TREE NOTES

CALIFORNIA DEPARTMENT OF FORESTRY AND FIRE PROTECTION

Gray Davis
Governor
State of California

Andrea E. Tuttle
Director

Mary D. Nichols
Secretary for Resources
The Resources Agency

NUMBER: 26 **August 2000**

Oak Mortality Syndrome: Sudden Death of Oaks and Tanoaks

Brice A, McPherson[1], David L. Wood[1], Andrew J. Storer[1], Pavel Svihra[2], David M. Rizzo[3], N. Maggi Kelly[,5], and Richard B. Standiford[5]

[1]Division of Insect Biology, University of California, Berkeley, CA 95720, [2]University of California Cooperative Extension, Marin County, Novato, CA 94947, [3]Department of Plant Pathology, University of California, Davis, CA 95616, [4]Center for Assessment and Monitoring of Forest and Environmental Resources (CAMFER), University of California, Berkeley, CA 94720, and [5]Division of Ecosystem Sciences, University of California, Berkeley, CA 94720.

Unusually large numbers of coast live oak (*Quercus agrifolia*), tanoak (*Lithocarpus densiflorus*), and black oak (*Q. kelloggii*) trees have died in coastal areas of California. This epidemic, currently referred to as oak mortality syndrome or sudden oak death, is characterized by a distinct set of symptoms. The similarity of symptoms on affected tree species is suggestive of a common causal agent. Pathologists at the University of California have recently isolated a previously unknown species of *Phytophthora* from infected trees found in most areas where the syndrome has been reported. This fungus is considered to be the prime candidate for the underlying cause of the syndrome, although more research needs to be conducted to determine all of the interacting factors associated with tree death. Other pathogenic fungi isolated from coast live oaks and tanoaks may also be associated with declining trees. Symptoms include brown or black discolored bark on the lower trunk, exudation of reddish-brown to black viscous sap (seeping, or "bleeding") from the bark, the presence of fruiting bodies of the fungus *Hypoxylon thouarsianum*, and fine granular powder resulting from the tunneling activities of up to three species of bark and ambrosia beetles (Coleoptera: Scolytidae). These symptoms may not all be present on a tree. Foliage of affected trees may appear to die rapidly, turning from green to brown within a few weeks. However, trees in which foliage rapidly turns brown after an initial change in color from yellow-green or gray-green are likely to have had other symptoms for more than one year. No reports of other symptomatic oak species have been confirmed. Valley oaks (*Q. lobata*) co-occur with infected coast live oaks in many locations, but symptomatic trees have not been observed.

Distribution

Tanoaks were first reported dying in large numbers in Mill Valley (Marin County) in 1995. Subsequently, dying coast live oaks and black oaks have been observed. Since then, there have been confirmed reports of symptomatic trees from Sonoma County in the north to Big Sur (Monterey County) in the south. Oak mortality syndrome appears to be particularly severe in Marin, Santa Cruz, and Monterey Counties and appears to be currently confined to the Coast Ranges. Recent observations are consistent with an expansion of the geographic range of affected trees, including reports of mortality from Napa and Alameda Counties. Dying trees have been observed in both urban and rural forests.

Overview

Oak mortality syndrome (sudden oak death) is characterized by the presence of dark sap seeping from the lower trunk. This is a common symptom associated with infection by *Phytophthora* species. Some affected tanoaks may die without exhibiting seeping. Bark beetles and the fruiting bodies of *H. thouarsianum* are organisms typically associated with severely weakened and dead oaks and related hardwood species. Two beetles that tunnel deep into the sapwood are the ambrosia beetles, *Monarthrum scutellare* and *M. dentiger*. These small (2-4 mm long) dark brown beetles generate reddish-brown and light tan to whitish boring dust where they tunnel into the trunk and larger branches. The western oak bark beetle, *Pseudopityophthorus pubipennis*, also tunnels into these trees and excavates galleries under the bark. Because this small (about 2 mm long) beetle feeds in bark and phloem tissue, its boring dust may be darker than boring dust excavated by ambrosia beetles. Adults of these beetle species make small (approximately 1 mm diameter) holes in the bark. None of these beetle species have been reported over the past 50 years to attack trees that are in good health in California. A notable aspect of the early stages of the syndrome is the presence of beetle boreholes and boring dust only below the upper limits of seeping and discolored patches on the lower trunk. Beetles have been observed to colonize late stage symptomatic trees well into the upper trunk and branches.

Fruiting bodies of the fungus *H. thouarsianum* appear as somewhat flattened hemispherical structures that emerge from the bark or wood. These structures range in size from less than 5 mm to greater than 30 mm in diameter. Newly emerged fruiting bodies are shiny black, and covered with a thin crust. These spore-producing bodies become khaki green and powdery as they enlarge or if the crust is disturbed. Older fruiting bodies are a dull dark brown to black.

A characteristic of oak mortality syndrome is the discontinuous and patchy distribution of infected trees. Infection foci or apparent expanding zones of infection are occasionally observed (Figure 1). However, the extensive geographic distribution and apparently rapid appearance of oak mortality syndrome along much of the length of the Coast Ranges are suggestive of a novel pathogen in these forests.

Figure 1. China Camp State Park, illustrating both the clumped and dispersed distribution of dead coast live oaks (reddish-brown trees have died within the previous six months; bare trees were killed earlier).

Field Studies

Twenty field plots have been established at two sites in Marin County, at China Camp State Park near San Rafael and on Marin Municipal Water District (MMWD) property near Fairfax. These sites were selected to represent different species compositions among the oaks and tanoak. In five plots, coast live oak is the only oak species present. Tanoak is found without the oak species in two plots and is mixed with coast live oak in five others. The other plots feature various combinations of coast live oak, black oak, and valley oak, in stands mixed with Douglas-fir, redwood, madrone, bay laurel, and toyon. Plots measure approximately 1/10 ha and contain between 25 and 50 trees. All tanoak, coast live oak, black oak, and valley oak trees greater than about 5 cm diameter measured at breast height (150 cm) have been tagged and initial symptom status recorded. Each tree has been geolocated using a survey grade global positioning system (GPS). These trees are being reevaluated every 6 to 8 weeks to monitor any changes in symptoms and extent of mortality.

Progression of Symptoms of Tree Decline

The similarities of the symptoms in the three tree species discussed here are suggestive of a common causal agent. The earliest symptoms are typical of infection caused by *Phytophthora* species and this is the only organism that has been isolated from all three hosts at the earliest onset of symptoms. Because the manifestation of symptoms differs between species, each will be described separately. For mature coast live oaks and black oaks, seeping precedes the other observed symptoms. Where beetles are present, they appear to tunnel first into the bark that overlies necrotic, seeping tissue. Fruiting bodies of *H. thouarsianum* may subsequently emerge from the bark, apparently where underlying tissue has been killed. Neither these fungi nor beetles have been found on the lower trunks of trees with green foliage, in the absence of seeping. The appearance of the seeping symptom on tanoaks may be much less distinct than for the other tree species. Some symptoms appear to differ between mature and juvenile tanoaks. Juvenile tanoaks may die without any bark discoloration, bleeding, or beetle infestation, but discoloration is apparent in the cambial area from which *Phytophthora* can be isolated.

Coast Live Oak:
Observations of greater than 450 individual trees in the two Marin County sites present a general sequence of symptom appearance (Figures 2A). The initial symptom observed in trees is seeping, characterized by a dark reddish/brown to black viscous liquid that exudes from the bark, typically on the lower trunk (Figure 3). The number of individual seeps observed on a tree is considered to indicate the severity of the infection. Mosses and lichens are killed where they are in contact with the exudate, an effect that can be a useful first indication that a tree is symptomatic. In coast live oak, the condition known as “wetwood” may be confused with the seeping described here. The seeping of oak mortality syndrome leaves a viscous, dark colored exudate that hardens on the bark to a solid mass. Wetwood is characterized by a clear, non-viscous discharge well above the root crown, often found above 3 m on the trunk or on larger branches. The residue of the wetwood condition does not leave a hardened residue.

Infection begins in the bark (phloem), progresses to the cambium, and eventually to the xylem. The

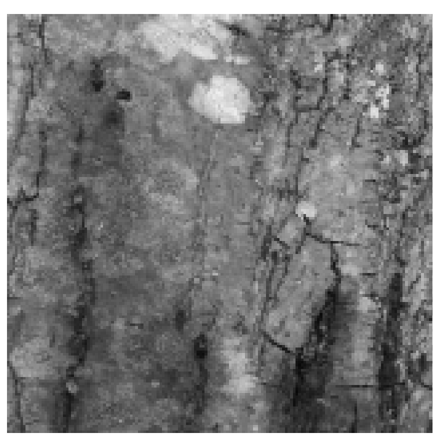

Figure 3. (above) Characteristic appearance of seeping in coast live oak.

Figure 4. (above) Infection of coast live oak by *Phytophthora* causes a characteristic lesion in the bark.

Figure 2A. Observed sequence of symptom appearance in living coast live oak. Arrows indicate observed transitions among symptomatic stages.

Tree has dark green foliage, no trunk symptoms.

Seeping appears on lower trunk, appearing as reddish-brown to black viscous discharge. Seeps are typically initially located near the root crown, but may be found up to several meters high. Bark may be cracked, in association with the seeping patches. Mosses and lichens growing on the trunk are killed and appear as brown patches where they are in contact with the exudate. Foliage is dark green.

Seeping patches may expand their coverage of the trunk, up to 2 meters or higher. The trunk may have multiple, apparently independent seeps. Insect attacks are not apparent. Foliage is dark green.

Bark and ambrosia beetles tunnel into the bark within the seeping patches. Bark directly above seeping zones is not attacked. Boring dust appears as reddish-brown to pale brown to whitish piles on the bark and may be abundant in crevices, in spider webs, and on the ground under the tree.

Fruiting bodies of *Hypoxylon thouarsianum* appear on the trunk below the upper perimeter of seeping patches.

Foliage color turns from dark green to a pale lime-green, then to yellow-brown, then to reddish-brown. Frass from beetle activity is abundant.

Brown leaves are retained on the dead tree for months, and possibly up to one year.

Figure 2B. Observed sequence of symptom appearance in tanoak. Arrows indicate transitions among symptomatic stages.

Tree has dark green foliage, no trunk symptoms.

Foliage turns from dark green to yellow-green, to light brown. Seeping may or may not be detected. This sequence is particularly characteristic of juvenile trees.

or

Seeping appears on the lower trunk. This may be represented by small, light to dark stains or by droplets of hardened reddish-brown to black exudate. On those trees with few seeps, these tend to be located near the ground (lower than 20 cm), or may be on the upper surface of exposed roots.

Seeping may become extensive, covering more of the trunk, typically within 2 m above the ground, but occasionally up to 3 m or more up the trunk.

Bark and ambrosia beetles tunnel into bark, often entering through natural fissures. Beetles are found on larger diameter trees. Boring dust may be abundant, particularly in crevices, spider webs, and on the ground under the tree.

Fruiting bodies of *Hypoxylon thouarsianum* may be found on the main stem. These structures may appear to a height of 5 m or greater.

Foliage may become bleached and yellowed. Branch tips may wilt and turn brown, as if treated with herbicide. In latter stages, leaves turn pale yellow-green, then brown. New shoots may appear at the base. These typically wilt before they reach about 50 cm.

Brown leaves may be retained on dead trees for 6 months or more. Basal shoots may be produced for at least several years after the main stem is dead.

phloem is often a bright red color with numerous thin black lines that delimit the canker (Figure 4). Infection and discoloration are always more extensive in phloem tissues than xylem. Black discoloration can extend up to 2 cm into the xylem below the seeping canker. The extent of the area affected below the canker is often not correlated with the appearance of the outer bark. Discoloration in the phloem and xylem may extend up to 50 cm in all directions from the point of seeping. *Phytophthora* is typically isolated from the margins of these discolored areas, although it can often be isolated from older portions of the cankers.

Beetles may attack these trees once the seeping is visible. These beetles can produce copious amounts of boring dust (Figure 5). Observations in Marin County reveal that beetles begin to emerge from host trees in mid to late March, with a second emergence beginning in late July to August. Beetles fly to new host trees, producing entrance tunnels where the conditions are suitable. Trees with extensive seeping often exhibit approximately uniformly spaced entrance tunnels, which can be observed up to 5 m and higher on the main stem as well as on side branches.

Fruiting bodies of the fungus *H. thouarsianum* may appear on the trunk, typically below a region with seeps (Figure 6). The fruiting bodies of these fungi appear to be associated with dead tissue under the bark, and often are found on patches of older seeping bark.

As the syndrome progresses, the foliage becomes a pale green to yellow-green color, and may rapidly fade to brown in a matter of weeks. This color change is associated with slightly cupped leaves that are twisted away from the sunlight. Once this stage has been reached, foliage does not recover. A tree with brown foliage is considered dead. A distinctive characteristic of these dead trees is retention of dead leaves for up to six months or longer. Some sprouting from the base of late symptomatic trees has been observed, but this does not appear to be a common attribute of coast live oaks. These shoots characteristically wilt and die

Figure 5. Beetles can produce copious quantities of boring dust.

Figure 6. Fruiting bodies of *Hypoxylon thouarsianum* typically occur on trees in an advanced state of infection.

within months. Coast live oak advanced regeneration is rare in the shade of mature trees in our study plots. Therefore, the syndrome is not described for small coast live oak trees.

Tanoak:
Observations on over 150 tanoaks provide the basis for the sequence of symptom appearance (Figure 2B). The appearance of seeping in tanoak is similar to that in coast live oak (Figure 7). In tanoak, seeping can be the earliest indication of the syndrome, but, particularly in smaller understory trees, rapid browning of foliage may occur in the absence of seeping. On those trees with few seeps, these tend to be located near the ground (below about 20 cm). Where seeping is found up to a height of 2 meters or more, the number of these patches can exceed 10 per tree. Detection of seeping on the bark of large (>50 cm diameter) tanoaks can be difficult due to the very deeply furrowed and dark-colored bark, particularly where seeps are from a previous year. Older seeps overlie dead tissue, which may no longer produce sap. Phloem and xylem symptoms are similar to those of coast live oak. Cankers on smaller tan oaks are not as distinct and zone lines are not always apparent in either the phloem or xylem. *Phytophthora*, however, is isolated from the margins of discoloration in the cambium and phloem.

The same three bark beetle species associated with coast live oaks apparently attack tanoaks and are observed first at or below zones of seeping. Trees with brown leaves may exhibit beetle infestations beyond the seeping areas in the lower trunk. The appearance of a tanoak under beetle attack is similar to a coast live oak. Evidence of tunneling beetles is more likely to be found in the deep crevices of bark on larger trees. Observations in both tanoak and coast live oak dominated forests suggest that a lower proportion of symptomatic tanoaks may be attacked by these beetles.

Fruiting bodies of *H. thouarsianum* may be found on the lower trunk, frequently associated with vertical fissures in the bark.

Foliar symptoms differ from those in coast live oak. Symptomatic tanoak foliage is characterized by yellowing leaves, as well as dead brown leaves

Figure 7. The appearance of seeping in tanoak trees.

interspersed with dark green leaves. Some branch tips exhibit drooping, in which both the twigs and leaves wilt (Figure 9). A symptomatic tanoak often shows a number of brown and pale green to green-tinted, light brown leaves dispersed among the evergreen leaves. These leaves turn a darker brown with time. Neither *H. thouarsianum* fruiting bodies nor beetles have been found on trees with green foliage and without seeping. Sprouting from the root crown is common as the foliage dies. These shoots often wilt and die within a growing season, but their long-term fate is not known.

Black Oak:
The study sites evaluated so far have not had a large number of black oak trees in the stands. Symptoms of those trees affected include trunk seeping, the presence of *Hypoxylon* fruiting bodies, and boring dust, likely generated by the three bark beetle species noted above. As the bark of black oak tends to be more deeply and consistently fissured than either coast live oak or tanoak, the boring dust is typically found in these deeper, vertical crevices. Dissection of seeping areas reveals symptoms in phloem and xylem that are similar to those observed in diseased live oaks. In the year 2000 growing season, symptomatic trees flushed healthy green foliage, but by mid-May, the foliage on some trees changed from bright green to yellowish green within a period of several weeks. Too few understory and sapling black oaks have been observed to evaluate their symptoms.

Figure 8. Wilting of shoot tips in tanoak.

Biological Questions

The interaction of various biotic and abiotic environmental factors is likely to have influenced the development of this syndrome over its extensive geographic range. Over the past decade, both prolonged drought and record high levels of precipitation have characterized the California climate. Generally, stressed trees have elevated susceptibility to various diseases and insects. The combination of drought and high rainfall levels is unlikely to have caused the observed widespread mortality, in the absence of a pathogenic organism.

The symptoms observed are consistent with the effects of a fungal pathogen. Every tree species has defenses against pathogens and insects, but may not be resistant to a virulent pathogen to which it has had no previous exposure. The historic record of introduced pathogens affecting a tree species over entire forests or landmasses includes chestnut blight in North America (caused by *Cryphonectria parasitica*), Dutch elm disease in North America (caused by *Ophiostoma novo ulmi*), pitch canker disease in California (caused by *Fusarium circinatum*), jarrah dieback in Australia (caused by *Phytophthora cinnamomi*), and ongoing oak diebacks in Mexico and Europe (caused by *Phytophthora* species including *P. cinnamomi*). The presence of opportunists such as *Hypoxylon* and bark beetles could be a consequence of the trees being weakened by an introduced pathogen.

Prospects

Coast live oak, black oak, and tanoak trees are characteristic components of the forested and urban landscape of coastal California. These trees are generally capable of withstanding wildfires. Tanoaks and coast live oaks occur in a number of habitat types, sometimes in nearly pure stands. As tanoaks die in large numbers in coast redwood and Douglas-fir forests, the likelihood of large crown fires is increased. Increased tree mortality will also result in accelerated accumulation of fuels on the ground. The many communities that are built within and adjacent to these coastal forests are increasingly at risk for wild fires. In addition, many species of wildlife depend upon acorns for food, including rodents, birds, and deer. The insect herbivores of oak leaves are also food for numerous bird species.

Recommended Treatment

There is currently no known control of this syndrome. *Phytophthora* species are primarily moved in water and soil. Spread of the pathogen in the highly populated areas of California has probably been enhanced by hikers, bikers, and vehicles, as well as by cattle, horses, deer, and other vertebrates. The possibility that the pathogen is spread by insects, including bark beetles, is being investigated. Prevention of the movement of soil and wood may slow the spread of the fungus to areas that are not infested. Some fungicides are available for control of *Phytophthora* species in landscape oaks, and these are being tested as a cure or preventative for the current oak mortality.

Where individual trees are identified as having the early symptoms of seeping, judicious application of insecticide may prevent beetles from infesting the trunk and may prolong the life of a tree. The insecticide ASTRO® may be sprayed on the trunk of trees up to a height of 2.7 to 3.3 m, preferably **before** beetles have attacked them. Preliminary evidence suggests that this treatment can prolong the life of a tree, although the underlying pathogenic condition may may result in tree mortality in the absence of beetles. Before considering treatment, the County Agriculture Commissioners Office must be contacted in order to secure a homeowners' pesticide applicator permit. Follow EPA label instructions for applications of this and all pesticides. This treatment is not recommended for trees in forests and woodlands.

The mechanisms of spread of this syndrome are not known. Wood from oak and tanoak should not be moved out of infested regions. Within infested regions, wood should not be moved to areas where the syndrome appears to be absent.

Not all oak trees are dying of this new syndrome even in areas where the syndrome is prevalent. There are a number of pathogens and insects that attack oaks that are capable of occasionally killing trees. Several *Phytophthora* species (*P. cinnamomi*, *P. cactorum*, and *P. citricola*), as well as *Armillaria mellea*, have long been known to infest trees in low-lying areas that are over-watered or stressed for other reasons (e.g., soil compaction). Accurate diagnosis is critical to prevent overuse of chemicals. Seeping caused by these well-known *Phytophthora* species will probably be very similar or identical to oak mortality syndrome. However, these species can often be controlled by reducing the source of water. The new *Phytophthora* that has been isolated has come from hillsides in campgrounds, state parks, and recreation areas, and does not appear to require over-irrigation or low lying areas to infect trees.

Research Needs

Research on a number of aspects of this problem is presently being pursued. The research objectives of a team composed primarily of University of California researchers include:

- » Determine the geographic extent and distribution of the epidemic within California;
- » Develop effective remote sensing methodologies to evaluate the extent of affected trees;
- » Develop management options to mitigate the impacts of the syndrome;
- » Determine the movement of the disease over landscapes:
- » Identify the tree species presently affected, and those potentially at risk;
- » Develop a severity rating system for evaluating the risk of oak mortality syndrome;
- » Determine possible roles of climate, soil type, and anthropogenic disturbance;
- » Determine the progression of symptoms within stands;
- » Determine the role(s) of beetles in tree death;
- » Determine the ecological impacts of changing species compositions of forests;
- » Determine the mechanisms by which causal agents are vectored;
- » Evaluate the changing risks from wildfire due to increases in standing dead fuel.

The California Oak Mortality Task Force has been formed to address research, management and regulation, education, and fire needs relating to oak mortality. Information about this Task Force is available at links listed below.

Further Reading and Online Resources:

Svihra, P. Protecting Live Oaks Against Bark Beetles and Ambrosia Beetles. Pest Alert #3B., January 2000, University of California Cooperative Extension, Marin County, 4 pp.

http://camfer.cnr.berkeley.edu/oaks

http://cemarin.ucdavis.edu/

http://frap.cdf.ca.gov/oak_mortality

http://www.cnr.berkeley.edu/forestry

http://www.suddenoakdeath.org

Metric-English Conversions
1/10 ha = 1/4 acre
1 mm = 1/25 inch
2 mm = 1/12 inch
4 mm = 1/6 inch
5 mm = 1/4 inch
30 mm = 1 1/4 inch

Jesse Rios: Editor
CDF Forest Pest Management (916) 653-9476