-fir
- Douglas-fir, redwood
- Jeffrey pine
- knobcone pine
- ponderosa pine
- Shasta red fir
- sugar pine
- white fir

Number of Dead Conifers, 2018 - 2023: Stanislaus NF

Legend:
- California red fir
- Douglas-fir
- Jeffrey pine
- knobcone pine
- limber pine
- lodgepole pine
- ponderosa pine
- white fir
- whitebark pine

Number of Dead Conifers, 2018 - 2023: Tahoe NF

Legend:
- California red fir
- Douglas-fir
- incensecedar
- Jeffrey pine
- lodgepole pine
- ponderosa pine
- sugar pine
- western white pine
- white fir