# SUDDEN OAK DEATH

*Integrated Pest Management in the Landscape*

Sudden oak death is a disease of oak trees caused by an invasive plant pathogen, *Phytophthora ramorum*. It currently occurs in coastal California counties from Monterey to Humboldt and in a small portion of southwest Oregon. It is estimated to have killed more than 1 million oak and tanoak trees during the last decade (Fig. 1). In addition, more than 100 other plant species are susceptible to the pathogen, but most suffer only minor damage limited to leaf spots or twig dieback.

Although sudden oak death is a forest disease, it is common in urban-wildland interface areas—places where development meets or intermingles with undeveloped wildland—and can present many challenges for residential landscapes. Diagnosis of infected trees and proper disposal of contaminated wood and other material are essential to limiting the spread of the disease. Management options include treatment with phosphonate compounds and selective plant removal.

Because *P. ramorum* can be spread by moving infested soil and plant materials, state and federal regulations are in place to control the potential spread of the pathogen to uninfested areas. The California Department of Food and Agriculture (CDFA) and the U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA–APHIS) regulates movement of any known host species. A quarantine is in place for the infested counties. Before moving regulated plant material out of quarantined areas, you must contact your agricultural commissioner for a permit.

## LIFE CYCLE/BIOLOGY OF PATHOGEN

*Phytophthora* species are funguslike organisms, related to algae, which occur worldwide. They are water loving and produce plentiful spores in moist or humid conditions. Most known *Phytophthora* species are soil-dwelling root pathogens; however, *P. ramorum* acts primarily as a leaf pathogen. In California, it thrives in the coastal tanoak/redwood forests and oak woodlands within the fog belt. Nurseries outside of these cool, moist areas often create microclimates that mimic an environment supportive of *P. ramorum* and allow it to grow and spread far from the coast.

While most nonoak hosts are not killed by the disease, they do play a key role in the spread of *P. ramorum*, acting as a breeding ground for inoculum that can spread through water, wind-driven rain, plant material, or human activity. Oaks are considered terminal hosts, since the pathogen does not readily spread from intact bark cankers; they become infected only when exposed to spores produced on the leaves and twigs of neighboring plants.

Research in California forests has shown that the greatest predictor of *P. ramorum* canker on oak is the presence of California bay laurel (*Umbellularia californica*). Pathologists believe *P. ramorum* drips or is blown down onto oak trunks from neighboring bay leaves when it rains. Once on the oak trunk, *P. ramorum* uses natural openings in the bark to colonize the bark tissues, killing cells and clogging water and nutrient transport vessels.

**Figure 1. Tanoaks killed by *Phytophthora ramorum*.**

## IDENTIFICATION

Infections caused by *P. ramorum* must be confirmed in the laboratory utilizing either culture techniques or DNA analysis for detection of pathogen DNA. They cannot be identified on field symptoms alone. However, infected plants typically are found near other infected plants, so when oaks or other hosts with characteristic symptoms of sudden oak death are found within forests or woodlands where the disease already has been confirmed, these plants should be suspected to be infected with *P. ramorum.* Oaks growing farther from infested forests are not as likely to be infected unless infected material or nursery stock has been brought to the area. Check online mapping resources (www.oakmapper.org) for the most current data on pathogen distribution.

There are two categories of hosts for *P. ramorum*—trunk hosts and foliar hosts. Trunk hosts, such as tanoaks and oaks, get infections in their bark. These trunk infections often are fatal. Other organisms often attack diseased oak and tanoak trees once *P. ramorum* has weakened them. These include ambrosia beetles (*Monarthrum scutellare* and *M. dentiger*), bark beetles (*Pseudopityophthorus pubipennis*), and a sapwood decay

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fungus (*Annulohypoxylon thouarsianum*) (Fig. 2). Though these attacks are secondary to the original *P. ramorum* infection, they act to further weaken the trunk and can hasten the tree's death.

On foliar hosts—such as California bay laurel, rhododendron, or camellia—symptoms can range from leaf spots to twig dieback, but these hosts rarely die from the infection. Rather than sudden oak death, a *P. ramorum* infection on these hosts is known as Ramorum blight. Symptoms of *P. ramorum* infection on some key hosts are detailed below.

### *Oaks* (Quercus *species)—Coast Live Oak, Canyon Live Oak, California Black Oak, and Shreve's Oak*

The oak genus is divided into three subgenera, or groups: white, red, and golden/intermediate. Oaks from the white group—valley oak, Garry oak, and blue oak along with some scrub oak species—are not thought to be susceptible to sudden oak death, although other oaks do get the disease.

Susceptible trees in the red oak group (coast live oak, California black oak, and Shreve's oak) and intermediate group (canyon live oak) develop a bark canker when infected. External symptoms of canker development can include the bleeding of a thick, sticky sap. It typically smells like the inside of a wine barrel and is a deep burgundy but can vary in color from nearly black to an amber-orange (Fig. 3). Recent rains can cause the sap to run, often producing large stains on the surrounding bark. Only larger trees—those that are more than 4 inches in diameter at chest height—show symptoms; infections of smaller saplings are extremely rare. Mosses and lichens growing on the tree trunk die if the sap comes in contact with them. Their death might be the only indication a tree is bleeding.

The bleeding is the external manifestation of an underlying, diseased area of the tree, or canker. Removing the surface bark will reveal discolored, brown tissue, normally separated from healthy bark by a distinct, black zone line (Fig. 4), although this line can be somewhat indistinct during periods of active pathogen expansion, typically in the spring. This zone line represents the active front of the infection. Cankers usually develop 3 to 6 feet from the ground, although they can be as high as 12 feet or greater; they can be as low as soil level, but they are not thought to extend below the soil line. Bleeding sap initially appears on intact bark, without any obvious holes or wounds, although in later stages of the disease the bark might split.

*P. ramorum* infections on oaks originally were called "sudden oak death" because of the rapid (2- to 4-week) browning of leaves without an apparent, prolonged period of visible decline. The foliage might appear healthy until shortly before it turns brown, or the leaves might turn olive green, pale green, or yellow green for several weeks to several months before browning. Infected coast live oaks also might lose leaves before they die. There are no other symptoms on leaves or small twigs of most *Quercus* species, although canyon live oaks, *Q. chrysolepis*, might have lesions on smaller twigs. While this browning of leaves can appear suddenly, it usually occurs after an extended period of disease, perhaps more than 2 years from the onset of a *P. ramorum* infection of the trunk.

### *Tanoak* (Notholithocarpus densiflorus)

Tanoak is highly susceptible to *P. ramorum*, and the disease can infect and kill all sizes and ages—seedlings, saplings, and mature trees. *P. ramorum* infects trunks, branches, twigs, leaves, and leaf petioles (the slender stems that support leaves). Experiments on tanoak trees revealed they could be infected without showing cankers or bleeding symptoms, making diagnosis difficult. When visible, trunk cankers are similar to those of the red oak group (Fig. 5). Death can occur with a sudden browning of the leaves, as with the red oaks, or over time with gradual leaf loss. *P. ramorum* infection in twigs can lead to shoot tip dieback and wilting. Shoot tip wilting, or flagging, can

**Figure 2. *Annulohypoxylon thouarsianum* fruiting bodies often are found on trees affected by sudden oak death.**

**Figure 3. Viscous sap oozing from trunk of coast live oak infested with *Phytophthora ramorum*.**

**Figure 4. Reddish, discolored tissue and distinct, black zone lines beneath the bark of a black oak infected with *Phytophthora ramorum*.**

**Figure 5. External bleeding symptoms on a tanoak trunk.**

be useful in identifying trees that are infected but not showing bleeding symptoms (Fig. 6). Tanoaks, unlike *Quercus* species, can produce spores from infected twigs, which can then be dispersed both within the tree and to neighboring susceptible plants, potentially causing new infections. Infected trees with brown foliage are effectively dead, although there might be some sprouting from the tree bases. Many of these new shoots are likely to become infected within a growing season.

### *Nonoak Hosts*

Just a few foliar hosts, listed below, support pathogen populations large enough to spread *P. ramorum* to susceptible oaks and tanoaks. For a more complete list and description of nonoak hosts and symptoms, see *Sudden oak death and associated diseases caused by* Phytophthora ramorum (Davidson et al. 2003) and *Nursery Guide for Diseases of* Phytophthora ramorum *on Ornamentals: Diagnosis and Management* (Tjosvold et al. 2005) in References. Please note that there are many potential causes of leaf spots on each of these hosts, so these symptoms descriptions should be used only as a guideline.

**California bay laurel (*U. californica*).** On California bay laurel, *P. ramorum* causes leaf spots, usually brown tips surrounded by a halo of yellow. Lesions typically are found where water collects on the leaf. This is generally its tip, although a leaf spot can develop elsewhere where water rests on the surface (Fig. 7). Bay laurel are not thought to die from *P. ramorum* infection, but these trees are a major source of inoculum for the pathogen and appear to play an important role in spreading disease to other plants in California.

**Rhododendron (*Rhododendron* species).** Leaf spots are the main symptom on rhododendrons, although more severe effects have been noted in some cases. Lesions penetrate through the plant tissue so that spots are identical both on the top and bottom of the leaf. They are often triangular and extend along the leaf midvein, but they can appear anywhere water collects on the leaf surface such as along edges, near the petiole, and at the leaf tip. Leaf spots have diffuse margins and might appear water soaked (Fig. 8). In severe cases, twigs, stems, or entire plants can die.

**Camellia (*Camellia* species).** Camellia symptoms usually are limited to leaf spots, which can vary in size from 1/4 inch in diameter to covering nearly half the leaf, depending on environmental conditions. Lesions usually are on the leaf tip or leaf edge, and diffuse margins or thick black zone lines can surround them (Fig. 9). Plants will drop their infected leaves, and the lower part of the plant can defoliate. Occasionally flowers or buds will be affected. Tip dieback or small branch cankers have not been observed on *Camellia* species.

## DIAGNOSIS

Many common maladies other than *P. ramorum* infections can cause damage that resembles sudden oak death. Other possible causes include boring insects, oak root rot (*Armillaria mellea*), root and crown rots (e.g., *P. cinnamomi*), physical injury, wetwood bacteria, and inappropriate cultural practices such as summer irrigation. (See *Pests of Landscape Trees and Shrubs* in References.) Figures 10, 11, and 12 provide assistance in determining whether *P. ramorum* is a likely cause of the symptoms on your plants.

Once you have determined that *P. ramorum* is a probable cause of the symptoms you have observed, the final step in getting a confirmed diagnosis is to submit the symptomatic plant material to a laboratory for testing. Even if you are concerned about the health of an oak, because the pathogen is more readily isolated from leaves than trunks, it is better to focus sampling efforts on foliar hosts such as bay trees that surround your oak. Following are two methods for collecting and submitting a sample for a more thorough *P. ramorum* diagnosis.

**Figure 6. Wilted, yellow branch tips of tanbark oak infected with *Phytophthora ramorum*.**

**Figure 7. Foliar lesions on California bay laurel infected with *Phytophthora ramorum*.**

**Figure 8. Leaf symptoms on *Rhododendron*.**

**Figure 9. Leaf symptoms on *Camellia*.**

**Figure 10. While only lab personnel can determine the presence of *Phytophthora ramorum*, certain steps can help diagnose if the symptoms you see on your oak tree likely are related to sudden oak death. By following the flow chart below, you can limit sampling and subsequent lab tests to only those plants that are mostly likely showing symptoms of a *P. ramorum* infection.**

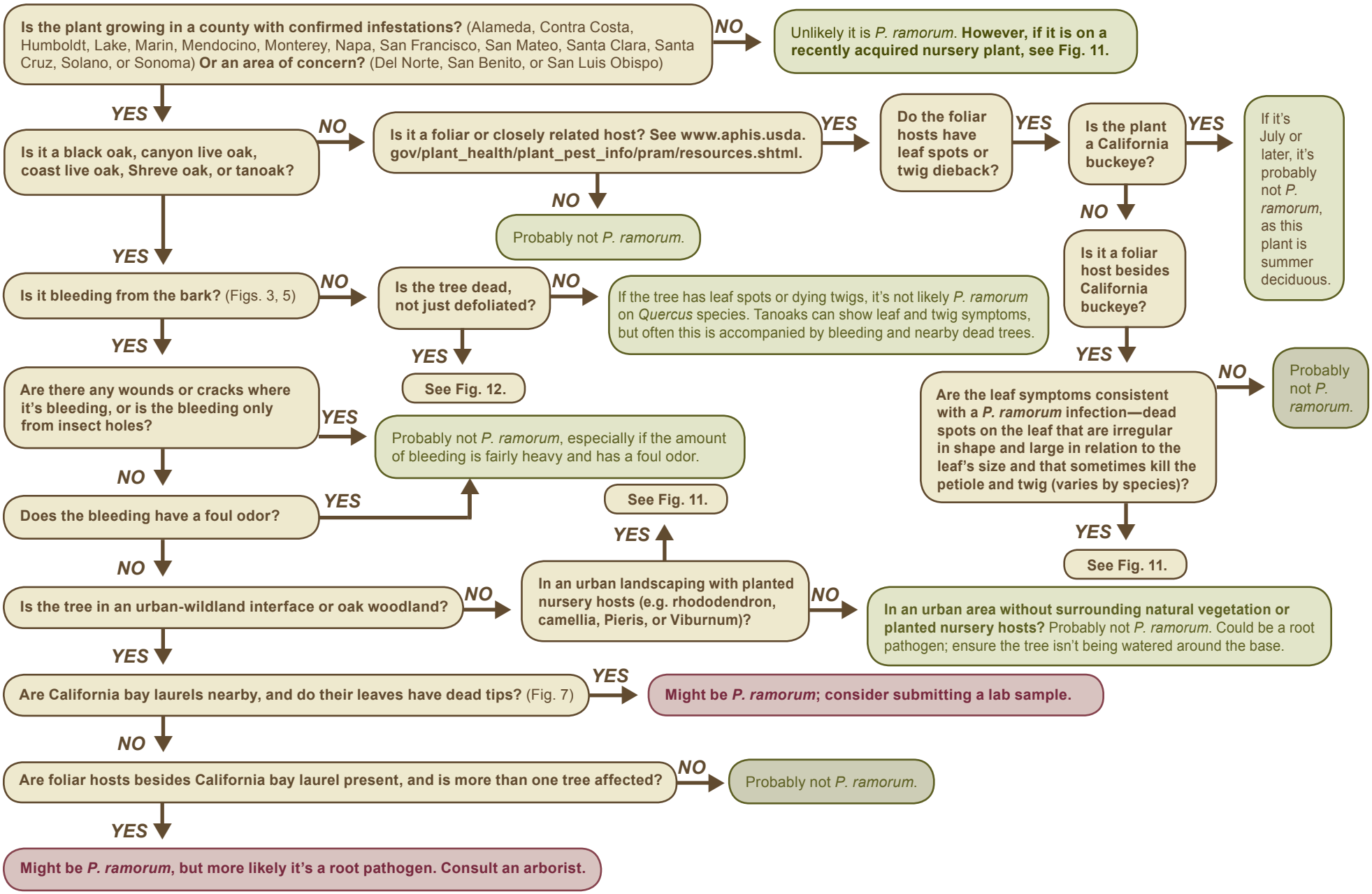


**Figure 11. Evaluating recent nursery purchases and naturally growing plants for *P. ramorum*.**

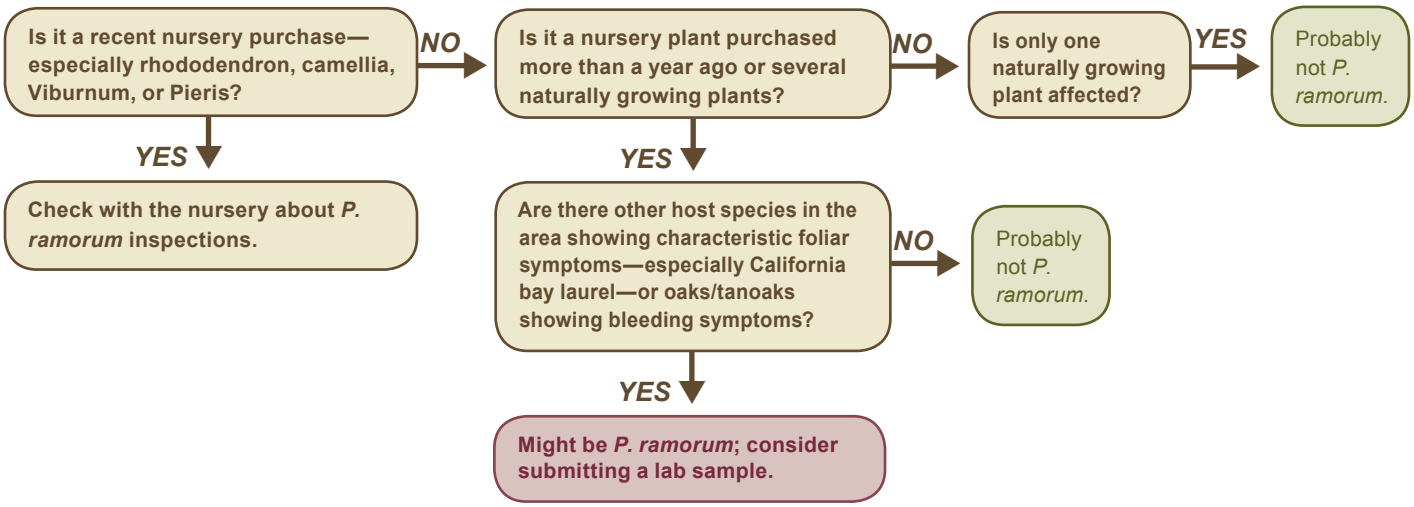
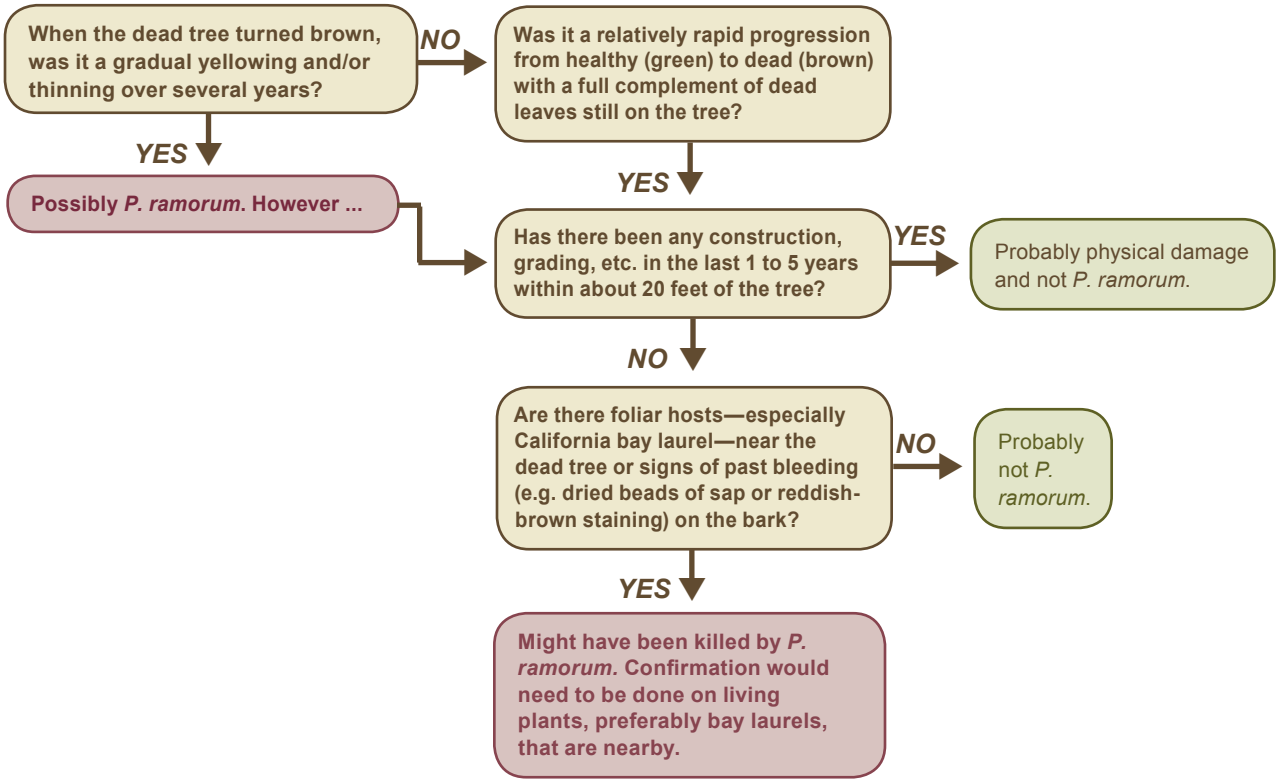



**Figure 12. Evaluating dead trees for *P. ramorum*.**



### *Foliar Sampling*

Foliar sampling involves collecting about 10 symptomatic leaves from a foliar host (typically bay laurel) and submitting them for analysis. It is perhaps the easiest and most reliable way to determine if *P. ramorum* is present at a given location. Because infestation levels vary tremendously throughout the state, it is best to contact your local Cooperative Extension or County Agricultural Commissioner's office for information on how sampling is being handled in your area.

### *Bark Sampling*

While bark sampling is the only way to directly confirm disease on an infected oak, this procedure is invasive, it requires special equipment from the laboratory, and improper sampling techniques will greatly influence results. If you do decide to collect a bark sample, you must request sampling materials in advance from the laboratory. It is recommended you work with a trained sampler.

## DAMAGE

*Phytophthora ramorum* affects different species in different ways. It can be lethal to trunk hosts and madrone (*Arbutus menziesii*) saplings, while it might cause only a minor leaf or needle disease for the numerous foliar hosts. Depending on a number of factors, some trees might never become infected, some might become infected and survive for various lengths of time, and others might become infected and die quickly. In a few, rare cases, trees have recovered on their own.

Because sudden oak death is a relatively new disease in California, it will take time to determine how likely different outcomes are for different tree species. Initial observations tell us that once infected, tanoak has a high probability of *P. ramorum* killing it, but some trees will survive. Coast live oaks appear to have a lower mortality rate than tanoaks, although the disease has killed many of them. There is little mortality information on California black oak at this time, so it is difficult to predict how this species will fare.

Trees growing in a mixed woodland or forest environment seem more likely to become infected by *P. ramorum*, as it spreads naturally in forest settings along coastal California. Oaks in residential landscapes seem less likely to be infected with sudden oak death, because they usually are not growing as close to foliar hosts such as California bay laurel. An exception would be when horticultural hosts such as rhododendrons and camellias are growing close to oak trunks.

## MANAGEMENT

Once sudden oak death infects oak trees, there is no known way to cure them. Therefore, most of the management practices discussed below are directed at preventing the spread of the disease to new plants or areas and protecting susceptible trees before they are infected.

### *Inspecting Nursery Plants Before Making a Purchase*

Many common horticultural plants are hosts for *P. ramorum*, and nurseries in California, other states, and other countries have found the pathogen on their plants. Plants are shipped all across the country, but they are strictly regulated. All *P. ramorum* host plants in California's regulated counties must be inspected and approved prior to shipment out of the regulated area, although sales within the regulated zone of 14 counties are not. In either case, carefully inspect the leaves of host plants for symptoms before making a purchase. Nurseries often use general fungicides that can mask *P. ramorum* symptoms, and some plants might have asymptomatic or latent infections that might not be visible at the time of purchase. Even if you do not see signs of infections when you make a purchase, consider quarantining the new plant in moist area of your yard for up to 8 weeks to see if symptoms manifest before you transplant it. You might want to refrain from planting any of these horticultural hosts near susceptible oaks in your yard.

### *Removing Infected Oaks*

A tree with sudden oak death needs to be considered and treated differently than a tree without the disease, but the disease alone is not justification for removal. In some cases, oak trees infected with the disease can remain relatively healthy for some time. Since data indicate nonoak foliar hosts actually spread the pathogen, removing infected oak trees probably will have little or no impact on local disease levels and spread. However, an important consideration with respect to any tree is whether it presents a hazard to life or property. All trees present some hazard, depending on the tree's structural integrity and its potential to do harm should it die or portions of it break off. Preliminary research has shown that trees *P. ramorum* has infected or killed are prone to rapid decay and unpredictable failure. Green infected trees and trees already dead from *P. ramorum* and/or secondary pests are at an increased risk of trunk and limb breakage.

The decision to remove a hazardous tree ultimately lies with the property owner. In order to get an objective assessment of hazardous conditions, contact a certified arborist or other qualified professional. While a dead tree has an increased risk of causing damage, consider leaving it standing if there is not a risk to life or property, such as when the tree is in a natural area. Standing dead trees provide important wildlife habitat, and after they fall and decay, they are a source of nutrients to be recycled into the soil.

Always consult regulatory officials regarding local tree ordinances before deciding to remove trees. Experienced tree service technicians should conduct tree felling, as infected trees might have an abundance of structural wood decay. If there is an acute emergency, contact your city arborist or local fire or police department.

### *Removing Nonoak Host Trees*

Large-scale removal of nonoak host plants is not a recommended way to prevent disease spread at a residential level. However, selective removal and/or pruning of these foliar hosts when they are in close proximity to uninfected, susceptible oaks might be helpful in preventing particular oaks from becoming infected, especially if there are few other disease hosts nearby. For more information, see *Sudden Oak Death and Residential Oak Care: Protecting Trees in Advance of Local Disease Establishment* (Lee, Valachovic, and Garbelotto 2010) in References.

### *Disposing of Plant Debris*

Since *P. ramorum* has been present in many areas of coastal California for a decade or longer, complete eradication is impossible. However, the disease is not uniformly distributed, and there are still many areas that remain uninfested. If infested plant materials are moved, they inadvertently can transfer the pathogen to uninfested areas. Disposal of infested material is extremely important, because branches, twigs, and leaves from California bay laurel, rhododendron, and other host plants can harbor *P. ramorum*, even after they are removed from the plant. In infested areas, the best option is to leave infested material on site, chipping the small material for use as ground cover and using larger pieces for firewood. Since inoculum levels already are thought to be high in these infested areas, leaving the additional inoculum from the infested plant material on site will not significantly worsen local disease conditions. Composting also can successfully kill the pathogen, but the compost must reach temperatures that probably are not possible or practical in a home-composting site.

Removing plant debris from the property is recommended only if it is the first infected tree detected in the area or if fire risk is high. If infected wood is removed from your property, make sure it is utilized or disposed of in a way that does not spread the disease. Avoid leaving wood next to roads where it could be picked up and transported off site by unauthorized parties. Regulations prohibit the movement of host plants and plant parts out of the quarantined area. If you have infected trees cut down, make sure the wood and other tree parts are not moved outside of the quarantine area.

### *Sanitation Measures to Minimize Pathogen Spread*

As a precaution against spreading the pathogen, clean and disinfect pruning tools after use on confirmed or suspected infested trees or in known infested areas. Sanitize pruning tools before pruning healthy trees or working in a pathogen-free area. Clean vehicles and shoes of mud, dirt, leaves, and woody debris before leaving a *P. ramorum*-infested site and before entering a site with susceptible hosts.

### *Replanting After Removing an Infected Tree*

If you want to replant, it is important to choose a tree that will suit your needs and adapt well to the site. There are many resources available that can guide you in making the right choice. Check to see if there are any local ordinances or guidelines that govern tree replacement or planting.

Resistance to *P. ramorum* in oak trees is just beginning to be explored. Resistant planting stock is not available at this time nor is it known if it ever will be available. Coast live oaks do not seem to be infected by *P. ramorum* until they reach about 4 inches in diameter, so small, new trees should be immune for a number of years, and high value trees can be preventatively treated once they reach a susceptible size. (See Preventative Phosphonate Treatments below.) Species in the white oak group (e.g., valley oak, Garry oak, and blue oak) are not susceptible to *P. ramorum*. If you have space for replanting many trees, consider replanting the lost species in combination with other trees that do not get the disease. Then, if some trees succumb to *P. ramorum* there still will be others that survive.

### *Preventative Phosphonate Treatments*

One phosphonate fungicide, Agri-Fos, is registered as a preventative treatment for *P. ramorum* for use on individual, high-value tanoak and oak trees. Treatment is not recommended in areas where infested plants are not already present. This treatment is not a cure, but it can help protect trees from infection and suppress disease progression in very early infections. The phosphonate compound can be injected or mixed with a surfactant and sprayed on the trunk for absorption through the bark. Booster treatments need to be made every 1 to 2 years.

Since the treatment must be made to healthy trees and the pathogen's distribution and activity is patchy and somewhat unpredictable, it is difficult to determine which trees need treatment. Generally, you should consider treating healthy, high-value oak or tanoak trees within 150 feet of other infested plants. You also might want to treat healthy, high-value oaks or tanoaks if they are surrounded by healthy California bay laurel and there are known infections within 150 to 1,000 feet. For more information, see *Sudden Oak Death and Residential Oak Care: Protecting Trees in Advance of Local Disease Establishment* (Lee, Valachovic, and Garbelotto 2010) in References.

### *Insecticides*

Using insecticides to treat or prevent *P. ramorum* infections provides no control and is not justified. However, treating individual, high-value landscape trees displaying early bleeding symptoms of sudden oak death might be justified to control damage from secondary bark beetle attacks. If using an insecticide, apply it only if the disease is not at an advanced stage and with the realization it might prolong the life of the tree only for a relatively short time. For more information, see *Pest Notes: Bark Beetles* in References.

## ONLINE RESOURCES

- California Oak Mortality Task Force, www.suddenoakdeath.org

- OakMapper, www.oakmapper.org

- UC Berkeley Forest Pathology and Mycology Laboratory, www.cnr.berkeley.edu/garbelotto/english/index.php

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