SUDDEN OAK DEATH IN CALIFORNIA

Integrated Pest Management in the Landscape

Sudden oak death is the name given to an epidemic, first detected in 1995, that affects three true oak species—coast live oak (*Quercus agrifolia)*, California black oak (*Q. kelloggii*), and Shreve oak (*Q. parvula* var. *shrevei*)—and tanbark oak (*Lithocarpus densiflorus*). Additional species affected include rhododendron (*Rhododendron* spp.), madrone (*Arbutus menziesii*), California huckleberry (*Vaccinium ovatum*), California bay laurel (*Umbellularia californica*), California buckeye (*Aesculus californica*), bigleaf maple (*Acer macrophyllum*), toyon (*Heteromeles arbutifolia*), and manzanita (*Arctostaphylos* spp.). A previously undescribed pathogen, *Phytophthora ramorum*, has been identified as the infectious agent.

Figure 1. The rapid decline of oak trees in the landscape may signal sudden oak death.

The disease is currently known to exist in the coastal ranges in California, between Big Sur in Monterey County and southern Mendocino County. Sudden oak death has been confirmed in Alameda, Marin, Mendocino, Monterey, Napa, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma counties. This disease has also been reported from several locations in southern Oregon. Within the affected counties, both the severity and occurrence of the disease vary considerably across the landscape. Infected trees are abundant in Marin, Mendocino, Monterey, Santa Cruz, and Sonoma counties. It is not known if the geographic distribution of infected trees is associated with climatic variables. Attempts to assess distribution patterns within California through surveys are currently under way. The numbers of infected and dead trees are suspected to be in the tens of thousands.

Before the recent discovery of sudden oak death in California, *P. ramorum* had not been known in North America. The pathogen was first reported in Europe in 1993 where it was infecting rhododendron (*Rhododendron* spp.) in nurseries but was not recognized as a new species until 1999. Death of oaks and tanbark oaks in areas of California outside the ten reported counties does not appear to be caused by this new *Phytophthora* species. Based on field observations and laboratory cultures, mortality of oaks and tanbark oaks outside the infested areas appears to be a result of the normally expected causes, and oaks in these areas are not dying at a greater rate than previously observed.

IDENTIFICATION

At present, the only definitive ways to diagnose a sudden oak death *Phytophthora* infection in a tree are by culturing the pathogen or by amplifying the DNA using PCR (polymerase chain reaction). No single field symptom is sufficient for diagnosis. Molecular probes for routine detection of the DNA of the pathogen are under development, though these may not discriminate between active and inactive infections. When trees with characteristic symptoms of sudden oak death are found within forests or woodlands where the disease is already confirmed, these trees are likely to be infected with *P. ramorum*. Infected trees are typically found in the proximity of other infected and dead trees (Fig. 1). To date, this disease has been found infecting oaks in forests, woodlands, and urban-wildland interfaces.

Symptoms of sudden oak death differ among the known hosts (Table 1). One characteristic of this *Phytophthora* infection in oaks and tanbark oaks is the sudden simultaneous leaf death on a major stem or an entire tree, an observation that gave rise to the term "sudden oak death." The occurrence of leaf death may occur a year or more after the initial infection by the pathogen and many months after the tree has been girdled.

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Table 1. Species Known to Be Infected by *Phytophthora ramorum* and Characteristic Symptoms.

Family/Species	External symptoms and indications
FAGACEAE	
Lithocarpus densiflorus (tanbark oak, tanoak)	Abnormal foliage is often the first symptom, showing dead leaves intermixed with green. Branch tips and basal shoots may wilt and turn brown ("shepherds' crook"), while the leaves on the rest of the stem remain green. When the tree dies, the foliage may turn color to reddish brown within weeks. Seeping cankers on the trunk usually within 6 feet of the ground, but sometimes much higher, can appear as red to brown stains, or as droplets, often translucent red, exuded from the intact bark. Dead lichens and moss may be evident as well as *Hypoxylon* fungi and red or white boring dust from bark beetles.
Quercus agrifolia (coast live oak)	Seeping from the lower trunk is the most reliable early symptom. This appears as red to brown stains, or often as hardened brown to red droplets. When the tree dies, the foliage may turn color to reddish brown within weeks. Bark beetle boring dust and *Hypoxylon* fungi may be present. Dead and stained moss may be evident.
Q. kelloggii (California black oak)	Seeping is the earliest visible symptom, but is often obscured by the fissured, dark brown, nearly black bark. The presence of bark beetles' boring dust and fruiting bodies of the fungus *Hypoxylon* may be more reliable indicators of infection. The deciduous habit of this species limits the usefulness of foliage conditions as an indicator of infection.
Q. parvula var. *shrevei* (Shreve oak)	Similar to those on coast live oak.
ERICACEAE	
Rhododendron spp.	Leaf spots and necrotic (dead) areas; twig and stem cankers.
Vaccinium ovatum (California huckleberry)	Leaves exhibit necrotic patches; both twigs and whole plants may die.
Arctostaphylos spp. (manzanita)	Leaf spots and necrotic areas; twig cankers and dieback.
Arbutus menziesii (madrone)	Leaf spots and necrotic areas; twig cankers and dieback.
CAPRIFOLIACEAE	
Lonicera hispidula (California honeysuckle)	Necrotic lesions on leaves.
Viburnum x *bodnantense*	Leaf wilting; infection on stem develops up from base.
HIPPOCASTANACEAE	
Aesculus californica (California buckeye)	Leaf spots and lesions on petioles.
ACERACEAE	
Acer macrophyllum (Big-leaf maple)	Leaf spots and necrosis on leaf margins.
LAURACEAE	
Umbellularia californica (California bay laurel)	Leaves have necrotic lesions.
RHAMNACEAE	
Rhamnus californica (California coffeeberry)	Leaf spots and necrotic areas; twig cankers and dieback.

Oaks

On coast live, California black, and Shreve oaks, the primary symptom is dark, hardened sap exuding from the main trunk, most often near the base of the trunk and up to about 6 feet above the ground (Fig. 2). These seeps ("bleeding") are always found above the soil level on the trunk and can also occur on exposed roots. Less frequently, this seeping is found much higher on the main stem. Seeps often appear to emerge through intact bark. They may take the form of discrete red, brown, and black droplets, viscous oozing, stalactite-like drips, and red to brown stains on the trunk. Mosses and lichens are killed where they are contacted by the exudate. Their death may often be the only reliable indication that a tree is seeping. The seeping is the external manifestation of an underlying, diseased area of the tree, referred to as a canker. Removal of the surface bark reveals discolored brown tissue, separated from healthy bark by

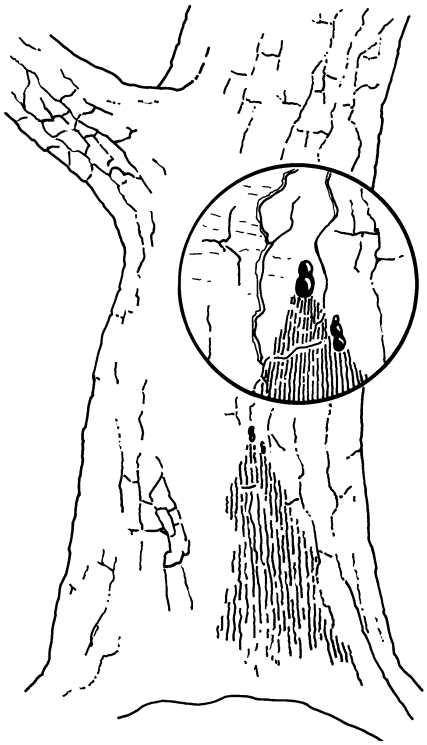

Figure 2. Diseased bark is a key symptom of sudden oak death on oak trees. *Inset:* Closeup of sap exuding from the trunk, causing bark discoloration.

a distinct black zone line. This zone line represents the active front of the *Phytophthora* infection. The foliage may appear healthy until shortly before it turns brown. Before turning brown, the leaves can be olive-green, pale green, and yellow-green for a period of weeks to months. Infected coast live oaks may also lose leaves before they die.

Tanbark Oaks

The most consistent initial symptoms in tanbark oaks are wilting branch tips and dead leaves interspersed among green leaves throughout the tree. Thus, a symptomatic tree may show a number of pale green, light brown, and darker brown leaves among the darker, evergreen leaves. Seeping is not a consistent characteristic of infected tanbark oaks, though this may be prominent on some trees. While understory and seedling tanbark oaks infected with sudden oak death *Phytophthora* may die without any external bark discoloration or bleeding, proof of infection has been determined by isolation of the pathogen from discolored areas in the cambium (tissue under the bark) of these trees. The pathogen has also been found on the leaves of these trees.

Infected trees with brown foliage are effectively dead, although there may be some sprouting from the tree bases. Many of these new shoots will wilt and die within a growing season.

Additional Indications of Sudden Oak Death. Oak and tanbark oak trees infected with sudden oak death can also be infested with bark beetles and have *Hypoxylon* fungus growing on the trunk. These secondary pests are not unique to trees with sudden oak death but can serve as a good indication that the tree is ailing.

Beetles in the family Scolytidae, such as the western oak bark beetle (*Pseudopityophthorus pubipennis*) and ambrosia beetles (*Monarthrum dentiger* and *M. scutellare*), may be associated with infected oaks and tanbark oaks in unusually large numbers. These insects are normally found in severely weakened and recently killed or fallen trees. The entrances to beetle tunnels closely track the seeping on the bark of trees bearing green foliage and are marked with red or white frass (wood residue from the beetle's tunneling activities) around and beneath the tunnel entrances. Extensive observations indicate that nearly all coast live oaks that die following infection with *P. ramorum* have been colonized by these beetles before dying.

Fruiting bodies of the fungus *Hypoxylon thouarsianum* are frequently found associated with both active and older seeping areas on the lower portions of the trunk of living oaks and tanbark oaks infected with sudden oak death *Phytophthora*. Fruiting bodies are somewhat flattened, dome-shaped structures (Fig. 3) that start out khaki green in color, but turn brown and then black as they age. These fruiting bodies indicate the presence of dead wood and are normally present on dead branches of living trees and on the trunks or branches of dead trees. In areas affected by sudden oak death, these fruiting bodies are rarely observed on the trunks of living trees in the absence of *P. ramorum* infection.

Other Hosts

Symptoms vary considerably among the other hosts and are primarily expressed in the leaves. *Rhododendron* species exhibit foliage symptoms, including brown spots and patches, particularly at the leaf tips. Twig and stem dieback are also common and may result in the death of plants. On huckleberry, the disease primarily causes twig and stem dieback, and ultimately, plant death. Leaves may exhibit necrotic patches leading quickly to abscission. In madrone, the symptoms are spots and necrotic areas on leaves, twig cankers, and stem dieback. Large branches and even entire trees may be killed. However, disease caused by *P. ramorum* is difficult to distinguish from cankers and twig dieback caused by *Nattrassia mangiferae* and *Fusicoccum aesculi*. Symptoms on manzanita appear to be similar to those on madrone. Bay laurel, buckeye, and big-leaf maple

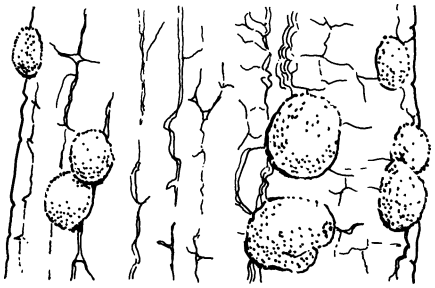

Figure 3. Fruiting bodies of *Hypoxylon* fungus on a tree trunk.

Other Conditions Confused with Sudden Oak Death

Other *Phytophthora* species (*P. cinnamomi*, *P. cactorum*, *P. citricola*) may cause seeping that resembles the symptoms of sudden oak death. This is especially true in irrigated landscapes. Even in areas where *P. ramorum* has been identified, a number of other pathogens are also capable of occasionally killing trees. Trees that are overwatered, located in low-lying areas, or stressed by soil compaction, root damage, or soil piled against the trunk may also appear to have sudden oak death but may be infected with *Armillaria mellea*.

Oaks and other hardwood species may develop a condition known as wetwood, which superficially resembles sudden oak death. Wetwood is distinguished by thin, watery, light to dark brown seeps, which are often associated with old branch holes or wounds, and they are usually found higher in the tree. *Phytophthora ramorum* does not appear to be dependent on pre-existing wounds or old branch stubs. Bark and ambrosia beetles have not been observed to be associated with wetwood seeping. This condition is not considered to be a serious health problem for trees.

Two fungal pathogens of oaks and tanbark oaks can produce crown symptoms similar to those of sudden oak death. *Diplodia quercina,* which causes oak branch dieback, is associated with drought and *Cryptocline cinerescens*, which causes oak twig blight, is associated with wet conditions. In conifer-growing areas, herbicide damage to tanbark oaks may be mistaken for *P. ramorum* infection.

leaves show necrotic lesions; lesions on petioles and small twigs have been noted on California buckeye. For these species, the foliage symptoms may be similar to other endemic diseases. Seeping has not been noted on these non-oak hosts.

DISEASE CYCLE

The biology, expression, and results of infection by *P. ramorum* can vary considerably among host species. The expression of symptoms is best understood for oaks and tanbark oaks but less so for shrubs such as rhododendron, huckleberry, and other known host tree species. In coast live oak, artificial inoculations of mature trees produced cankers up to 22 inches long (mean length 11 inches) within 16 weeks. Cankers in similarly inoculated tanbark oaks were up to 28 inches (mean length 18 inches). A number of inoculated trees were completely girdled (i.e., the infection spread around the entire circumference of the tree) by the pathogen during this 16-week period. Browning of the foliage occurred on several inoculated trees within one year. It is not clear whether viable spores are released from oaks and tanbark oaks. Where *P. ramorum* infects the leaves of host plants (particularly rhododendron, bay laurel, and tanbark oak), it has been found to readily produce spores on the leaf surface.

The vertical distribution of cankers on oaks and tanbark oaks and the presence of foliar and twig infections on other hosts is consistent with both aerial and rain splash modes of spore dispersal that are typical for many species of *Phytophthora*. There is no evidence for transmission by insects or other vectors.

Phytophthora ramorum appears to establish discrete infections in its hosts. In oak hosts, and especially in tanbark oaks, multiple independent cankers are common. These bark cankers may then expand and colonize more tissue, leading to girdling of the tree. Infection in the other hosts may be initiated in the leaves or stems.

DAMAGE

The ecological consequences of sudden oak death *Phytophthora* are unknown but certainly will be significant. Oak trees provide shelter for many animals, and their acorns are an important food source for wildlife. Sudden oak death is particularly prevalent in state parks and protected watersheds. Although other trees and woody species will likely grow in forests that have lost large numbers of oaks and tanbark oaks, they cannot replace these hardwood trees from an ecological point of view. There is also a serious potential for wildfires resulting from the buildup of fuel from large numbers of dead trees. The economic costs associated with losses of these trees from landscapes and forests will be considerable. The cost of removing a large dead tree can exceed $1,000, presenting financial hardships for some property owners. The economic value of the land may be reduced by 30 to 40 percent with the loss of the aesthetic value of the oaks.

MANAGEMENT

There is currently no known control for sudden oak death. The resting spores of other *Phytophthora* species are known to survive in soils for years and can be moved inadvertently in contaminated soil. *Phytophthora ramorum* has been isolated from plant debris in infested forests. It is likely that the spread of this pathogen in California has been facilitated by the activities of hikers, bikers, and vehicles, as well as by horses and deer. Preventing the movement of plant material (foliage and wood) may slow the spread of this pathogen to areas that are not infested. The lack of knowledge about the reproductive biology of this newly isolated species argues for restrictions on movement of such materials. Plants obtained from commercial nurseries may also serve as a means of spreading the pathogen.

There are no prospects for saving trees infected with *P. ramorum* in forested habitats. For infected plants in landscaped settings, preliminary research suggests that control of this disease may be possible in the future. Because fungicides can help control other *Phytophthora* species in trees, experiments are underway to test such materials against this new *Phytophthora* species. In rhododendrons, *P. ramorum* may be controllable using treatments registered for use on other *Phytophthora* species. However, insufficient data are available to make recommendations at this time.

The seeping symptoms of trees infected by other *Phytophthora* species can be very similar to those of sudden oak death. Reducing the excess water supply to a tree often can control these better-known *Phytophthora* species. The new *Phytophthora* has been isolated from hillsides in campgrounds, state parks, and recreation areas and does not appear to require overirrigation or low-lying wet areas to infect trees.

The influence of bark beetles on the progression of sudden oak death disease in trees infected with *Phytophthora ramorum* is unknown. Although insecticides are registered for the management of bark beetles on oaks, their use is not recommended for the management of bark beetles associated with sudden oak death at this time.

Dead trees are susceptible to structural failure because of infection by native decay fungi and wood-boring beetles, resulting in limb and trunk breakage. Therefore, trees killed by *P. ramorum* in residential areas should be cut down. The wood should be stored on site where possible and treated in a manner that dries it as rapidly as possible. Solarizing the wood by covering it with a clear plastic tarp in a location where it is exposed to sun will help kill the pathogen. This wood should not be moved from its source into regions where sudden oak death has not been reported. Movement within areas of infection should be minimized.

FURTHER READING

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Svihra, P., N. K. Palkovsky, and A.J. Storer. 2000. Sudden Oak Death: The Facts as We Know Them. Pest Alert #4, December, 2000. Univ. of Calif. Coop. Exten., Marin Co.

ONLINE RESOURCES

http://cemarin.ucdavis.edu/index2.html
(Sudden oak death information from Marin County)

http://camfer.cnr.berkeley.edu/oaks
(Monitoring sudden oak death in California)

http://www.suddenoakdeath.org
(California Oak Mortality Task Force Web page)

http://danr.ucop.edu/ihrmp
(University of California Integrated Hardwood Range Management Program Web page)

http://www.cnr.berkeley.edu/SOD/garbelotto/english/campus.html
(Sudden oak death information from University of California at Berkeley)

http://pi.cdfa.ca.gov/pqm/manual/455.htm
(State restrictions regarding wood infected with sudden oak death and regulatory sampling procedures)

For more information contact the University of California Cooperative Extension or agricultural commissioner's office in your county. See your phone book for addresses and phone numbers.

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