PHYTOSPHERE RESEARCH

Investigation of recent manzanita and knobcone pine dieback and mortality on Mount Diablo

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Prepared by:
Tedmund J. Swiecki, Ph.D., Principal/Plant Pathologist
Elizabeth Bernhardt, Ph.D., Principal/Plant Pathologist

Client:
Sean Burke, Land Programs Director
Save Mount Diablo
1901 Olympic Blvd., Suite 320, Walnut Creek, California, 94596
Phone: (925)448-1193 / (925)947-3535 Email: sburke@savemountdiablo.org

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Cover photo: Dieback of knobcone pine near sample point MD25 on 2/14/22. Foreground at left shows slash from previous clearing under transmission lines (tower at right).

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Acknowledgements

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Executive Summary

Extensive dieback and mortality of manzanitas (*Arctostaphylos auriculata* and *A. manzanita*) and knobcone pine (*Pinus attenuata*) were noted in the southwest portion of Mt. Diablo State Park starting in fall 2020. Affected areas were mainly on southwest-facing slopes and ridges of upper Domengine Formation strata that were tilted to a near vertical orientation, forming rock outcrop areas with poorly developed soils with low water holding capacity. Although dieback was related to severe plant water stress associated with historic drought conditions, our investigations suggest that the etiology of dieback differed for the pines and manzanitas. Mortality of pines appears to be driven primarily by an outbreak of the California fivespined ips (*Ips paraconfusus*), a bark beetle that infests stressed pines and recently cut pine slash. It appears that large amounts of knobcone pine slash left after transmission line clearing in 2018 may have elevated populations of *I. paraconfusus* enough to initiate a wider outbreak into adjacent water-stressed knobcone pines. Periods of extreme heat in August and early September 2020 synchronized canopy dieback in the most stressed trees in the area. Knobcone pine mortality expanded during 2021 to areas that were not symptomatic in 2020, apparently due to continuation of the *I. paraconfusus* outbreak into adjacent stressed trees. It is likely that the *I. paraconfusus* outbreak could have been minimized by better management of slash under the severe drought conditions that existed. For manzanitas, it appears that extreme August-September 2020 heat events in combination with high plant water stress induced scorching by overheating foliage beyond critical temperatures. Dieback in manzanitas appeared to have leveled off by early 2021 and regrowth occurred in many plants by 2022. Only a small percentage of the scorched plants appeared to be dead or nearly dead in 2022. No soilborne *Phytophthora* species were detected in sampling conducted in and near the affected vegetation. Preventing introduction of *Phytophthora* and other invasive pests and pathogens should be a priority to protect this and other important sensitive habitat areas of Mt. Diablo.

1. Introduction

Starting around September 2020, various observers noted severe leaf scorching in stands of several exotic species (mostly *Acacia melanoxylon, A. dealbata*, *Eucalyptus* species), and planted Monterey pine (*Pinus radiata*) in numerous locations around the San Francisco Bay area. About the same time, significant dieback and mortality of knobcone pine (*P. attenuata*) and scorching and dieback of *Arctostaphylos* species were noted in the southwest portion of Mt. Diablo State Park. The affected areas were mainly on southwest-facing slopes and ridges below Wall Point and Knobcone Point Roads from the Black Hills area in the southeast to near Pine Ridge in the northwest.

Initial investigations by Chris Lee and Curtis Ewing of CalFire in March 2021 showed that knobcone pine mortality was associated with attack by *Ips paraconfusus* (California fivespined ips), which mines the cambium area of many native pine species. It typically causes scattered mortality of stressed trees but is also known to cause outbreaks in sapling to pole-sized pine stands. Outbreaks of this beetle are favored by the presence of fresh cut or fallen pine material and trees under stress from overcrowding, injury, drought, or disease.

Chris Lee observed that most of the affected manzanitas had a mix of green and dead growing tips but relatively few whole plants were dead. On many but not all plants, damage was mostly limited to individual growing tips and did not extend far down the branches. Based on his observations, Chris Lee suspected that symptoms were largely related to drought or heat stress.

He observed leaf spotting and cankers at the base of dead twigs, but little whole-branch dieback. *Neofusicoccum australe* was the most common pathogen isolated from affected aerial portions of the plants. Several species of fungi known variously as *Neofusicoccum, Fusicoccum, or Botryosphaeria* are very widespread on *Arctostaphylos* and many other woody species in California and globally. During the wet season, aerially- and splash-dispersed spores of these fungi can infect susceptible tissues, such as young twigs or inflorescences, senescent tissues, or wounds. New infections can cause cankers and localized dieback of infected tissues. These fungi can also enter an endophytic phase in which they colonize tissue without causing obvious symptoms. In this phase, the fungi act as opportunistic pathogens and cause tissue death, canker expansion, and branch dieback when the host is subjected to elevated level of environmental stress, especially water stress or heat stress.

The fact that knobcone pine and manzanita dieback at Mt. Diablo developed about the same time that scorch and dieback appeared in other species in the Bay Area strongly suggested that regional climate and weather factors were likely to be contributing to both issues. Furthermore, the distribution of affected vegetation at Mt. Diablo relative to the terrain and visible geological features raised the possibility that edaphic conditions, especially soil water reserves, played a role in the observed dieback. In addition, initial data from several researchers has indicated that opportunistic diseases of stems and trunks that are favored by heat and drought stress could be involved.

One possible contributing factor to the dieback that had not been investigated was the possibility that root pathogens could also be involved in some of the affected areas. Pathogens that affect root health also cause water stress symptoms and plant mortality. Various native stands of manzanita species in northern California have experienced extensive dieback and mortality due to the introduction of exotic root-rotting *Phytophthora* species. We have identified various root-rotting *Phytophthora* species that are responsible for decline and mortality of *Arctostaphylos myrtifolia* and *A. viscida* in the Ione area, *A. pallida* and *A. crustacea* in the Oakland Hills, *A. densiflorus* in the Vine Hill area of Sonoma County, and *A. hookeri* ssp. *ravenii* in San Francisco. These diverse locations all have soils with low water holding capacity. We have also identified many other locations where introductions of soilborne *Phytophthora* species have been associated with decline and dieback of native vegetation.

One objective of our investigations was to determine whether any of the observed mortality in the affected areas at Mt. Diablo was related to introductions of soilborne *Phytophthora* species. The broader dieback and mortality seen in largely inaccessible portions of the affected areas at Mt. Diablo were very unlikely to be associated with *Phytophthora*. However, *Phytophthora* could occur in patches in the more disturbed areas where its effects would be difficult to distinguish from drought-related mortality. Such introductions would most likely occur along roads and trails and spread from points of introduction would be primarily downslope. Establishing baseline information on the presence or absence of *Phytophthora* in the affected areas has implications for improving the long-term management of these stands, including protecting the rare and endangered Mt. Diablo manzanita (*A. auriculata*) that occurs in the affected area.

In addition to surveying the affected area for *Phytophthora*, we also made additional observations on the affected vegetation to contribute to understanding of the factors that precipitated the dieback. This information is critical for predicting the long-term outcome of this event, the likelihood of recurrence or expansion to other areas, and whether various management actions or events (such as fire) could either mitigate or exacerbate the situation.

2. Methods

2.1. Selection of areas of interest

The general areas where symptomatic plants were observed were delineated by Nomad Ecology based on browning of vegetation visible in Google Earth imagery and consultations with Mount Diablo State Park (MDSP) and Save Mount Diablo (SMD) staff. Light brown foliage of affected knobcone pine and darker cinnamon brown foliage of symptomatic manzanita plants were visible in Google Earth imagery dated 2/12/21 but not in the preceding October 2019 imagery. We used the 2/12/21 Google Earth imagery to help identify areas of interest for sampling as well as the September-December 2021 drone imagery taken by Heath Bartosh of Nomad. Potential sampling areas for *Phytophthora* were initially identified based on:

1. Proximity to roads and trails that could serve as routes of introduction.
2. Plant symptoms, particularly if they appeared to be more locally intense or in areas where topography suggested water availability might be greater than surrounding areas (e.g., along drainages), which would favor *Phytophthora* infection.

Coordinates of these potential points of interest (MD01-11) were uploaded to GPS receivers so that the points could be located in the field.

Ted Swiecki visited the affected areas on 2/14/22, 3/7/22, and 4/13/22. The previously identified areas of interest were inspected and sampled in some cases, but in-field observations were used to select other sampling locations of interest on all three days. Sean Burke of SMD assisted on all three dates. Curtis Ewing of CalFire joined us in the field on 2/14/22. Curtis took a number of stem water potential readings to measure plant water stress levels on that date and we assisted, collecting a few readings using Phytosphere's pressure bomb.

2.2. Root/soil sampling.

Root/soil samples were dug near the root crowns or under the canopies of symptomatic plants using hand tools (trenching shovels, masonry hammer, trowel). The specific tools had been selected and, in some cases, modified to ensure that they could be thoroughly cleaned and sanitized between samples. Most samples consisted of 3-4 (range 2 to 7) subsamples typically separated by one to several meters, that were taken around one to several adjacent plants. Because of the uneven distribution of both roots and *Phytophthora* inoculum in soil, pooling multiple subsamples provides greater detection efficiency than collecting an entire sample from a single hole.

When collecting root/soil samples, duff and debris on the soil surface were scraped aside and roots and soil were collected to a depth of 10 to 20 cm. Clean or new disposable nitrile gloves were worn for each sample. For each sample, we collected roots and rootzone soil and placed them into labeled 1-gallon heavy duty zip-closure plastic bag (freezer Ziploc® bag). Because most *Phytophthora* propagules in soil are associated with the roots, samples consisted mainly of live and dead roots extracted by hand from soil sample holes, with some adhering and associated soil. A total volume of about 1.5 L of roots and soil was collected per sample. After sampling, holes were backfilled with the excavated soil and tools were thoroughly disinfested by brushing off soil into each sampling hole and thoroughly cleaning tools with 70% isopropanol or ethanol to remove all visible soil. After all subsamples were collected, the sample bag was sealed and shaded to prevent excessive heating until transferred into coolers for transport to the lab.

2.3. Sample processing

We baited root/soil samples with green pears to detect soil-borne *Phytophthora* species. Upon return to the lab, samples were wetted to about field capacity with charcoal-filtered tap water to create favorable environmental conditions for sporangium production. Moistened root/soil samples were incubated for 3 days at 21-24 C (70-75 F) to allow time for sporangia to form. Over this period, samples were misted with additional water as needed to keep roots from drying out and to maintain target moisture levels.

After 3 days, root/soil samples were flooded with charcoal filtered tap water and baited with green pears and incubated at temperatures that fluctuated diurnally between about 21 and 24 C (70-75 F). Flooding stimulates the release of *Phytophthora* zoospores that can infect the pears. Sporangia formation and zoospore release can also continue while samples remain flooded. Pears were removed as soon as *Phytophthora* lesions were evident or after 5 days if no symptoms were seen. Because late symptom development can occur, pears were monitored for symptoms for at least 8 days after the initial flooding date.

After removal from the sample bags, pear baits were rinsed with tap water and placed individually on clean paper towels for further incubation. Symptomatic pears were photographed, and notes were taken on the number of lesions observed. To obtain potential *Phytophthora* isolates, pears were first surface-disinfested by placing them in 0.5% NaOCl (diluted bleach) for 45 seconds. Pieces were cut from the edges of suspect *Phytophthora* lesions using aseptic technique and placed into carrot-cornmeal agar in petri dishes. Mycelium that grew out of the tissue pieces was examined under a microscope. Initial identification was based on morphology of mycelium. Isolates determined to be *Pythium* species based on the morphology of pear lesions and mycelium from isolations were not identified to species.

2.4. Additional site data and data processing

All data related to individual samples were entered into a database. Data included sampling coordinates, site observations, baiting results, and pathogen identifications. Sample data were extracted and converted into ArcGIS Pro layers for visualization. Additional geographic data layers were obtained or developed as noted in Table 1.

Table 1. Spatial data used in the analysis of *Arctostaphylos* and *Pinus attenuata* dieback at Mt. Diablo.

Spatial data type	**Source**	**Notes**
Polygons of affected areas, drone imagery	Nomad	Drone imagery for these polygons was acquired by Heath Bartosh between September and December 2021
Historical fire data	CalFire-FRAP	April 2022 release of historical fire perimeters (firep21_1) for fires with perimeters ≥ 10 acres. Database extends to 1878 in some areas; earliest fire in the Mt Diablo area in the database is 1961.
Soil type and properties	Web Soil Survey	https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
Geologic formation boundaries	Graymer and Langenheim 2021	https://doi.org/10.1130/MWR.S.15148989.v2

Sean Burke supplied weather records for Mount Diablo Junction (2171 ft elevation) for April through October 2020, which were obtained from State Parks staff. Records come from National Weather Service station index number 04-5915-04 (US Department of Commerce, National Oceanic and Atmospheric Administration), and include the maximum and minimum temperature for the previous 24 hours for each day. We also downloaded daily weather data for April through October in 2019, 2020, and 2021 from Weather Underground (wunderground.org) station KCADANV196, located about a mile south of the South Gate entrance at approximately 600 ft elevation. Areas with affected vegetation ranged from 800 to 1800 feet in elevation.

Estimated ET and precipitation data were downloaded for a portion of the site using the OpenET (https://openetdata.org/) Data Explorer. Data was downloaded for a polygon encompassing the east end of the affected area (see Table 2 for coordinates of polygon vertices). Data were downloaded for the calculated ensemble ET estimate (developed from multiple models) and the gridMET precipitation estimate for the available data set (Jan 2016-July 2022).

Table 2. Coordinates of polygon vertices used for OpenET data downloads.

Latitude	Longitude
-121.86104	37.83358
-121.90112	37.84741
-121.92781	37.85066
-121.93202	37.84409
-121.86473	37.82809

3. **Results and discussion**

3.1. Soils and geology

The areas with affected manzanita and knobcone pine are almost entirely restricted to the upper member of the Domengine Formation (Tdu). These are Eocene strata that are mostly massive white quartz sandstone that is pebbly in areas. The formation includes some light-brown quartz sandstone, light gray siltstone, and foraminifer-bearing mudstone (Graymer and Langenheim 2021). In the lower part of the slope in the northwest part of the affected area, some portions of the stand may be on the adjacent Miocene Sobrante Sandstone (Ts), a massive white marine quartz sandstone. The approximate limits of these two geologic units within the affected area are shown in Figure 1.

Within these geologic formations, the affected areas occur almost exclusively where the strata are nearly vertical due to folding and thrust faulting. These areas coincide with the soils mapped as Rock outcrop-Xerorthents (Re) association in the Web Soil Survey (WSS, https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm). We calculated the estimated plant available water (inches) for each of the soil units in the affected area based on soil depth and soil available water capacity for each unit as reported in the WSS (Figure 1). Available water holding capacity of all the rather poorly developed soils in the affected area was very low, due to both coarse soil textures and shallow soil depths.

Rock outcrops corresponding to more resistant rock strata were evident in both aerial imagery of these areas as well as from vantage points on the ground (Figure 2). The soils as classified as excessively drained, primarily due to the sandstone parent material, and highly prone to runoff due to both slope and the presence of impermeable surface rock. Depth to the water table is estimated as more than 2 m, indicating that the soils lack a shallow permanent water table. Plant-available water in the subsoil in this area is not only limited by depth to parent material and soil textures with low water holding capacity, but also by the presence of parallel vertical rock strata. These limit the total soil volume that plants located between the strata can exploit. Our own observations of soils in sampled areas were that they were light-textured, typically sandy to silty loams with low available water-holding capacity.

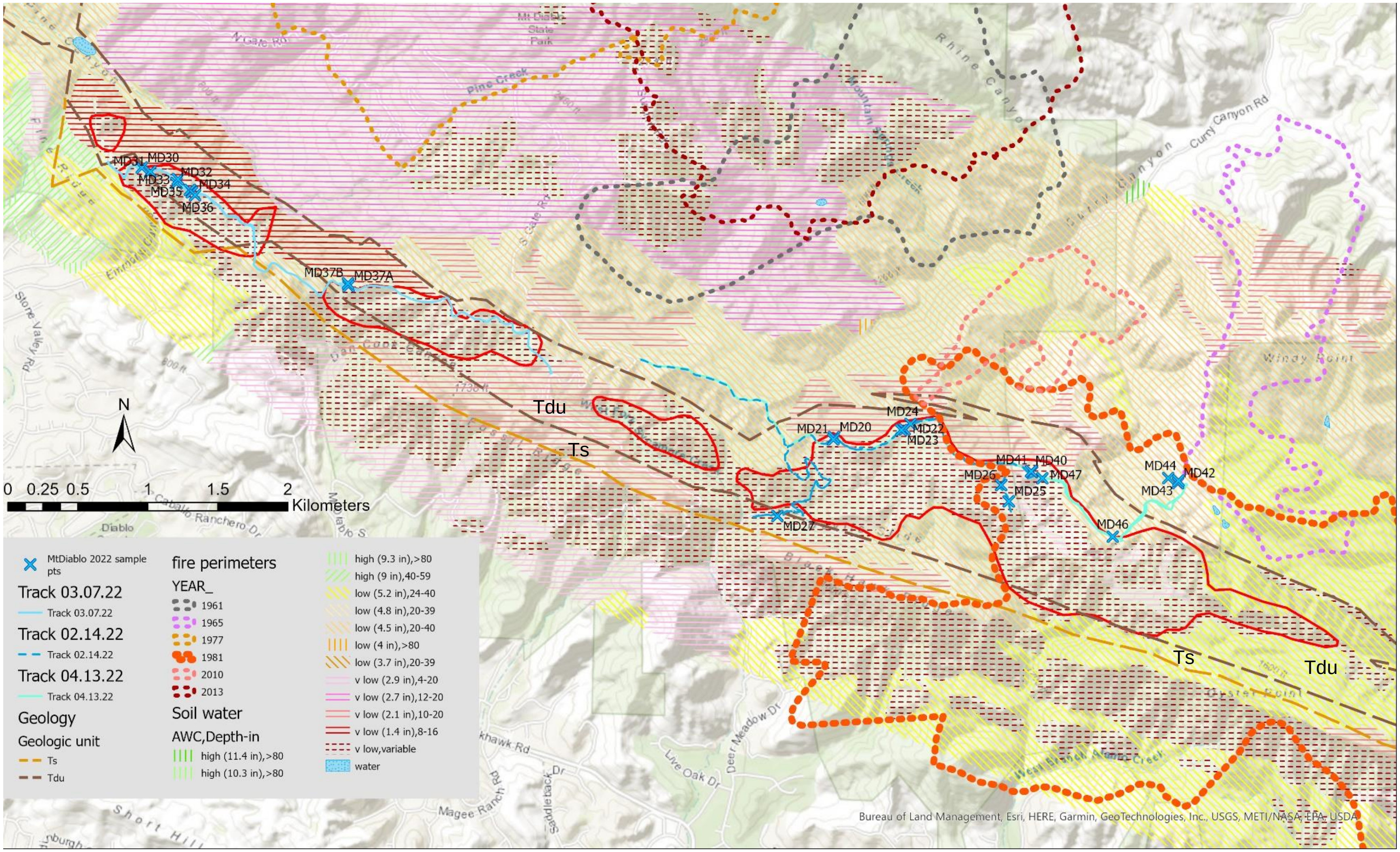

Figure 1. Map showing affected areas of Mt. Diablo (polygons with solid red lines) and sample points (blue x's) and GPS tracks for field visits (blue lines). Overlays include geologic formations (Tdu, Ts, limits shown only within affected areas), fire perimeters by year of fire, and soil types by overall water holding capacity, based on both soil texture and depth.

Figure 2. The overall spatial distribution of knobcone pine and the distribution of symptomatic pines and other species were associated with vertical layers of weathered sandstone parent material between layers of fractured rock. At top, knobcone pine is distributed in linear bands aligned with now-vertical layers of sandstone. In the bottom image, the road surface shows rocky bands with varying degrees of fracturing. The more stunted and mostly dead pines to the left align with the less fractured rock strata visible in the road.

3.2. Temperature, precipitation, and evapotranspiration

Comparison of maximum and minimum temperatures for the nearby weather station KCADANV196 for 2019, 2020 and 2021 are shown in Figure 3. The most significant anomaly between the three years is the week from 8/14-8/21/2020, when daily minimum temperatures were unusually high. Comparison of daily summer minimum and maximum temperatures in 2020 at KCADANV196 and Diablo Junction are shown in Figure 4. It is evident that daily minimum temperatures are warmer, and daily maximum temperatures are cooler at Diablo Junction compared to KCADANV196. The 2020 summer high heat event resulted in unusually high daily minimum temperatures from 8/14 to 8/21/20 at both the lower (KCADANV196) and higher elevation (Diablo Junction) weather stations (Figure 4). A second shorter heat event, with less elevated overnight low temperatures, occurred from 9/5 to 9/7/20. These high heat events occurred shortly before large areas of *P. attenuata* and *Arctostaphylos* species with browning foliage were observed in the southwest portion of Mt. Diablo SP.

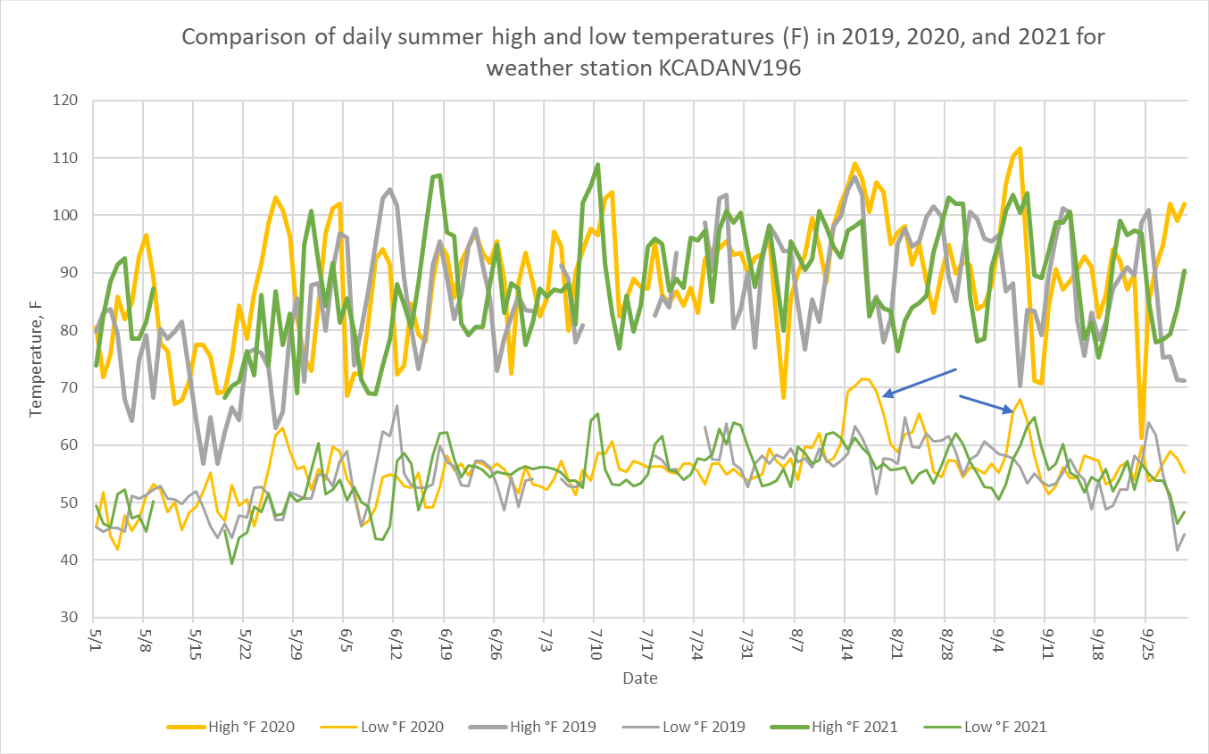

Figure 3. Daily maximum and minimum temperatures (F) by date (month/day) for Weather Underground station KCADANV196 (elev 600 ft) in summer 2019, 2020 and 2021. Extreme heat episodes in August and September 2020 were characterized by multiple days of both high daytime temperatures and unusually high overnight minimum temperatures (blue arrows).

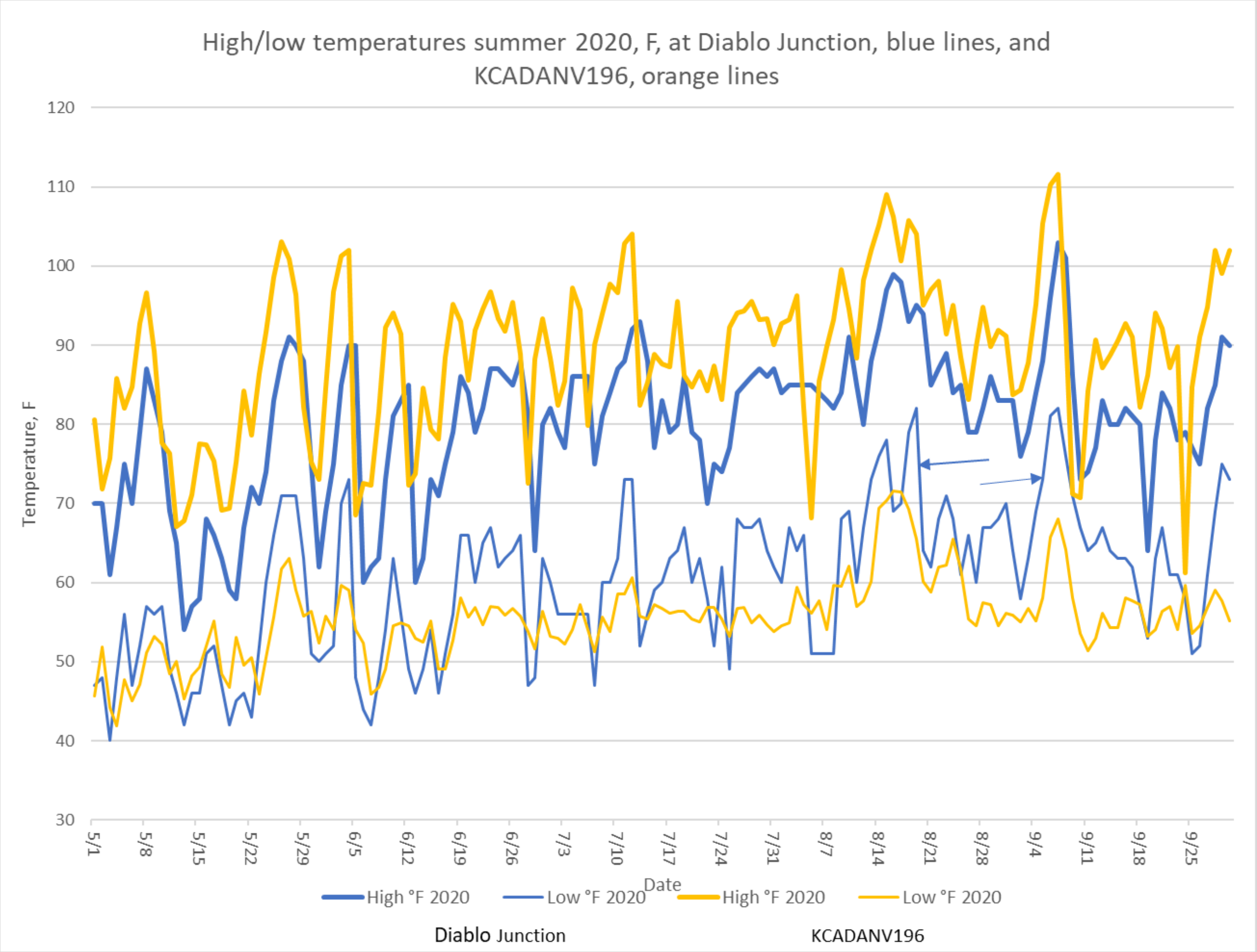

Figure 4. Daily maximum and minimum temperatures (F) by date (month/day) for Weather Underground station KCADANV196 (orange, 600 ft elev.) and Diablo Junction (blue, 2171 ft elev.) in summer 2020. Extreme heat episodes were characterized by multiple days of both high daytime temperatures and unusually high overnight minimum temperatures (blue arrows). Elevated overnight temperatures were higher at Diablo Junction than at KCADANV196.

Water-year (July-June) rainfall totals at Diablo Junction are shown in Figure 5. Average rainfall for the period is 25.4 inches. Water years 2019/20 and 2020/21 received 50% or less of this average precipitation.

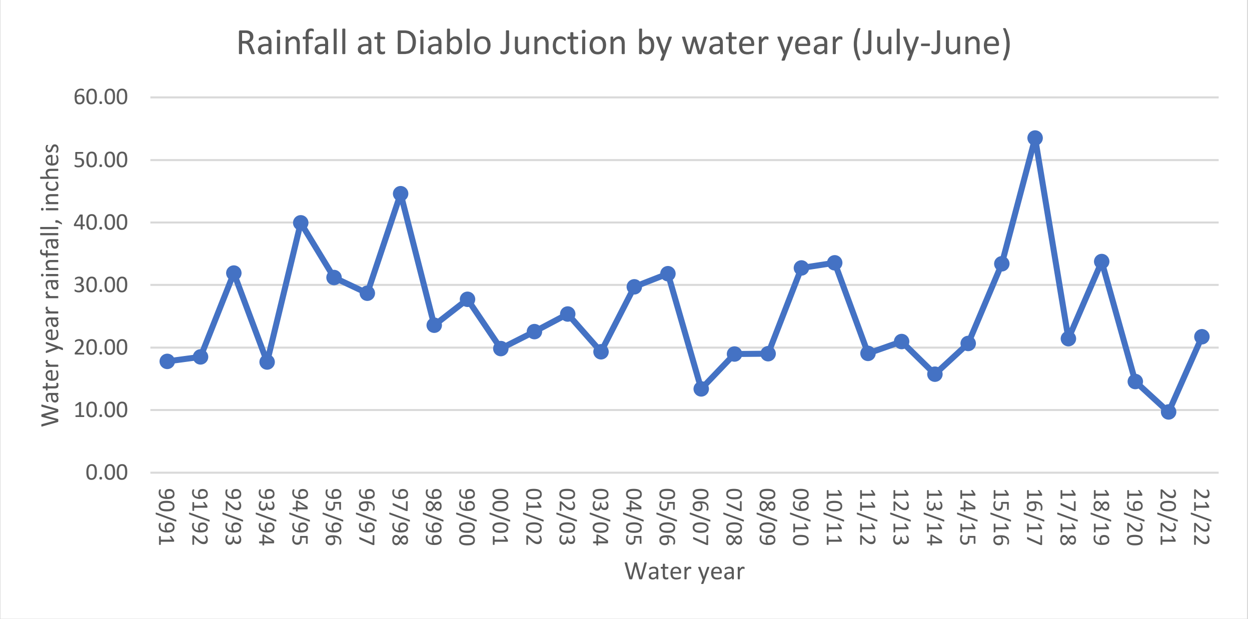

Figure 5. Diablo Junction total precipitation in inches by water year (July-June) from 1990/91 through 2021/22.

Drought stress is a function of precipitation, evapotranspiration demand (which is affected by solar radiation, air temperature, and humidity), the amount of available water held in the rootzone, and the degree to which various plants are competing for scarce water resources. The relative balance between precipitation and evapotranspiration in the affected area is shown in Figures 6 and 7. In Figure 6, the annual input of precipitation for the 2016-17 into the 2021-22 seasons are compared with annual reference evapotranspiration. For these graphs, an October to September water year is used. Two relatively wet growing seasons (2017 and 2019) are apparent from these graphs, whereas the 2020 and 2021 growing seasons were quite dry. It is possible that the effects of the extreme drought in 2020 were intensified by the fact that water was less limiting in two of the preceding 3 years. Plants may have produced additional canopy growth in the period from 2017-2019 that could no longer be supported under the extreme drought conditions that developed in 2020.

The amount of moisture stored in the soil does not start at the same level every year but is influenced by water storage and use in previous seasons. In Figure 7, data in figure 6 are replotted in a cumulative fashion to illustrate this phenomenon. This plot shows an increasing deficit of precipitation relative to evapotranspiration developing from about mid-2019 and intensifying through 2020 and 2021.

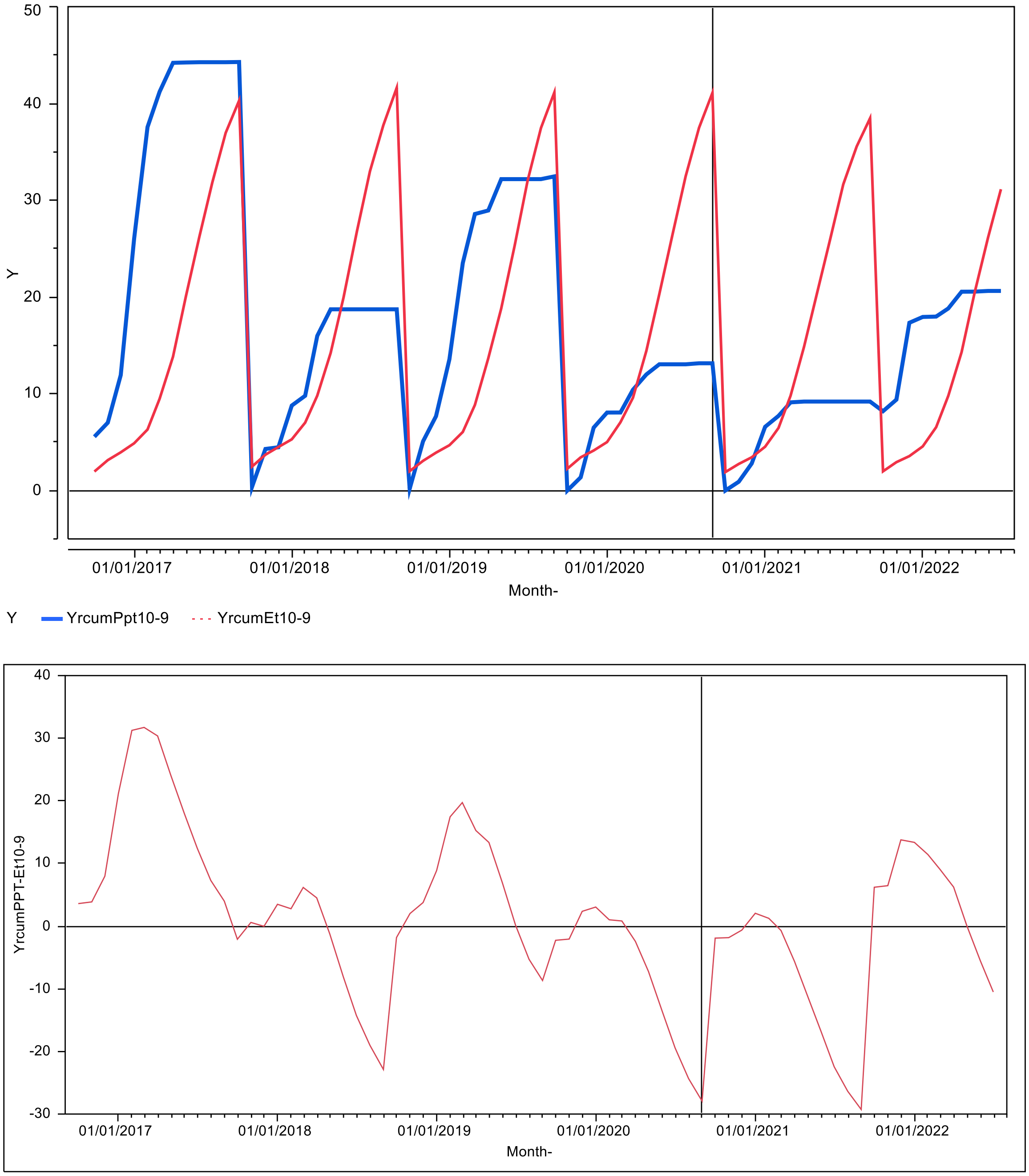

Figure 6. Top - Comparison of modeled cumulative precipitation (blue line) and reference evapotranspiration (red line) in inches for the affected area of Mt. Diablo for 2017 though mid 2022 by year. Cumulative rainfall and evapotranspiration are calculated from October 1 through September 30 of the following year but are not carried over between years in this plot. Bottom – Plot of the difference between the two lines in the top graph (cumulative precipitation – cumulative ETo, inches) without carry-over between years. Points above the horizontal line have a positive water balance (precipitation exceeding ETo). The vertical lines mark September 2020.

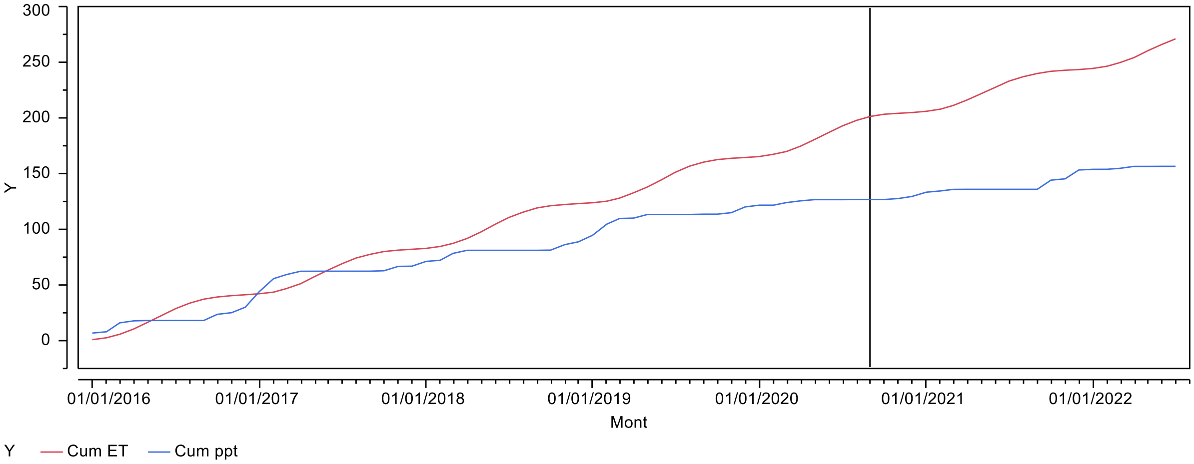

Figure 7. Comparison of modeled (from Open ET) cumulative precipitation (blue line) and reference evapotranspiration (red line) in inches for the affected area of Mt. Diablo for 2017 though mid 2022. Cumulative rainfall and evapotranspiration are calculated from October 1 through September 30 of the following year and are accumulated over time across years. The vertical line marks September 2020.

3.3. Phytophthora sampling

We collected a total of 23 samples in the three days of sampling for *Phytophthora* (Table 1, Figure 1). The majority of these were collected along and near roads, mostly in the downslope direction, which is more likely to become infested if *Phytophthora* contamination has been deposited along roads. Manzanitas (*A. auriculata* and /or *A. manzanita*) were the primary species targeted in 13 of the samples, although roots of associated chaparral plants were included in many of these samples. Dead manzanitas were in the sample areas in many of these samples, but roots of associated live plants were always included in samples. Ten samples included oaks as the primary or secondary target. Oaks sampled most commonly were *Q. agrifolia* or *Q. chrysolepis*, although one sample (MD37) also included *Q. kelloggii* and a likely *Q. agrifolia* × *Q. kelloggii* hybrid (this hybrid has been referred to as *Q.* ×*chasei*, McMinn et al. 1949). Only one sample was collected near *Pinus attenuata* (MD25), and this sample also included some *Q. agrifolia* roots. Sample MD26 was collected close to an area with extensive *P. attenuata* mortality, but only included roots from manzanita and adjacent shrubs. Three samples (MD42-44) were taken in an area east of the madrone and pine mortality areas on a slope where many California bay (*Umbellularia californica*) trees within a mixed oak-bay stand were dead or dying from apparent root disease. No water or wet areas were available for sampling in the portions of the area that we accessed, but one creek sample (MD27) was indirectly collected by removing and baiting soil that had adhered to boot soles after walking through a wet streambed.

No *Phytophthora* was detected in any of the collected samples. *Pythium* species, a related genus of water molds (Oomycetes) were detected in 13 of the 23 samples (Table 3).

Although some *Pythium* species (including taxa split from *Pythium*, such as *Phytopythium*) are aggressive pathogens of some plants, most *Pythium* species are relatively weak pathogens of mature plants or are saprophytes We did not attempt to identify the *Pythium* species given the limited scope of our studies. Heavy *Pythium* colonization of baits can reduce the efficiency of *Phytophthora* detection, particularly if *Phytophthora* species are slow-growing. Possible interference with *Phytophthora* detection due to heavy *Pythium* colonization was limited to only a few of the baits.

The lack of *Phytophthora* detection from any of the samples suggest that levels *Phytophthora* contamination, if present, are generally low in the sampled areas. The results do not indicate that *Phytophthora* contamination is absent from the entire surveyed area, and localized infested areas might exist that were simply not sampled. Nonetheless, as noted in the introduction, the overall distribution of symptomatic vegetation in the affected areas was not consistent with *Phytophthora* or other introduced root pathogens given the lack of association of dieback with roads, trails, and other potential routes of pathogen introduction.

Of the sampled areas, the two that looked most like active root disease centers were in the vicinity of MD40-41 (in an area affected by transmission line clearing) and the vicinity of samples MD42-44. The amount of sampling in these areas (2 and 3 samples, respectively) was not sufficient to conclude that *Phytophthora* was absent from these areas. Additional observations and sampling would be needed to determine with a higher degree of certainty whether *Phytophthora* or other root-infecting pathogens might be involved in the observed decline and mortality in these areas. The MD42-44 area was unusual in that mature California bay appeared to be severely affected whereas intermixed oaks (*Q. agrifolia* and *Q. chrysolepis*) and buckeye (*Aesculus californica*) did not show obvious symptoms other than some possible canopy thinning in oaks. Both sites warrant further observation for continued symptom development and the MD42-44 area warrants a more detailed investigation given that to date, only Phytophthora root rots have caused areawide bay declines in other locations.

3.4. Knobcone pine

3.4.1. Mortality

Because many of the affected stands of knobcone pine were located well away from roads and trails, many of our observations on this species are based on aerial images and views at a distance from the ground. One affected area that was examined close up was in the vicinity of point MD25, where a root sample was also collected and the cut cross-section of a fallen dead tree was photographed (Figure 8).

Figure 8. Cross section of dead knobcone pine that failed at its roots across the road near sample point MD25. Cut face was about 1 m above the soil line. Growth ring dates are based on the assumption that the tree died in 2020. The center of the cross-section dates to about 1988, 6.5 years after the Blackhawk fire.

Affected knobcone pine stands were mostly very dense (cover photo, Figures 2, 9) and had recruited after the Blackhawk fire (Figure 1), a 2,361-acre arson fire that started in mid July 1981. Many of the trees were pole-size in diameter or smaller (Figures 2, 9), Ring counts from the stem section in Figure 8 indicates that this tree reached the height of the cut (about 1 m) about 6.5 years after the fire. It grew rapidly between 1990 and 2000, which was a relatively wet period (Figure 5). Reduced increment growth occurred in several dry periods including 2014 and 2015, but increment growth increased in response to the wetter 2016-17 and 2018-19 seasons. The growth of this particular tree had leveled off as the stand became more mature and competitive, but increment growth was not chronically low and the tree was capable of responding to greater water availability within the last couple of years before it died.

Figure 9. Knobcone pine mortality near sample point MD25.

As shown in Figure 10, although the initial wave of knobcone pine mortality was seen in late 2020-early 2021, additional mortality occurred between February 2022 and late 2022 (October-December). This new mortality mostly resulted in expansion of affected areas, typically progressing from trees at edges of stands into the centers of the stands. In some cases, stands showing very little mortality in February 2022 were largely dead later the same year (Figure 10; note stands on diagonal SE from cleared area at upper left). Based on images in the Nomad Technical memorandum (Ender 2022), the remote sensing classification used did not regularly assign grayish, older dead knobcone pines to the dead pine category. Hence, data presented in that report mainly apply to more recent dead trees (those turning brown over summer 2022), and likely underestimate the total amount of knobcone mortality that developed since late 2020.

3.4.2. Factors associated with knobcone pine mortality

At least three interacting factors appear to have contributed to the knobcone pine mortality that became apparent in 2020: drought stress, extreme heat events in late 2020, and attacks by *Ips paraconfusus* beetles.

Drought stress

Overall, the pattern of mortality across the entire affected landscape clearly suggested that dead and dying trees were likely to have been highly water stressed due to a variety of factors:

- low water holding capacity of the soils in combination with extended drought conditions,
- restriction of soil volume by vertical rock strata,
- topographic position, commonly on steep slopes and ridges,
- aspect, mostly south- to southwest-facing slopes, and
- very high tree density, particularly in portions of the area that burned in the 1981 Blackhawk Fire.

Most of the affected knobcone pines were in very dense stands that were largely confined to narrow bands between sedimentary rock layers that have been tilted into a nearly vertical alignment. These bands are likely to have very limited soil moisture reserves, particularly after an extended severe drought. As noted above, knobcone pines located along some of the narrowest rock strata or at the edges of wider vertical strata appear to have been affected earlier than others (Figures 10,11). These are areas where soil moisture is likely to have been depleted more rapidly. Although knobcone pines are highly drought tolerant and commonly occur on poor soils, the cumulative effects of low precipitation and evapotranspiration over multiple years (Figures 6, 7) in combination with the high stand densities likely exposed the trees to exceptionally high water stress levels by late summer 2020.

Vogl (1973) demonstrated that knobcone pine stands in the Santa Ana Mountains of southern California received significant amounts of water during typically dry months from fog drip. Fog from the San Francisco Bay regularly funnels into the knobcone pine area at Mount Diablo and likely has a similar effect of providing additional soil moisture, especially during the summer. However, climate change has been reducing the number of days of summer fog in the San Francisco Bay area and elsewhere (https://www.nbcbayarea.com/news/local/climate-in-crisis/climate-change-decreasing-bay-area-fog/2593724/). Although we do not have data for fog in the affected knobcone pine areas of Mt. Diablo, elevated daytime and overnight low temperatures seen in summer 2020 (Figure 4) are consistent with little or no fog intrusion into the area over much of this period, and especially during the high temperature periods in late August and early September 2020. High heat coupled with a lack of fog drip moisture would have intensified the level of water stress experienced by the trees in late summer 2020.


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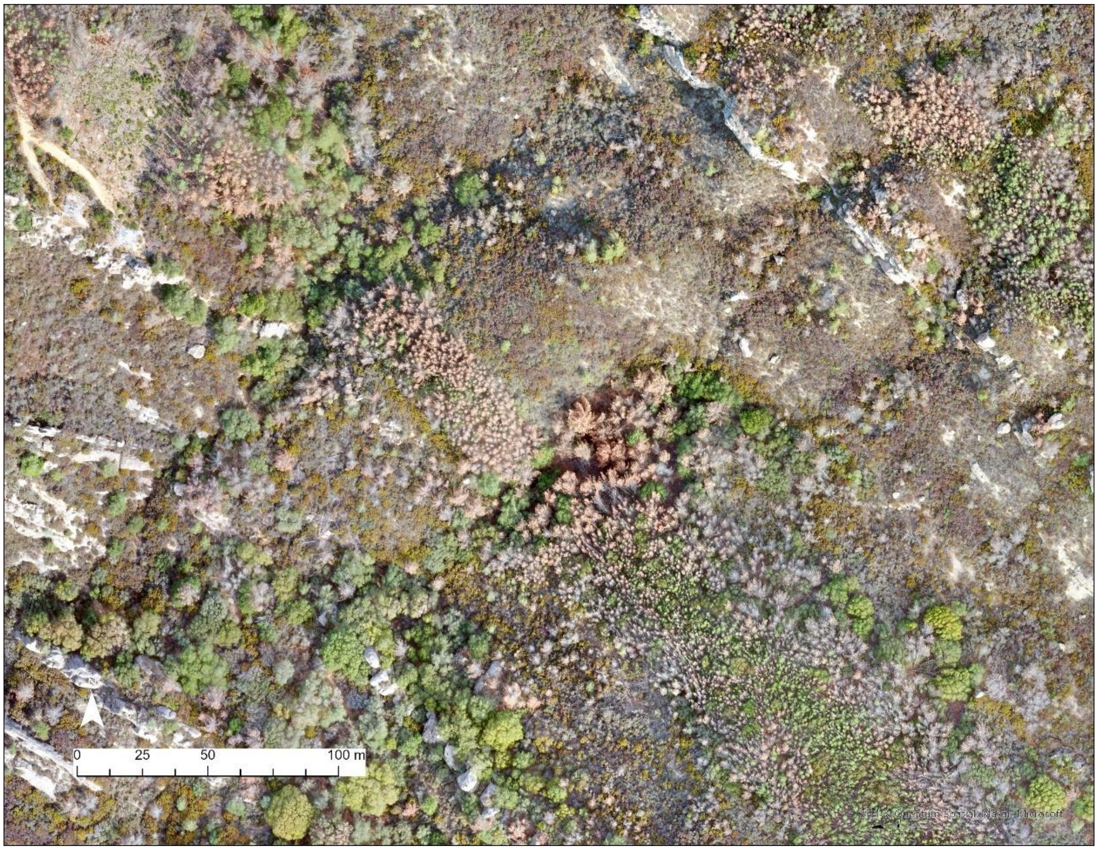
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Figure 10 (preceding page). Expansion of knobcone pine mortality between 12 February 2021 (top, Google Earth image) and October-December 2021 (bottom, Nomad Ecology Group E drone imagery) in area near transmission line clearing (upper left in both). Recent dead canopies appear brown (both images) whereas older dead canopies appear grayish (bottom image). Many knobcone pine tops were dead by February 2021 (top), more commonly in narrow bands between rock strata and at the edges of wider vertical strata. A second round of mortality affected this area by late 2021 (bottom), often spreading into wider bands of trees and further into areas where only edges had been affected previously (compare diagonal band extending from upper left near clearing to lower right in the two images).

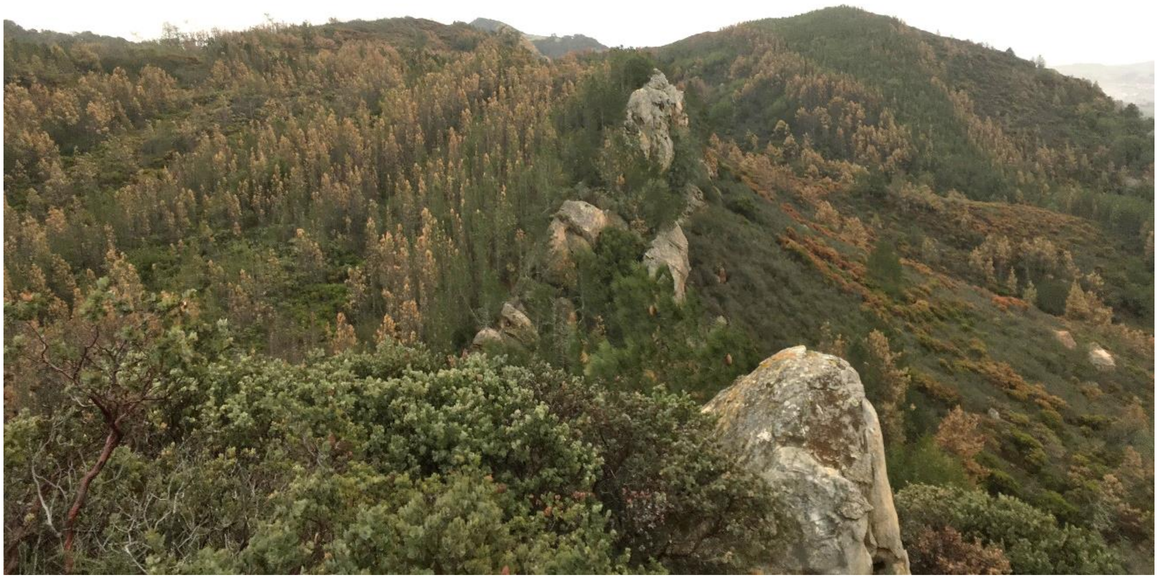

Figure 11. Knobcone pine and associated manzanita in January 2021, shortly after symptoms began to develop. At left, only tops of knobcone pine trees are symptomatic, whereas entire trees are brown to the right, which is adjacent to the transmission line clearing area. Manzanita foliage is still very light brown, and some foliage may still have been be turning brown at this point in time. Image courtesy of Sean Burke, Save Mount Diablo.

Figure 12. Expansion of knobcone pine mortality between 10 March 2021 (top, photo by Chris Lee, CalFire) and 13 April 2022 (bottom) in area near transmission line clearing. The same area is visible at center of the images in Figure 10 and on the right side of Figure 11. Recent dead canopies appear light brown (top) whereas older dead canopies are a darker grayish brown (bottom). In this view, most knobcone pine tops were dead by March 2021 (top). Some additional trees that appear to be fading in the middle of the central peak in the top photo are dead in April 2022 (bottom), and trees on the closer slope at right center that were mostly green in 2021 (top)were dead in 2022 (bottom). Canopy browning of manzanita is less apparent in some areas in 2022 due to growth of new shoots on affected plants.

California fivespined ips

Ips paraconfusus, the California fivespined ips, is widely distributed throughout conifer habitats in the Coast Ranges and extends from the Cascade Range in Oregon to Southern California and to the west slope of the Sierra Nevada. It attacks all of the native pine species found in the Mt. Diablo area, including knobcone, Coulter (*P. coulteri*), and foothill (*P. sabiniana*). It does not affect hardwood species, including manzanitas. This bark beetle mostly attacks pines with relatively thin bark (3-25 mm thick), so sapling and pole-size pines (2.5-25 cm DBH) are more commonly affected, along with the upper small-diameter portions of larger trees. *I. paraconfusus* primarily attacks trees that are stressed by drought or other factors. Notably, the beetles also colonize fresh slash of almost any diameter and reportedly breed more successfully in slash than in live trees. The presence of fresh slash can lead to high beetle populations that are more likely to cause widespread mortality in nearby living, stressed trees.

Pine mortality due to *I. paraconfusus* is typically scattered or limited to small groups of stressed trees. Top dieback of larger trees is also generally scattered. However, outbreaks of widespread mortality can develop in small-diameter stands, such as the affected knobcone pine stands at Mt. Diablo. These outbreaks are normally associated with both stressed trees and the presence of slash. Both of these conditions existed prior to the mass mortality observed at Mt. Diablo in Sept 2020. As noted above, the affected knobcone pines were located on drought-prone soils and experienced an extremely dry period during 2020 and 2021 (Figure 6). Furthermore, large accumulations of slash were created within the affected area as the result of clearing under PG&E transmission lines in 2018 (Cover photo, Figure 10). The large amounts of slash left in these areas could have allowed beetle populations to reach high levels, greatly increasing the attack rate and subsequent mortality of knobcone pines, at least in areas near the slash. Spread of beetles from this area may have increased the areawide populations of *I. paraconfusus* throughout this stand of highly-stressed trees. Drought conditions continuing into the 2021 and 2022 seasons (Figures 5, 6) would have placed the residual trees in affected stands under severe water stress, allowing beetles to move from dead and dying trees killed in 2020 and later to other trees, extending the duration of the outbreak.

Extreme heat episode

As noted above, severe heat episodes occurred in August and September 2020 (Figures 3, 4, 5) that likely contributed to the rapid onset of symptoms in late 2020. A similar extreme heat wave (referred to as a heat dome) occurred in late June and early July of 2021 and caused severe foliar scorching of several conifer species in the Pacific northwest, especially on trees with direct solar exposure and on south-facing slopes. Researchers estimated that more than 200,000 acres were affected across Oregon and Washington from this event. Effects were generally more severe on the western slopes of the Coast Ranges that typically experienced cooler temperatures due to marine influence (https://extension.oregonstate.edu/forests/health-managment/june-2021-heat-impacts-trees-explained, https://www.forestry.oregonstate.edu/heat-dome, Klein et al. 2022). Although most of the research into this event has yet to be published, high air temperatures were associated with foliar necrosis in many different species within the affected area, but variations in heat tolerance were observed. Areas receiving more direct solar radiation and elevated temperatures associated with hot surfaces (such as roads) and trees under water stress were more likely to be affected. Some research indicates that high overnight temperatures, as occurred in the 2020 heat events at Mt. Diablo (Figures 3, 4), may be an important contributing factor to plant damage.

The affected knobcone pine stands are mostly on southwest-facing slopes that would experience significant heating. Exposed light colored rock near many of these trees (including edges and narrow bands) would likely reflect thermal infrared radiation onto nearby trees and may act as heat islands that are analogous to hardscape-related urban heat islands. Figure 11 shows that in many of the affected knobcone pines, dieback initially occurred at the very tops of the trees, which would have been most subject to heat-related scorching due to water stress and exposure to solar radiation. In some cases, scorching of the trees may have encouraged additional beetle invasions that eventually killed the trees. In other cases, the onset of foliar necrosis in pines that were already being attacked by beetles could have been synchronized by the combined effects of the extreme heat and increasing water stress. Either or both of these scenarios may have applied to various trees across the affected area.

3.5. Manzanita

3.5.1. Distribution of dieback

Areas with affected manzanita are fairly evident in aerial imagery from 12 Feb 2021 available on Google Earth. The main distribution of affected plants is shown in Figure 13. The polygons of the affected areas were developed by Heath Bartosh of Nomad. A few small patches of dieback can be seen on ridges to the south and east of the Balancing Rock polygon. Aerial images show patches of manzanita with brown foliage that vary in size, ranging up to about 1 ha (2.5 acres). Within the patches, the density of brown vegetation varies, indicating that levels of foliar necrosis varied with the affected patches. As noted above for *P. attenuata*, all the affected areas are in the rock outcrop areas and other soils with low water holding capacity on the upper member of the Domengine Formation (Tdu) and are on south- to southwest-facing slopes or on ridges. Foliar browning/dieback developed very quickly and more or less synchronously over this entire area.

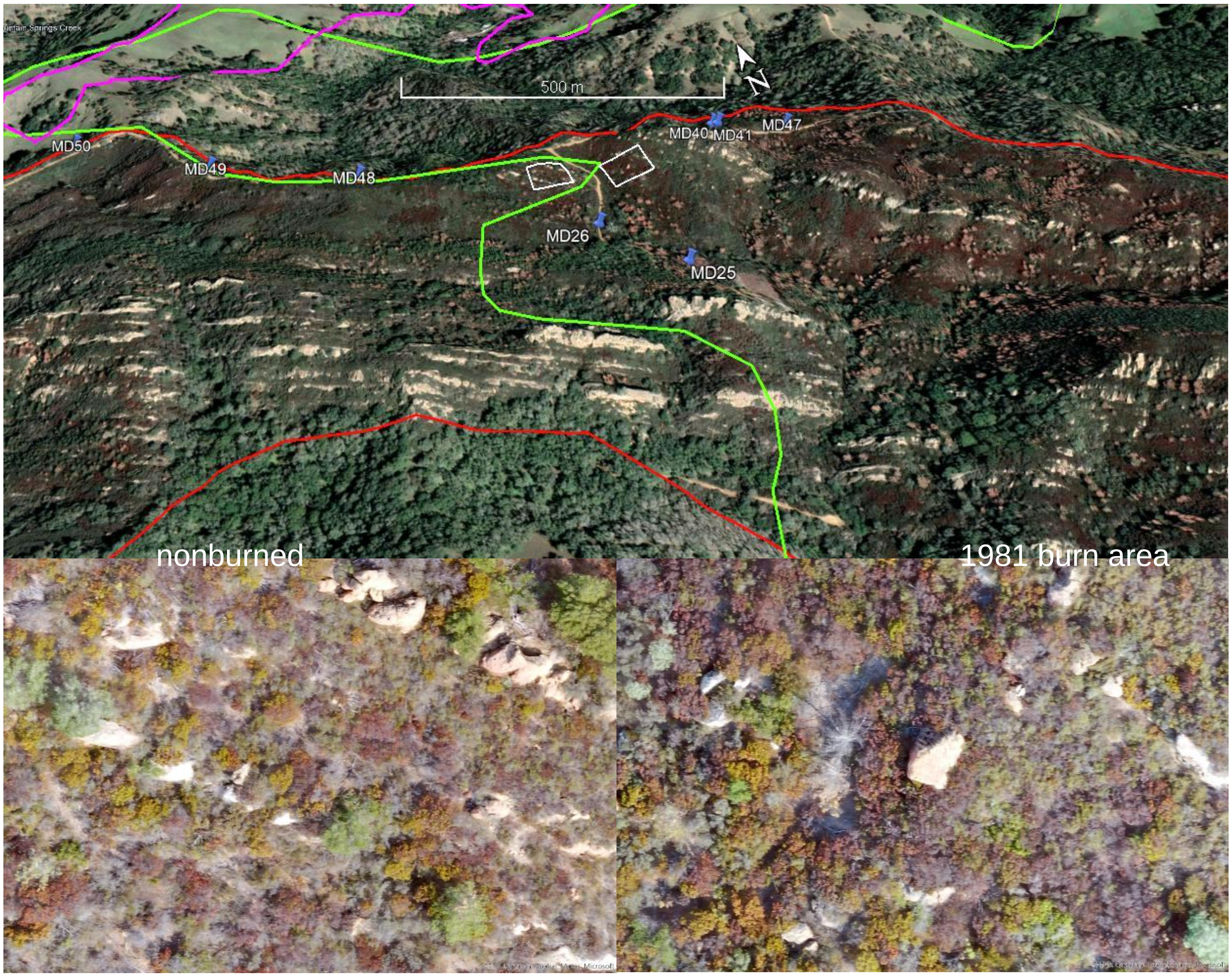

Figure 13. Aerial images of the easternmost (Balancing Rock) portion of the affected area. Top – overview of area in Google Earth 2/12/21 image. Red lines: polygon of the affected area (Balancing Rock). Green line: edge of the 1981 Blackhawk fire polygon; burned area is east (right) of line. Pink line: portion of the 2010 Curry fire perimeter. White squares are the location of the two Sept-Dec 2022 drone image closeups from the unburned (lower left) and burned areas (lower right). Overview shows greater intensity of browning overall within the 1981 burn polygon. Closeups of adjacent vegetation on oppoiste sides of the burn limit show somewhat greater shrub density in the burned (lower right) area relative to the nearly adjacent nonburned area (lower left).

Dieback intensity visually appears to be greater in the portion of the stand within the 1981 Blackhawk fire polygon based on 2/12/21 Google earth imagery (Figure 13), but this visual difference could be due to stand density differences rather than different percentages of affected plants. The stands burned in 1981 would be younger and potentially denser (Figure 13) than stands to the west that have not burned within the period of the CDF-FRAP database records that extend to 1961 in this area. Denser stands are subject to greater drought stress due to interplant competition for limited soil moisture.

At the time of my visits in early 2022, dieback on manzanita was quite variable throughout the affected area, both on the landscape scale and at local scales. Patches of severely affected plants were evident across the area, but the intensity of foliar dieback varied greatly. Within local areas, individual manzanita plants exhibited considerable variation in the amount of foliar necrosis that was visible in 2022. Some manzanitas showed high levels of foliar necrosis and shoot dieback, whereas nearby or even adjacent plants of the same species had only minor amounts of dieback. Many plants that had some previous dieback showed recent shoot growth. This regrowth also contributed to the visual variability in dieback seen among plants in the affected areas.

In some areas, other plant species intermixed with manzanitas also showed dieback symptoms (Table 3). *Salvia mellifera* (black sage) dieback and mortality were observed at sample points MD34 and 35 and *Baccharis pilularis* (coyote bush) was also symptomatic at MD34. *Ceanothus cuneatus* (buck brush) had canopy thinning at multiple locations. *Adenostoma fasciculatum* (chamise) commonly did not show any obvious symptoms where it was intermixed with symptomatic manzanita, but some dieback was seen in this species at several sample locations (Table 3). As discussed under ***Phytophthora sampling*** above, dieback and mortality were observed in some areas in various other woody dicot species including *Quercus chrysolepis* (canyon live oak), *Umbellularia californica* (California bay), *Arbutus menziesii* (Pacific madrone), and *Heteromeles arbutifolia* (toyon)**.**

3.5.2. Distribution of mortality

Both recent and older manzanita mortality were scattered in affected areas. Mortality categorized as recent likely occurred after 2020 and included dead plants that had attached dead foliage and fine twigs. In comparison, older manzanita mortality was characterized by fully defoliated plants with loss of fine twigs and significant weathering of dead stems (Figure 14). In a few areas, recent mortality was seen in the same areas as older dead plants, but we did not observe this situation in most areas.

Because older dead plants typically recede visually into the background, especially after main stems fail, comparative data are needed to make an unbiased comparison of mortality rates over time. These data are probably best collected by aerial imagery because it is very difficult to collect such data in field surveys given the vegetation density and steep terrain. Based on our field observations in the areas traveled (Figure 1) it appeared that recent mortality, though not high overall, may have been somewhat elevated compared with what would be expected from older mortality.

Figure 14. Older dead manzanita (right) at sample point MD32 near plant showing recent dieback (upslope).

An additional caveat relative to recent manzanita mortality is that it was difficult to determine how many of the plants that appeared to have total canopy dieback were actually dead. Upon close inspection, many plants that appeared to be dead still had live tissue, sometimes including new green shoots, in the inner canopy (Figure 15). It is not known at this point how many of the plants with these high levels of canopy dieback may recover. Many plants with lower amounts of dieback had already shown significant recovery by spring 2022.

Figure 15. Many manzanitas that developed complete or nearly complete dieback of the outer foliage were not completely dead in spring 2022. New epicormic sprouts were often present in the inner canopy. Peeling away the thin outer bark showed that stem section above the caliper tip was dead (light brown necrotic tissue under outer bark), whereas the tissue under the outer bark below this point was still green and live.

3.5.3. Interpreting symptoms in affected plants

In Ione manzanita (*A. myrtifolia*), we have observed that foliage remains attached and is a relatively bright cinnamon brown on stems dead for less than a year (Swiecki and Bernhardt 2003). Over time, the dead foliage weathers, accelerated by moisture over the rainy season. Dead foliage becomes darker brown and later a duller grayish brown, gray, or blackish before it eventually begins to fall off. The oldest affected stems are defoliated. We have seen a similar pattern of weathering and defoliation over time in other manzanita species, including *A. pallida* in the Oakland Hills. A similar progression appears to occur for dead manzanita foliage at Mt. Diablo (Figures 16, 17). In photos of affected manzanitas taken by Chris Lee on 10 Mar 2021, the color of recently dead foliage ranges from bright cinnamon brown to somewhat darker or more faded shades (Figure 18). The speed at which the foliage weathers and changes color over time at this site may be affected by fog as well as rain and solar radiation. Nevertheless, the color and retention of dead foliage can be used to assess how long ago dieback occurred.

Figure 16. Recent (occurring within about the past 6 months) shoot tip dieback on manzanitas is characterized by bright medium brown coloration. The symptoms on this common manzanita (*A. manzanita*) are typical of tip dieback caused by *Neofusicoccum* species and related fungi. Image date 2/14/22.

Figure 17. Mt. Diablo manzanita (*A. auriculata*) with extensive foliar and twig dieback. A few brighter brown shoot tips with recent dieback are visible, but most of the foliage is a dull, faded brown, indicating that the foliage was dead before the 2021-22 rainy season. At far left, dead foliage is a light grayish brown and many of the leaves have dropped. This represents foliage that has been dead longer or may have been exposed to greater weathering from sun and wind. Image date 4/13/22.

Figure 18. Common manzanita (*A. manzanita*) plants with moderate (top) and severe (bottom) foliar necrosis. Dieback affected fine branches in the outer canopy. Images courtesy of Chris Lee, CalFire, 3/10/21.

To better quantify the pattern of dieback in affected manzanitas, we sampled 20 dead shoot tips with leaves from the outer canopy of three Mt Diablo manzanita plants with varying amounts of foliar dieback, ranging from about 5% to 95% (Figure 19). Branches were chosen by grabbing shoot tips without looking. Sampling was spread spatially around the outer plant canopy to the degree possible. This sampling was not entirely random but was fairly unbiased. Older dead and defoliated branch tips without leaves in the inner canopy were not included in the sampling since these were not associated with the late 2020 dieback event. If the blindly-selected shoot tip in the outer canopy had attached dead leaves (indicating that it had likely died in late 2020 or later), the dead shoot tip was traced back to the point where the stem tissue was still live, based on the presence of a green cambial layer. The diameter of the dead stem at the live-dead interface point was measured with a digital caliper (Figure 15).

Frequency distributions of the maximum dead shoot diameters (Figure 20) showed that small diameter (≤ 5-6 mm) stems, mostly the youngest terminal shoots, accounted for most of the observed dieback in the three sampled manzanitas. However, the plant with 95% foliar dieback had a few relatively large diameter (14-40 mm) shoots that had died back nearly to the base of the plant (Figure 20, bottom graph). One of these dead branches had a preexisting canker that had been present for many years. The small remaining strips of live tissue that connected to live shoots had finally been killed by the expanding canker after 2020. In the other large branch, the canker from a low branch had rapidly expanded to the subtending larger branch junction, girdling the entire branch at that point (Figure 21, bottom).

Figure 19. Mt Diablo manzanita (*A. auriculata*) plants with low (top, estimated 5%), intermediate (center, estimated near 50%) and high (bottom, estimated near 95%) amounts of outer canopy shoot dieback.

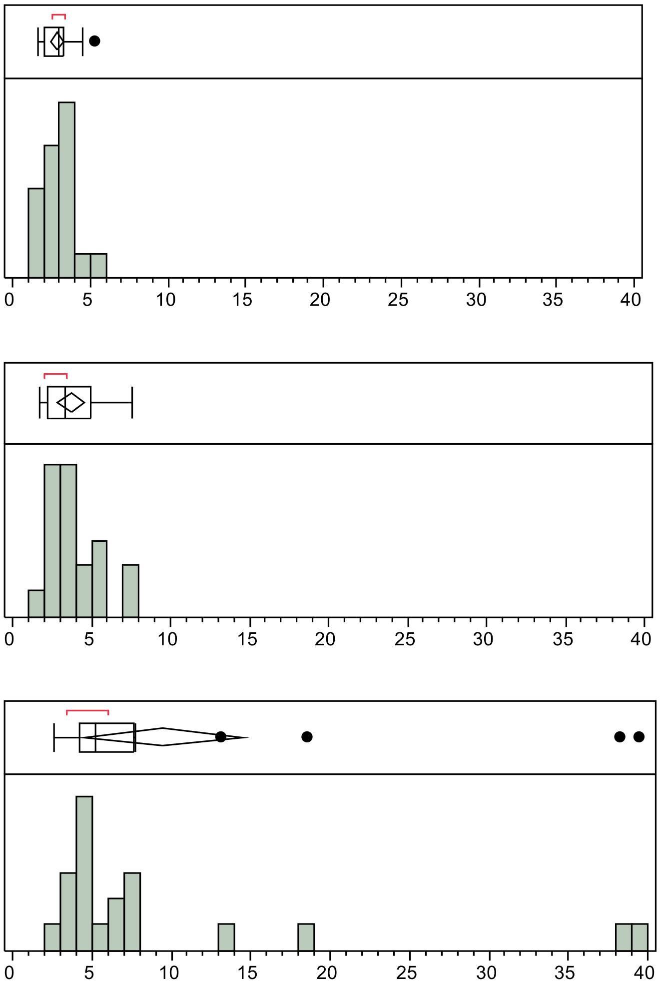

Figure 20. Frequency distributions of maximum dead shoot diameters on Mt. Diablo manzanita plants (shown in Figure 19) with low (top), intermediate (center), and high (bottom) amounts of outer canopy shoot dieback (measurements taken 4/13/22). Smallest bars in each graph indicate one stem, n=20 for each plant.

Figure 21. Large-diameter dead stems on plant with high foliar necrosis. Top – dead stem with old canker that extends nearly to the main stem. This entire branch had been dead for several years. Bottom – 38.3 cm dead stem (from bottom right) apparently killed by extension of canker from older dead branch (right center) into the subtending branch.

3.5.4. Factors associated with manzanita dieback

Fungi affecting stems and leaves

Many plants showed minor amounts of foliar necrosis associated with low amounts of scattered branch tip dieback (e.g., Figure 16). Shoot blighting of this type was most obvious in shoots that died after fall 2020. Such branch dieback is commonly associated with infection by *Neofusicoccum* and related fungi, which initiate new infections by spore dispersal and infection during wet weather. In small diameter branches (≤ 5 mm), twig blighting by *Neofusicoccum* and similar fungi cause twig dieback that typically extend no further than the branch union with the subtending branch.

In some cases, these infections may remain viable in a latent or endophytic state at the base of shoots killed by twig blighting. When a plant has been sufficiently stressed, by conditions such as injury or excessive drought or heat, latent infections can become active and infection may progress some distance into the subtending branch. The extent of canker development is influenced by the condition of the host. A resistant host reaction may restrict fungal infection and only a limited canker may develop. If the infection proceeds without a sufficient host reaction, the canker may expand further. If the canker expands enough to girdle the stem, the entire branch may die back to the location of the girdling canker. When this process is repeated multiple times, successively larger branches can be killed (e.g., Figure 21). Gridling can occur more rapidly when multiple cankers on a stem coalesce as they expand.

Neofusicoccum species and related fungi in the Botryosphaeriaceae can cause perennial cankers that originate from latent infections (Marsberg et al 2017). *N. australe* was isolated from stem cankers on manzanitas in the affected area by Chris Lee (CalFire) and Matteo Garbelotto (UC Berkeley). This same species was previously found to be one of at least two species that cause shoot dieback and cankers in *A. myrtifolia* and *A. viscida* in the Ione area (identified as a *Fusicoccum* sp. in Swiecki and Bernhardt 2003, reisolated and identified by Suzanne Latham, CDFA, in 2015). We isolated both *N. australe* and *N. luteum* from *A. pallida* cankers in the Oakland Hills and *N. australe* has also been isolated from *A. glauca* with branch dieback and cankers in Santa Barbara County (Schultheis et al. 2019).

Cankers caused by *Neofusicoccum* and similar fungi are associated with branch cankers and dieback in many if not all manzanita stands in California. At Mt. Diablo, *N. australe* and potentially other opportunistic stem-infecting fungi have probably contributed to the decline and death of larger manzanita branches over time both before and since 2020. However, the rapid areawide onset of scorch symptoms observed in late 2020 and the distribution of scorch/dieback symptoms within individual plants is not consistent with increased activity of latent canker fungi alone.

Root pathogens

Severe root disease, such as Phytophthora root rot, can cause rapid decline of entire plants, especially during hot, dry conditions. Root disease causes shoot dieback and leaf necrosis by severely restricting or cutting off the supply of water to the shoots and inducing severe water stress. Rapid canopy dieback and plant death can develop fairly synchronously in groups of plants, particularly those at the edge of an advancing disease front. However, the wide distribution of plants that became symptomatic within a very brief period is not consistent with the pattern seen in stands of woody plants affected by an introduced root pathogen such as *Phytophthora*. Furthermore, most of the symptomatic plants were not killed; the root systems of plants with Phytophthora root rot are typically killed before the plant top dries out and turns brown. Also, most of the affected plants were distributed widely across areas where the risk of introduction of exotic soilborne pathogens would be very low. Lastly, no *Phytophthora* spp. were detected in sampling that we conducted, which was focused on areas where vegetation was symptomatic and the risk of pathogen introduction was higher overall due to the proximity of the sites to roads, trails, and other disturbed areas. Although our detection methods may not detect every species of *Phytophthora*, this methodology has been used to detect a wide variety of soilborne *Phytophthora* species in California landscapes. Based on sampling data and other observations, it does not appear that root diseases caused by *Phytophthora* or other introduced agents played a significant role in the observed manzanita dieback in this portion of Mt. Diablo.

Heat scorch interacting with water stress

An unusually sudden decrease in available water can have the same effect as severe root disease, causing plants to become water stressed to the point that canopy dieback and plant death may occur. This effect is more common in mesic plants that have access to a permanent water table that is suddenly depleted or lowered. In highly drought-adapted plants such as manzanitas, drying typically occurs gradually and plants osmotically adjust to deal with progressively more negative water potentials that result from drought stress. In extreme drought, leaves may drop and shoot dieback can occur, and some plants may die back substantially or die completely.

Although drought played a key role in the dieback, the rapid and uniform onset of symptoms is not consistent with soil moisture depletion alone. The relatively synchronous dieback observed in late 2020 is best explained as scorching of sun-exposed foliage and terminal shoots during the periods of high air temperatures in August and September 2020, in combination with high levels of water stress throughout the affected plant populations. Based on the timing of symptom onset and our analysis of the weather conditions, it appears likely that the extreme heat events in late August and early September 2020 (Figures 3, 4) posed an additional heat stress to exposed, critically dry manzanita leaves. This caused lethal overheating of exposed foliage in the driest plants that killed or severely damage the outer foliage and shoots, causing them to synchronously turn brown. Note that drought intensity in 2021 was very similar to levels seen in 2020 (Figure 6), but extreme high temperatures did not develop in the late summer of 2021 (Figure 3). Field observations indicate that no dieback event similar to the late season 2020 event occurred in 2021.

As discussed above, foliar scorching has been documented in many plants in association with extended periods of extremely high air temperatures, such as occurred in both August and September 2021 in the Bay Area. High temperatures interact with solar radiation, so leaves exposed to sun for most of the afternoon (W and S aspects) would be expected to sustain the greatest amount of scorching. Areas where leaves were shaded in the afternoon would be expected to show less damage, and this was observed in various locations where manzanitas were shaded by knobcone pine canopy (Figure 22).

Younger leaves at the outer sun-exposed parts of the canopy are most susceptible to high temperature scorching. Excessive heat and radiation can also affect stems, so small outer canopy twigs and exposed upper sides of larger stems could be subject to heat damage. Images taken by Chris Lee in March 2021 (Figure 23) showed that twig dieback extended further down small diameter young shoots that were more exposed to solar radiation, especially those at the top of unshaded plants.

Effects of excessive heat are also likely to interact with drought, since evaporative cooling will be reduced or lacking, allowing tissues to reach higher temperatures. Hence, scorching due to high temperatures could be variable across the landscape, but is expected to be most intense in south and west facing slopes and ridge tops with limited soil moisture, which is where affected plants were located. Small variations in water status of individual plants due to the extent of their root systems or genetic differences related to drought stress adaptations could account for the plant-to-plant variation in scorching severity seen within stands.

Although no measurements of plant water status were collected in September 2020, Curtis Ewing measured stem water potentials (SWP) of some plants in the affected area on 7 June 2021 and 14 February 2022. June 2021 SWP measurements from five manzanita plants in the affected area ranged from -2.8 to -3.7 MPa, indicating that high levels of water stress had developed by late spring during the dry 2021 season (Figures 6, 7). These few measurements also showed substantial variability in water stress levels between plants within the affected area. SWP measurement in February 2022 ranged from -0.3 to -0.6 MPa, indicating low levels of water stress. The February 2022 readings, occurring after abundant rainfall occurring mostly in October 2021, indicate that plant water potentials were responding as expected to additional soil moisture and low evapotranspiration. This degree of recovery would not be expected in plants with extensive root rot because the lack of healthy functional roots would not allow plants to absorb enough water to recover plant water potentials to this degree.

Figure 22. At this and some other sites where overstory knobcone pines were killed, understory manzanitas did not show substantial canopy dieback. This implicates high heat episodes in 2020 as a main factor causing folar scorching and dieback of manzanita. All plants at this site would have experienced high levels of water stress, but shaded manzanita would have avoided peak leaf temperatures during the heat episodes. This explanation is also consistent with the hypothesis that *Ips paraconfusus* played a significant role in the observed knobcone pine mortality.

Figure 23. Appearance of dieback on common manzanita (*A. manzanita*) on 10 March 2021. Images at right are details of the same plant at left. Shoot dieback is more severe in the upper exposed shoots at the top of the canopy (upper right). Color differences suggest that some leaves were killed earlier, others (dull greenish) had died more recently, probably as shoots died back further. Less initial dieback/scorching occurred in the lower section of the canopy (bottom right), but fading leaves here indicate that shoot dieback was continuing. Photos courtesy Chris Lee, CalFire.

As shown in Figure 23, it appears that some shoots that were severely damage by the August-September 2020 heat event continued to die back over the winter. Some of the leaf and stem tissue damaged in the heat event may have continued to desiccate in the following months. In addition, this damaged tissue would have been susceptible to various agents, including *N. australe* and similar fungi, which could have caused additional dieback and girdling of affected stems. However, field observations and data discussed above (Figure 20) suggest that further dieback of heat-damaged terminal shoots was limited in most plants, leading to varying degrees of refoliation by early 2022 despite continued drought conditions. This suggests that most of the initial damage that occurred in late 2020 was physiological in nature, rather than being primarily due to opportunistic stem pathogens.

4. Management implications and recommendations

4.1. Preventing introduction of *Phytophthora* and other exotic pests and pathogens

Although we did not detect *Phytophthora* in our sampling, the intensity of sampling was not sufficient to conclude that *Phytophthora* was completely absent from the observed areas. However, given that sampling occurred in areas that were at higher overall risk for *Phytophthora* introduction, it is unlikely that the affected area was widely infested with *Phytophthora* . Overall, the *Phytophthora* introduction risk in the areas we surveyed were minimized by the distance of the impacted areas from sources of contamination (such as urban landscaping or habitat restoration plantings utilizing nursery stock). Furthermore, roads and trails in the area receive relatively light use, especially by vehicles. Any changes that increase the amount of foot, bicycle, and vehicle traffic through the area, especially during wet conditions, will increase the overall risk of pathogen introduction unless adequate measures are instituted to reduce this risk.

The appearance of the wide area of dieback in the affected area should serve as a wake-up call for more proactive management of this and other sensitive areas to prevent the introduction of serious pathogens such as soilborne *Phytophthora* species. It appears likely that the dieback and mortality seen in both knobcone pine and manzanitas are not permanent and that over time, both of these plant communities will recover. However, in areas affected by soil borne *Phytophthora* species, negative effects on native vegetation are permanent and irreversible. Severe impacts to native habitats due to *P. cinnamomi* and other soilborne *Phytophthora* species have been documented at other State Park units (including China Camp SP and Jack London SHP) as well as at a number of other parks, preserves, and watershed lands in the greater Bay Area and beyond. Native habitat is best protected by taking steps to improve biosecurity and phytosanitation practices before destructive agents are introduced as there is little that can be done after introduced agents have become established.

Trucks and equipment used in utility line clearance operations, road and trail maintenance, etc., have the potential to transport damaging agents including *Phytophthora* and can inadvertently introduce pests and pathogens into sensitive plant communities. This risk can be minimized by requiring all trucks and equipment to be free of plant material, organic debris, and soil from other locations before entering park or preserve lands to conduct operations. This same basic level of phytosanitation should apply to all contractors or others that conduct work in park and preserve lands. Detailed best management practices (BMPs) specifically for avoiding introduction of soilborne *Phytophthora* species during various work and maintenance activities are available at calphytos.org and http://phytosphere.com/publications/Phytosphere_GGNPC_Soil_Phytophthora_BMPs_Jan2018.pdf

Foot, equestrian, and bicycle traffic through the area also has the potential to move contamination into sensitive areas. Establishing decontamination stations (shoe and tire brushes, etc.) can be used to minimize risks of introducing soilborne pathogens. Decontamination stations should be maintained at trailheads and at the outer bounds of known or likely infested areas. Educational signage should accompany the decontamination stations to both explain their importance and to explain what degree of cleaning is needed to minimize risks.

Grazing animals, especially cattle that are brought from other locations, have the potential to transport substantial amounts of soil and associated plant debris, especially during the wet season or when livestock have been in muddy areas. Livestock operators should also be required to ensure that animals, trailers, and vehicles are free of contamination that could be transported to the site when livestock are offloaded.

4.2. Conifer slash from clearing operations

It is likely that the pine slash left after clearing knobcone pines under transmission lines increased populations of *Ips paraconfusus* in close proximity to highly susceptible stressed, pole-sized trees. Creating slash close to susceptible trees is a known risk factor for initiating outbreaks in susceptible pines. The USDA Forest Service (https://apps.fs.usda.gov/r6_decaid/views/california_fivespined_ips.html) provides a number of guidelines to reduce the risk initiating outbreaks of this beetle during thinning of commercial stands.

These guidelines include the following:

- Do not create green slash with diameters greater than 7.6 cm (3 in) during January through July. Down material less than 7.6 cm (3 in) may be created at any time because it dries out rapidly, and these beetles avoid breeding in partially dried or dried slash.
- Scatter slash in openings away from shade to encourage rapid drying. Slash piles result in shading that slows the drying process and maintains favorable habitat.
- Keep slash at least several yards away from the boles of standing trees. If enough beetles are attracted to slash near trees, adjacent trees may be killed.
- Reduce the amount of suitable breeding material before August by chipping fresh slash, or by trampling slash with heavy machinery to break it into small pieces

> and then scattering it in open areas. The use of heavy equipment in this manner, however, should be carefully prescribed to prevent adverse effects upon soil structure and future stand health.

Other techniques are also discussed in this publication, but not all techniques are applicable to the stands at Mt. Diablo. Most importantly, this publication notes that even the most careful slash management techniques may not be effective during prolonged drought conditions. Under highly conductive drought conditions, slash generation should be avoided altogether, such as by chipping all cut material above the 7.6 cm (3 in) diameter threshold.

4.3. Sudden oak death management

One other situation that should be noted is related to prevention of sudden oak death (SOD), cause by the aerially-dispersed pathogen *Phytophthora ramorum.* Although the climate at Mt. Diablo tends to be drier than is optimal for SOD, conditions can be favorable during wet years. Conditions may be somewhat more favorable in this area due to fog influence, especially on north facing slopes. Furthermore, *P. ramorum* was previously detected on California bay (*Umbellularia californica*) at a location about 2.7 km north of the Balancing Rock polygon by the Garbelotto Lab at UC Berkeley (SODMAP, https://nature.berkeley.edu/garbelottowp/?page_id=755). In various sections of Knobcone Point Road beyond the Balancing Rock polygon (e.g., 37.842887°, -121.883332°), stands of mature overstory SOD-susceptible coast live oaks (*Quercus agrifolia*) and canyon live oak (*Q. chrysolepis*) on north-facing slopes had a relatively dense understory of small diameter California bay (Figure 24). If *P. ramorum* is introduced into this area, high levels of SOD could develop in the oaks under favorable wet winter conditions, leading to extensive overstory mortality of oaks. Given that the oaks are more drought tolerant than bays, the oaks are a more sustainable canopy species under climate change conditions. Furthermore, mortality of these overstory oaks would result in an increased fire risk in the area. Fire risk is already elevated to some degree by the dense bay understory, which creates a ladder fuel situation.

At least near the road, multiple benefits could be achieved by removing these understory bays and some small-diameter overstory bays to proactively protect this oak stand. This strategy has been successfully implemented elsewhere, and is likely to be especially effective at Mt. Diablo, where conditions favorable for SOD occur sporadically. Further details on this SOD prevention method are in Swiecki and Bernhardt (2013).

Figure 24. In a wet year, the understory bay saplings could become infected with *P. ramorum*. The coast live oaks overstory would then have a high risk of being killed by sudden oak death. Removing the bay understory would also reduce understory fuel loading and reduce competition for soil mositure.

Table 3. Description of root/ soil samples collected at Mount Diablo. No *Phytophthora* was detected in any of the samples. Detection of *Pythium* spp. (species not identified) on sample baits is denoted by aqua highlighting in the sample number column. In host species column, boldface indicates the primary species of interest in the sample and highlighting indicates samples in which manzanita (yellow), oaks (green), knobcone pine (blue), or California Bay (violet) were the primary target host.

Point name	Sample date	Sample number *(Pythium detected)*	Host species	Sub-samples	Sample root density	Soil condition	Soil temp C	Symptoms	Sample notes
MD20	2/14/2022	PR20220214-MD20	***Arctostaphylos manzanita**, Adenostoma fasciculatum, Ceanothus cuneatus*	3	high	moist	10.9	Several dead incl old dead, large declining manz	N side of road
MD21	2/14/2022	PR20220214-MD21	***Arctostaphylos manzanita**, Adenostoma fasciculatum, Ceanothus cuneatus, Eriodictyon californicum*	3	moderate	sl. moist, loamy	10.4	manz: 1 dead (>1` yr), 1 live w/dieback	downslope from road
MD22	2/14/2022	PR20220214-MD22	***Arctostaphylos auriculata, A. manzanita**, Adenostoma fasciculatum, Ceanothus cuneatus, Diplacus aurantiacus*	3	high	nearly dry, loamy	12.1	dead AM, AA w dieback	along social trail leading from road
MD23	2/14/2022	PR20220214-MD23	***Arctostaphylos manzanita**, Adenostoma fasciculatum, Eriodictyon californicum, Salvia mellifera*	3		nearly dry, sandy loam	12.1	AM with dieback	along social trail leading from road
MD24	2/14/2022	PR20220214-MD24	***Arctostaphylos auriculata, A. manzanita**, Adenostoma fasciculatum*	3	high	nearly dry, light fluffy texture	11.8	AM with dieback, less in AA	N side of road
MD25	2/14/2022	PR20220214-MD25	*Quercus agrifolia, **Pinus attenuata***	2	high	nearly dry, light fluffy texture	10	Small (7 cm DBH) thin QA surrounded by dead/nearly dead PA	downslope from road, misdlope, N facing
MD26	2/14/2022	PR20220214-MD26	***Arctostaphylos manzanita, Adenostoma fasciculatum,** Baccharis pilularis, **Ceanothus cuneatus**, Diplacus aurantiacus, Lepechinia calycina*	4	high	moist, silty clay loam	13.5	dead AF, thin CC	2 subsamples each opposite sides of road; nearby PISA looks OK

Point name	**Sample date**	**Sample number *(Pythium detected)***	**Host species**	**Sub-samples**	**Sample root density**	**Soil condition**	**Soil temp C**	**Symptoms**	**Sample notes**
MD27	2/14/2022	PR20220214-MD27	soil from creekbed	1	none	moist when sampled but dry when flooded 16 h later		no obvious symptoms	50 g of soil from boots from creek crossing where Vanagon got stuck, very low water flow
MD30	3/7/2022	PR20220307-MD30	***Arctostaphylos manzanita,*** *Adenostoma fasciculatum, Diplacus aurantiacus, Heteromeles arbutifolia*	3	high	moist fine sandy loam	9.1	AM mostly defoliated with live bark, also 1 dead and several with dieback; dead AF, declining QA and QD nearby	downslope from road, toe of slope
MD31	3/7/2022	PR20220307-MD31	***Quercus chrysolepis***, *Diplacus aurantiacus, Pinus sabiniana*	3	high	sl. moist fine sandy loam	8.2	QC with 2 dead stems, others thinning; near dead PISA	downhill side of road
MD32	3/7/2022	PR20220307-MD32	***Arctostaphylos glauca***(?), *Adenostoma fasciculatum*	4	high	moist fine sandy loam	8.5	some old manz mortality, also severe dieback or defoliation on some, new epicormic growth seen	W (downhill) side of road, but partly on rise above road level
MD33	3/7/2022	PR20220307-MD33	***Arctostaphylos auriculata,*** *Adenostoma fasciculatum, Heteromeles arbutifolia*	3	high	sl. moist fine sandy loam, crusty at surface		AA mostly dead, other plants no symptoms	downslope from road NE side across road from MD32. At wide pullout, possible old fire line or control burn area? Charcoal (coal?) on ground in area
MD34	3/7/2022	PR20220307-MD34	***Arctostaphylos*** *sp., Acmispon glaber,* ***Baccharis pilularis, Salvia mellifera***	5	high	compacted dry sandy loam	9.8	dieback and mortality in BP and SM	Low saddle area where water may pool, below road. Prob too dry for BP in severe drought. Area possibly graded in past (fire line?), charcoal (coal?) seen
MD35	3/7/2022	PR20220307-MD35	***Arctostaphylos auriculata, Adenostoma fasciculatum, Salvia mellifera***	3	high	sandy but dense, rocky		dieback especially in SM, also AA, some in AF	edge of previously graded areas adjacent to road but upslope from it

Point name	Sample date	Sample number ***(Pythium detected)***	Host species	Sub-samples	Sample root density	Soil condition	Soil temp C	Symptoms	Sample notes
MD36	3/7/2022	PR20220307-MD36	***Arctostaphylos auriculata, A. manzanita***, ***Adenostoma fasciculatum***, *Pickeringia montana, Salvia mellifera*	3	high	light fluffy sandy loam	12	manz with varying amounts of dieback, mostly long-term (chronic) but some recent, also some AF dieback	plants along both sides of road
MD37	3/7/2022	PR20220307-MD37	***Quercus x chasei, Q. chrysolepis, Q. kelloggii, Q. agrifolia, Arbutus menziesii, Pinus sabiniana***, *Toxicodendron diversiloba*	5	high	moist sandy loam	11	many thinning and declining oak/pine/madrone trees in area, some with epicormic sprouts	subsamples spread out over wide area (MD37A to MD37B) near road/trail intersection in saddle area
MD40	4/13/2022	PR20220413-MD40	***Quercus chrysolepis, Ceanothus cuneatus***, *Diplacus aurantiacus*	4	high	loose moist sandy loam		QC 3/4 dead, Cecu mostly dead; localized patch of symptomatic woody spp including madrone (mostly dead) and bay	slope below road under transmission lines at edge of clearcut
MD41	4/13/2022	PR20220413-MD41	***Arbutus menziesii***, *Diplacus aurantiacus*, ***Heteromeles arbutifolia, Quercus chrysolepis***, *Toxicodendron diversiloba*	4	high	loose moist sandy loam		madrone mostly dead, other nearby trees thin	slope below road under transmission lines at edge of clearcut
MD42	4/13/2022	PR20220413-MD42	***Umbellularia californica***, *Quercus agrifolia,*	4	high	sl. moist clay loam		UC with recent dead top, brown dead foliage QA and QC in stand with possibly some thinning, stand with many dead/dying UC	woodland midslope at edge of grassland
MD43	4/13/2022	PR20220413-MD43	***Umbellularia californica***, *Quercus agrifolia,*	4	high	sl. moist clay loam		mostly dead UC shows long decline, top dieback > 10 ya, dead epicormics, weak basal sprouts	midslope at edge of grassland

Point name	**Sample date**	**Sample number *(Pythium detected)***	**Host species**	**Sub-samples**	**Sample root density**	**Soil condition**	**Soil temp C**	**Symptoms**	**Sample notes**
MD44	4/13/2022	PR20220413-MD44	***Umbellularia californica,*** *Quercus agrifolia*	7	high	nearly dry clay loam		sampled near 3 well-spaced (5-8 m) UC in various stages of long term decline, 2 with recent dieback of epicormics	lower 1/3 slope in stand
MD46	4/13/2022	PR20220413-MD46	***Quercus chrysolepis***	4	high	nearly dry clay loam		young multistem tree with about half of stems dead, others thinning	at edge of road downslope side, near pig trap
MD47	4/13/2022	PR20220413-MD47	***Arctostaphylos auriculata, A. manzanita***	2	moderate	sl. moist loam or clay loam; very shallow with vertical rock strata based on adj roadbed	15	localized area mostly within 5 m of both sides of road with a few dead manz and some with dieback surrounded by mostly OK plants	level area, dirt from road pushed up both sides

8. References

Ender, C. 2022. Technical Memorandum – Baseline Drone Survey of Tree and Shrub Mortality in the Knobcone to Wall Point Areas of Save Mount Diablo and Mount Diablo State Park Lands, Contra Costa County, California. Prepared for Save mount Diablo. Martinez, CA: Nomad Ecology. 33 p.

Graymer, R.W.; Langenheim, V.E. 2021. Geologic framework of Mount Diablo, California. p1-34 in: Sullivan, R.; Sloan, D.; Unruh, J.R.; Schwartz, D. P. eds. Regional Geology of Mount Diablo, California: Its Tectonic Evolution on the North America Plate Boundary. Geological Society of America Memoir 217.

Graymer, R.W.; Langenheim, V.E. 2021. Supplemental Material: Geologic framework of Mount Diablo, California. Geological Society of America. Figure. https://doi.org/10.1130/MWR.S.15148989.v2

Klein, T.; Torres-Ruiz, J.M.; Albers, J.J. 2022. Conifer desiccation in the 2021 NW heatwave confirms the role of hydraulic damage. Tree Physiology 42 (4):722–726. https://doi.org/10.1093/treephys/tpac007

Marsberg, A.; Kemler, M.; Jami, F.; Nagel, J.H.; Postma-Smidt, A.; Naidoo, S.; Wingfield, M.J.; Crous, P.W.; Spatafora, J.W.; Hesse, C.N.; Robbertse, B.; Slippers, B. 2017. *Botryosphaeria dothidea*: a latent pathogen of global importance to woody plant health. Mol Plant Pathol. May;18(4):477-488. doi: 10.1111/mpp.12495.

McMinn, H. E.; Babcock, E. B.; Righter, F. I. 1949. The Chase oak, a new giant hybrid oak from Santa Clara County, California. Madroño 10(2):51–55. http://www.jstor.org/stable/41422647

Schultheis, L.D.; Oono, R.; D'Antonio, C. M. 2019. First report of *Neofusicoccum australe* causing canker disease and branch dieback on *Arctostaphylos glauca* in California. Plant Disease 103(1):158. https://doi.org/10.1094/PDIS-06-18-1026-PDN

Swiecki, T.J.; Bernhardt, E.A. 2003. Diseases threaten the survival of Ione manzanita (*Arctostaphylos myrtifolia*). Prepared for San Francisco State University / California Department of Fish and Game. Vacaville, CA: Phytosphere Research. 49 p. http://phytosphere.com/publications/ionemanzdis.htm

Swiecki, T.J.; Bernhardt, E.A. 2013. A reference manual for managing sudden oak death in California. Gen. Tech. Rep. PSW-GTR-242. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 129 p. https://www.fs.usda.gov/psw/publications/documents/psw_gtr242/

Swiecki, T.J.; Bernhardt, E.A. 2018. Evaluating threats posed by exotic *Phytophthora* species to endangered Coyote ceanothus and selected natural communities in the

Santa Clara NCCP area. Final report. Prepared for Santa Clara Valley Habitat Agency. Vacaville, CA: Phytosphere Research. 135p. http://phytosphere.com/publications/Swiecki_Bernhardt_Evaluating_threats_posed_by_exotic_Phytophthora_species_3-15-18.pdf

Vogl, R. J. 1973. Ecology of Knobcone Pine in the Santa Ana Mountains, California. Ecological Monographs 43(2):125–143. https://doi.org/10.2307/1942191

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