RESOURCE MANUAL

Oak Woodlands Disease Management

within the Nature Reserve of Orange County and Adjacent Wildlands

First Edition 2014

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NATURE RESERVE of ORANGE COUNTY

Produced in-part by Kelley Blue Book. KBB.com

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Introduction

Purpose

The purpose of this manual is to provide an overview of new or important fungal pathogens and diseases of coast live oak, and to guide best management practices in dealing with diseased oak trees within the Nature Reserve of Orange County. This manual is not a comprehensive guide of all disease agents that affect coast live oak, and does not cover bacterial or viral diseases or other problems caused by insects and other animals. Descriptions of some important agents (including insects) that are not within the reserve are included herein for prevention management.

The practices suggested herein do not guarantee that an introduction or spread of a pathogen will be prevented, but offer ways this may be minimized. Practices are subject to revision as more knowledge about fungal pathogens and their control is revealed through research. They are not to be used as a substitute for consultation with appropriate professionals. The use of these practices is at the user's own risk.

Monitoring for Disease and Overall Health of Oak Woodlands

Need for Comprehensive Monitoring Studies

Comprehensive monitoring studies are critical in disease management. New and emerging diseases that negatively impact forest ecosystems are an unfortunate reality, given the current conditions of climate change, over-population, and movement of plant material on a local and global scale. In addition, our understanding of these diseases continues to change. Given this, there is a continual need to monitor and study these forests on a regular basis, re-visiting trees over an extended period of time, so that compositional and environmental factors explaining the occurrence, incidence, and impact of fungal pathogens are accurately determined. Strategies for control are best determined through accurate findings from "ground-truthing" over time.

Therefore, this manual is a guideline and does not replace the need to conduct surveys to ensure early detection of potentially threatening pest populations and/or damage to forest vegetation. Biological evaluations are essential to determine the need to initiate, continue, revise, or discontinue pest management activities.

Early Detection and Rapid Response

The early discovery and accurate diagnosis of tree health problems are critical to successfully selecting appropriate strategies that will prevent pest-caused damage. In addition to comprehensive monitoring studies, this manual can be used as a tool to identify new agents and recent invasions of other agents, and to prevent the spread of the agents mentioned herein.

As a practical example, Fusarium dieback (FD) (page 49), an emerging disease/pest complex that was discovered in California in 2012, poses a serious threat to wildlands in southern California, and in particular to the Nature Reserve of Orange County. Signs and symptoms of the problem may be confused for other agents such as *Geosmithia pallida* and the western oak bark beetle, the cause of foamy bark canker (FBC) (page 38). Early verification of FD or FBC in a tree adjacent to or within a wild area will determine the appropriate procedures to address the problem. These procedures may differ in their levels of aggressiveness, but implementing them appropriately and quickly may prevent a more serious invasion.

General Recommendations on Monitoring (at the level of the land steward)

As officials that frequent the reserve and see the same trees on a regular basis, land managers play a critical role in monitoring for disease. In general, watch for unusual patterns of decline, and for unusual or newly developed symptoms. Be on particular look-out for signs and symptoms of Fusarium dieback (page 49), goldspotted oak borer (GSOB) (Fig. 35 d-e), bot canker (caused by *D. corticola*, page 21), foamy bark canker (page 38), or any other new diseases that have emerged since the time of this writing. Follow the general guidelines for making decisions concerning diseased trees (page 5) and do not hesitate to contact your appropriate local authority if there is any uncertainty.

Overview on Fungal Diseases

What is Oak Decline?

A dead or dying tree is not always an indicator of decline. In fact, dieback or death of an oak tree is crucial in maintaining the ecological balance of oak woodlands. Essential nutrients, including carbon, nitrogen, phosphorus, calcium and potassium are slowly released by microbial decomposition and returned to the soil (30). It is often the artificial introduction of a particular agent, or conditions that predispose other agents to flourish, that exacerbates tree decline to the point where the system cannot recover.

While there are cases in which one biological agent is the cause of large-scale mortality, often a series of factors, or a particular assemblage of factors, contributes to causes of tree decline. An agent shown to be causing disease on a plant may be present because of another predisposing biotic or abiotic stress. In addition, signs of a particular agent may be an indicator of the original cause, and not necessarily the primary cause of the decline. An assemblage of several agents may also contribute to the overall loss of tree vigor. This can happen to an individual tree, or to an area. It is important to look for patterns, and to identify symptoms and signs of disease within the context of the area in any given time.

What is a pest?

A pest is any destructive organism that attacks and causes damage to plants. These can be fungal, bacterial, or viral pathogens, insects, other plants, or animals. Agents may be the primary cause of mortality, without the need for predisposing factors, or they may be secondary agents that cause a reduction in tree vigor due to other predisposing factors. Native destructive agents are a natural part of ecosystems worldwide. Exotic organisms that have been introduced to new locations are typically considered pests. However, under circumstances where abnormal abiotic and biotic stresses occur, native organisms may become pests due to imbalances in the system. This manual focuses on the management of fungal pathogens.

What is a disease cycle?

A disease cycle is the process by which a pathogen carries out its life. Fungi typically exist on or within various plant tissues during different life stages, depending upon season, climate, stress, or other factors. These stages are in the form of mycelia, asexual, or sexual fruiting bodies that produce spores. They may all occur on a plant simultaneously, as one stage, or in any combination of stages. The spores are the source of inoculum. For disease management, it is important to identify these stages.

General Disease Life Cycle

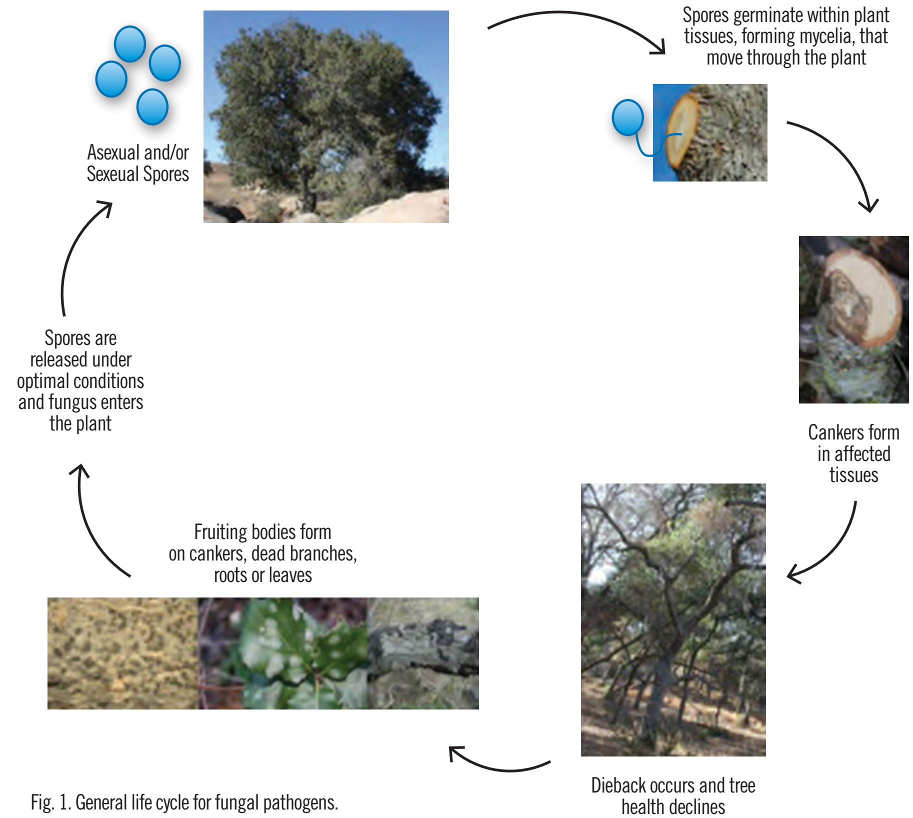


Fig. 1. General life cycle for fungal pathogens.

Identification, Assessment, and Sampling of Diseased Trees

Identifying Diseased Trees

How do I know if a tree is diseased?

The presence of dead branches on a coast live oak tree does not necessarily mean it is diseased. In fact, coast live oak is adapted to drop dead branches in its litter, and these branches are an essential part of its own mulch (17). Generally, the appearance of unusual symptoms or the presence of symptoms at unusual frequencies is a red flag that there is a problem.

It may not be clear that a tree is diseased until one goes through the necessary steps to assess the tree in question (see below). Sometimes the problem is entirely abiotic. Furthermore, symptoms are typically generic, meaning that the same symptom can be the result of very different causal agents (17). Once all factors have been taken into consideration, samples have been collected, and agents have been identified, one may conclude whether or not the impact is due to disease.

Assessing Trees

To help determine an appropriate diagnosis, follow the steps below and write down your observations.

1. Observe the entire tree. Are signs and symptoms uniform or restricted to particular parts of the tree?
2. Observe adjacent trees for similar symptoms. Note how the injury is distributed within a stand (scattered, grouped, patchy, etc.).
3. Note any obvious signs of physical, mechanical, animal, human, or environmental disturbances.
4. Look for signs and symptoms of classes of pathogens on different locations of the plant (i.e., leaves, twigs, branches, roots, the main trunk [above soil line or at or nearly above soil line]).
5. Look for signs of activity by insects (wood borers, twig girdlers, leaf rollers, etc.).
6. Look for signs of pathogens (e.g., fruiting bodies in the form of conks, mushrooms, or nearly microscopic pycnidia/perethecia).
7. Note other environmental factors such as precipitation, relative humidity, temperature, wind cycles, and any recent abnormalities within the last 6-12 months.
8. Note time of year symptoms are observed.
9. Note topographic location (slope, aspect, alluvial flat, ridgetop, etc.).
10. Note site history (past management activities, etc.).
11. Note tree age and stand age.

How Decisions are Made Concerning Diseased Trees

Because diseases are complex and symptoms can be generic, decisions concerning diseased trees will usually be handled on a case-by-case basis and are not always left solely to the land steward. The tree(s) must be assessed and many different parties may be involved before a management decision is made. Refer to page 8 for a general map of the process.

Depending on the agent identified, the land steward may be required to implement specific management protocols. It may be necessary to hire a contractor/specialist to carry out the management procedures. The land steward's role in the decision making process is to clearly communicate his/her observations with the appropriate personnel, regarding the tree in question.

Who to Contact

Your appropriate agency will have more specific protocols on how to take tissue samples, who should be taking them, and to where they should be sent. You may be asked to take a photo of symptoms on the tree(s) in question. It may require a field visit by your local authority or UC Cooperative Extension advisor. Specifics will be handled on a case-by-case basis. Please familiarize yourself with your point person of contact, or call the general lines listed below and ask to be connected with that individual.

State Parks: (916) 653 6995

Orange County
UC Cooperative Extension: (714) 708 1606

San Diego County
UC Cooperative Extension: (858) 822 7711

Riverside County
UC Cooperative Extension: (951) 683 6491

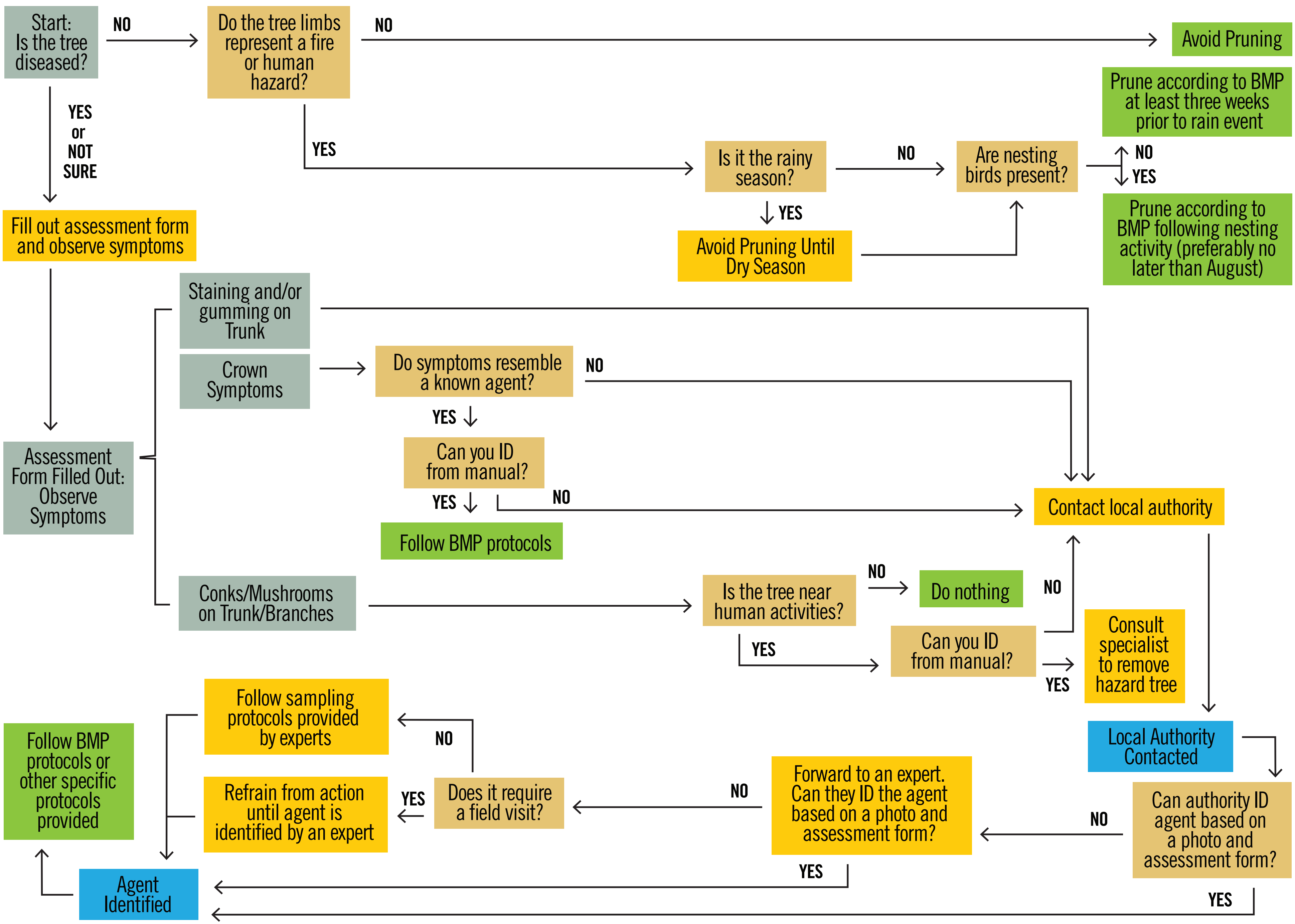
Los Angeles County
UC Cooperative Extension: (626) 943 3840

My Contact Person

Name: ______________________________

Phone Number: ______________________________

How Decisions are Made Concerning Diseased Trees



Best Management Practices (BMP)

There are currently no government-regulated plant pathogens present within the Nature Reserve of Orange County. That said, good hygiene practices might reduce the risk of potential invasions or spread of other unregulated pathogens that cause damage to coast live oak.

Most Important Rule: Avoid unnecessary pruning

In general, coast live oak is adversely affected by pruning (18). Pruning depletes carbohydrate storage of the tree, slowing its growth (18). In addition, pruning wounds serve as entry points for many fungal pathogens.

Unless a serious disease with specific management guidelines has been identified within the reserve, management of oaks and dead wood in support of recreation and infrastructure maintenance activities should be limited to trees and snags located near recreation areas and to areas supporting existing infrastructure. These areas include campgrounds, trails, and parking lots. They also include areas around power lines, and those accessed by emergency vehicles.

Sanitation Practices (when pruning is considered necessary)

To reduce the spread and sporulation of fungal propagules, conduct management activities during dry periods, and avoid any activity shortly after periods of precipitation. Whenever possible, it is best to wait until the ground is dry. If management activities cannot be avoided during wet periods, stay on maintained roads and trails as much as possible.

Equipment Disinfecting

Because propagules of many pathogens may persist on dead wood and soil for several years, it is important to ensure that equipment is properly cleaned of plant debris, mud, and soil before travelling between locations. Residual debris collected on equipment may be a source of inoculum, and sanitation practices will reduce their potential introduction and spread.

1. Use pruning techniques that minimize plant wounding and speed wound closure (see below).
2. Prior to cutting/pruning, remove soil and organic debris from equipment, such as hand and power tools used for cutting vegetation (e.g., loppers, chainsaws).

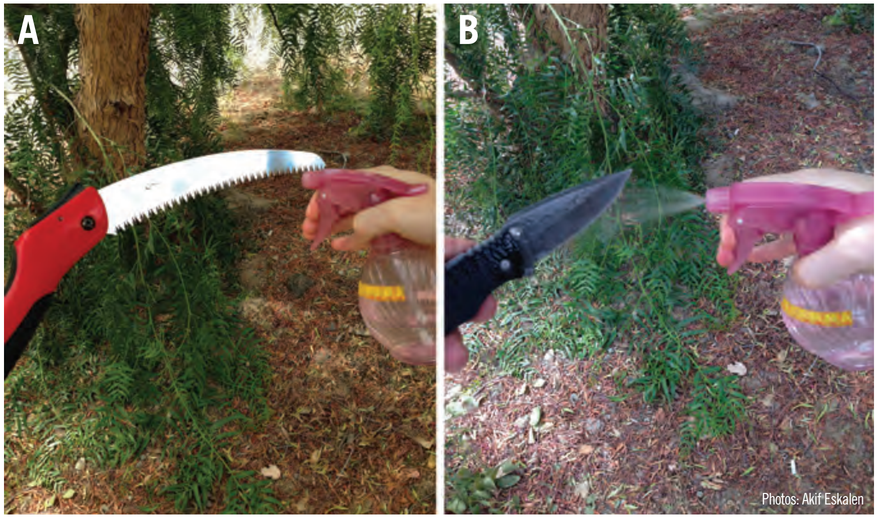


Fig. 2. Handsaw (a) and sampling knife (b) sprayed with 70% ethanol (Lysol may also be used).

   Then spray or wipe with either Lysol or 70% ethanol (Fig. 2). Clorox bleach diluted to 5-25% may be used, but may cause corrosion and thus pitting in the blades. Pitting can harbor microbes that are unaffected by quick sterilization (9). Dry blades with a clean towel, and spray blades with sterilizing solution in between trees.
3. Never use disinfections on pruning wounds, as they could be phytotoxic (9).
4. Remove any accumulated soil/mud or plant debris from heavy operating equipment with a hose (high pressure is best), prior to relocation of equipment to another wilderness park. Equipment includes vehicle tires, shovels, stump grinders, trenchers, chipper trucks, mowing equipment, chippers, tractors, fertilization and soil aeration equipment, cranes, etc. Spray with Lysol.
5. Prior to leaving a site (e.g., wilderness park), remove any accumulated soil/mud and plant debris from shoes and tires, and spray with Lysol (Fig 3a). A five-gallon pump sprayer is useful for debris removal (Fig 3b).

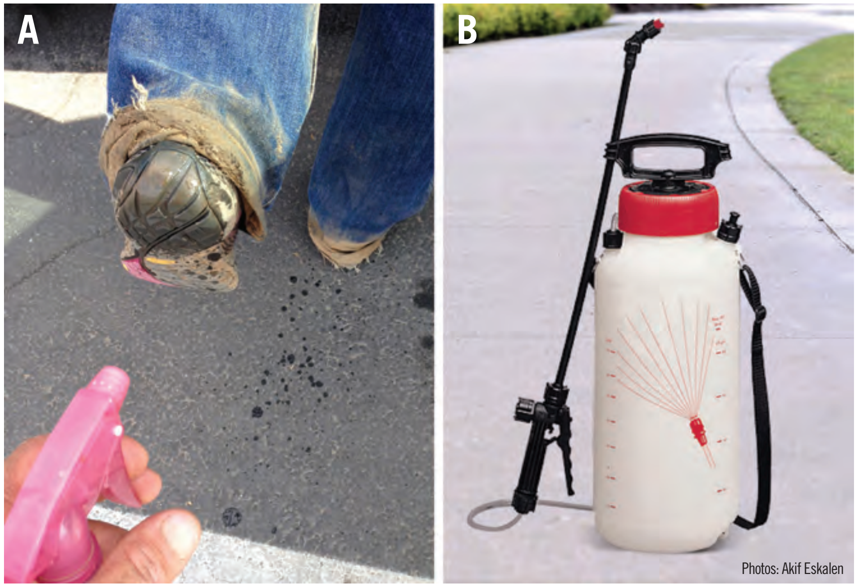


Fig. 3. Soiled shoes sprayed with 70% ethanol (Lysol may also be used) after removal of larger soil debris (a); a five-gallon water pump used to remove organic and soil debris from shoes, small tires, and other equipment (b).

Preventing Spread within a Tree

Wound coating is no longer a BMP when pruning.

If pruned properly, trees have natural methods of healing wounds (3). Studies that focused on the use of wound dressings to prevent the entry of decay fungi into trees have shown that wound dressings can be phytotoxic (9) or non-beneficial to trees, sometimes killing the cambial tissue or even creating a favorable environment for wood inhabiting microorganisms to grow and cause decay (3,23). Research has also shown that treated wounds do not close more quickly than untreated wounds (23).

Recommended Pruning Techniques

To prevent infection by pathogens, conduct activities during the dry season, at least three weeks prior to wet periods, so calluses form on the plant tissue to close the wound. If this interferes with bird nesting, adjust pruning projects accordingly, but be advised that pruning should be avoided if a precipitation event is expected to occur within a three week period after treatment, ideally no later than August. When to prune within this time frame may be determined on a case-by-case basis, depending on the site and locations that require pruning.

The following guidelines are recommended to minimize plant wounding and speed wound closure (18).

1. Find the branch collar and branch bark ridge of the tree. The branch collar is the swollen area of trunk tissue surrounding the base of a branch (Fig. 4a). The branch bark ridge is a line of rough bark running from the branch-trunk crotch into the trunk bark (23) (Fig. 4a).

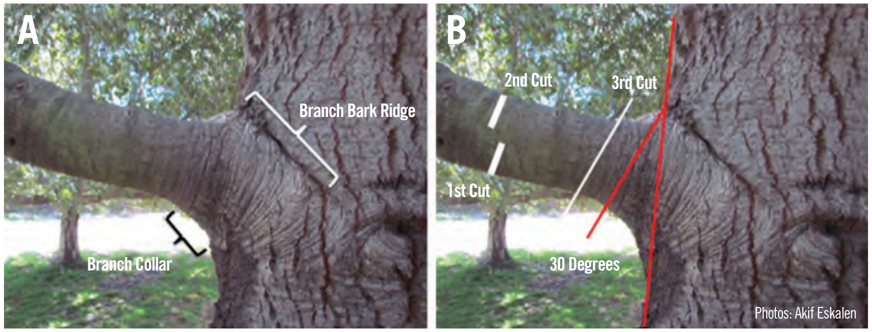


Fig. 4. Branch collar and branch bark ridge (a); the three cut method (b).

2. Draw a line flush along the trunk, outside the branch bark ridge (Fig. 4b).
3. Cut the branch at least 30 degrees away from the flush line so the cut will close evenly (Fig. 4b).
4. For branches larger than 3 inches in diameter, utilize the three cut method. This prevents unnecessary branch tearing under its own weight, below the collar (35):
   a. The first cut should be about one foot away from the branch union with the trunk (crotch). Cut from under the branch, approximately one-third to halfway through the branch (Fig. 4b).
   b. Make the second cut from above, approximately two inches past the first cut (Fig. 4b).
   c. Make the third cut at the proper pruning point, just outside the branch collar.
5. Make a clean cut of the remaining stub, using sharp implements to ensure quick and even callus formation.
6. Never cut into the branch collar, or branch bark ridge (Fig 5). A cut too close, or flush to the trunk, results in greater wound surface area and uneven callus formation. Furthermore, the branch collar serves as a protection zone that limits infection in the parent stem by forming pathogen-resistant compounds (3). Thus, flush cuts, or any cuts into the branch collar, damage the tissue and impair the tree's natural ability to defend against pathogens (Fig 6). To err on the side of caution, make the cut 1/8 inch beyond the branch collar for small branches, and 1/4 inch beyond the branch collar for large branches.

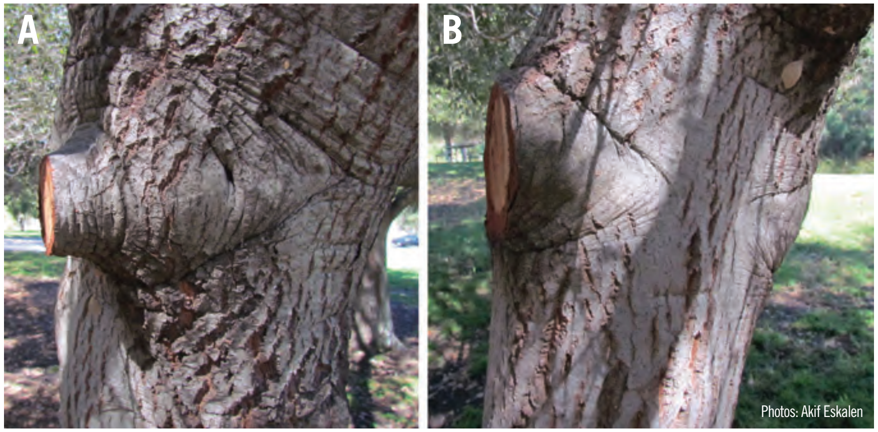


Fig. 5. Examples of effective (a) and ineffective (b) pruning cuts. The effective pruning cut does not go into the branch collar. Given that branch collar has been exposed on the ineffective cut, the tree is predisposed to infection by decay organisms and canker pathogens.

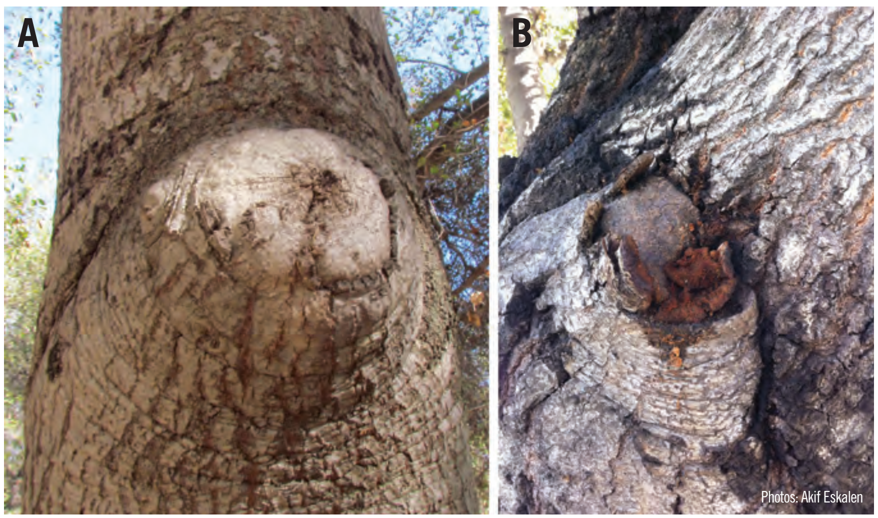


Fig. 6. Callus formation from an effective cut (a) versus an ineffective cut (b). The effective cut has even callus formation throughout the entire perimeter of the cut. The ineffective cut shows decay as a result of cutting through the branch collar.

7. Make smaller cuts rather than fewer large cuts when pruning to minimize decay forming columns.
8. Cuts on small branches should be square to the diameter of the stem (not at a diagonal), to minimize wound surface area (Fig. 7).

Fig. 7. Example of a square cut (a) and a diagonal cut (b). The square cut has less surface area exposure for entry of fungal pathogens.

Preventing Spread from a Diseased Tree

Pruning Infected Material

1. Inspect branch for symptoms of branch canker.
2. If the canker has not reached the branch collar, cut entire branch back using the techniques described above.
3. If the canker has extended into the branch collar, the infection has already reached the trunk. At this point, remove the dead limb 1/8-1/4 inch from the branch collar, to reduce inoculum. Do not cut into the branch collar, or any other living tissue (Fig 8).

Fig. 8. Dead branch tissue, with the recommended pruning line approximately ¼ inch from the branch collar in red.

Tree Removal

Evaluate trees with decay for structural failure potential and remove those that are near people and property. Specialists should be consulted to avoid unnecessary removal of ecologically valuable snags. It is a misconception that dead trees should, by definition, be cut down.

Pruned and Cut Plant Debris

1. Do not move plant material for use of firewood outside of local areas. This is especially important because the assemblage of canker pathogens differs between locations. According to www.dontmovefirewood.org, "local areas" refers to the closest convenient source of wood that you can find. As a general rule of thumb, 50 miles is too far, and 10 miles or less is best. However, with the threat of GSOB and Polyphagous Shot Hole Borer (PSHB) in southern California, these rules are continually changing. It is best to consult the website to determine the local rules and regulations, when transporting wood from one jurisdiction to another. Please refer to www.dontmovefirewood.org for more information.
2. Create a designated area for plant material and soil debris that is removed from managed areas. Ensure debris piles are not in areas that drain towards native stands.
3. Do not move plant material and soil debris between locations.
4. Chip plant debris, starting with any infested material first. This will assist with cleaning out potentially contaminated material from the chipper, as suggested for management of Sudden Oak Death (SOD) (16).
5. Cover woodpiles with a clear plastic tarp. This is not only good practice for insect management, but also prevents splash dispersal of pathogenic fungal propagules.

Use of Seedlings for Restoration Projects

1. Know the source of plants and soil. Ensure growing media is from an area free of pathogens.
2. Plants that are slated for use in restoration projects should be screened for presence of pathogens, prior to deployment. If important pathogens are present, all plant material must be destroyed appropriately.
3. Minimize accumulation of standing surface water in plant beds to reduce the potential for sporulation and dissemination of soil borne pathogens (2).
4. Prior to deployment, place potted plants on a barrier between native soil and containers. A barrier may be raised benches, a gravel layer, etc. Do not place containers directly on native soil. This practice is used for management of SOD in nursery facilities, so that pathogens won't be transferred among plants through water or infected soil (2).

Management of Rots and Decay Fungi

In general, rots aid in providing important habitat for wildlife and play an important role in ecosystem processes. Management strategies should be targeted towards trees close to recreation areas to prevent hazards, and minimized in areas unfrequented by visitors to allow for natural ecosystem processes to take place. Check trees near trails, roads, or other recreation sites periodically for signs and symptoms. Conks for most species indicate advanced decay and structural hazard. Removal of deadwood should be limited to these areas, so not to remove wildlife habitat (18). Suggestions for specific rots follow.

White Rots

Armillaria root disease

Armillaria sp. is fungicide-resistant (83). It has been recommended to thin in stressed stands to avoid overcrowding, prune old oaks to reduce transpiration and competition (70). However, this should only be done where high tree density is causing stress and seems to be increasing disease, and where disease has been confirmed (89). Thinning itself can predispose trees and stands to infection by *Armillaria* spp. and other pathogens. Remove infested stumps and associated root systems with an excavator (82,89). Infection will not survive over the long term in residual small roots (88). Oaks should not be cut or killed near conifers (83). Conduct good sanitation practices.

Ganoderma root rot

Individuals with basidiocarps have extensive decay, and are prone to elevated risk of failure (68). Because infection occurs through wounds, particularly at the base of the tree, practice caution when operating mechanical equipment near the tree. Periodically check trees that are near recreation activities for conks, especially after periods of drought stress. Remove severely affected trees (displaying conks on the trunk) that are adjacent to areas frequented by visitors. Avoid any activity that traps moisture around the tree base (mulching, wood piling, etc.) to prevent fungal spread.

Inonotus spp.

Prevent injury to the tree base and roots. Periodically check trees that are near recreation activities for conks. Remove severely affected trees (displaying conks on the trunk) that are adjacent to areas frequented by visitors.

Brown Rots

Topping, leaving high stumps, and falling but not removing hollow stems, may be employed to reduce the hazard while maintaining wildlife habitat (83).

Because spores enter through open wounds, minimize injuries to trees during management activities. Remove slash to prevent fire hazards and the spread of other fungal pathogens.

Education and Outreach

Annual public meetings are essential for managing pathogens. These meetings keep land managers and public officers up to date on BMPs and disease identification.

Diseases

Diseases are grouped based on the types of symptoms they produce (canker pathogens vs. rots). Specifics on each agent (host range, status, signs and symptoms, disease life cycle, damage and importance) are provided to give context on management strategies and these specific strategies are mentioned. Following is a list of insect agents, with pictures, to use as a reference as they are discussed with respect to fungal pathogens.

A note about "Status"

Between 2010 and 2013, several locations were surveyed throughout Orange, Riverside, and San Diego Counties for the occurrence of fungal pathogens.
Within Orange County, these sites include Limestone Canyon (Limestone Canyon Wilderness Park), Serrano Wash (Whiting Ranch Wilderness Park) (inland), Wood Canyon (Aliso and Wood Canyons Regional Park), and Laguna Laurel Canyon (Laguna Coast Wilderness Park) (coastal). Results from these studies were published in Lynch et al. 2013-14 (43,44,45,46). For each pathogen, "Status" refers to the location where that particular agent was recovered in these surveys. "Status" may also refer to other surveys conducted by the Eskalen lab since that time.

Canker Pathogens

Biscogniauxia mediterranea

Hosts

Several oak and other tree species worldwide.

Status

Occurs in Orange, Riverside, and San Diego Counties.

Signs and Symptoms

Symptoms include bark cracking and peeling, followed by the presence of perithecial stromata in the cracks on tree trunks and branches (Fig. 9). Stroma is a cushion-like plate of solid mycelium that forms, and for *B. mediterranea* it appears in the form of a charcoal-black surface. Chlorosis of leaves, crown dieback, bark cankers, tannic exudations, and reduced ring growth and tree mortality are also described as symptoms (80). Symptoms typically appear after severe drought and unusually hot weather (34,68,80).

Disease Cycle

The stromata develop raised edges that cause the overlying bark to crack and fall off (30,68) (Fig. 9b,c). Embedded in the stromata are large numbers of ball-shaped perithecia (0.5-1 x 0.4- 0.5 mm) that develop single celled asci, each containing eight ascospores. Precipitation and high relative air humidity have been reported as the main factors for the ejection of ascospores, germinating ideally at 95° F (79).

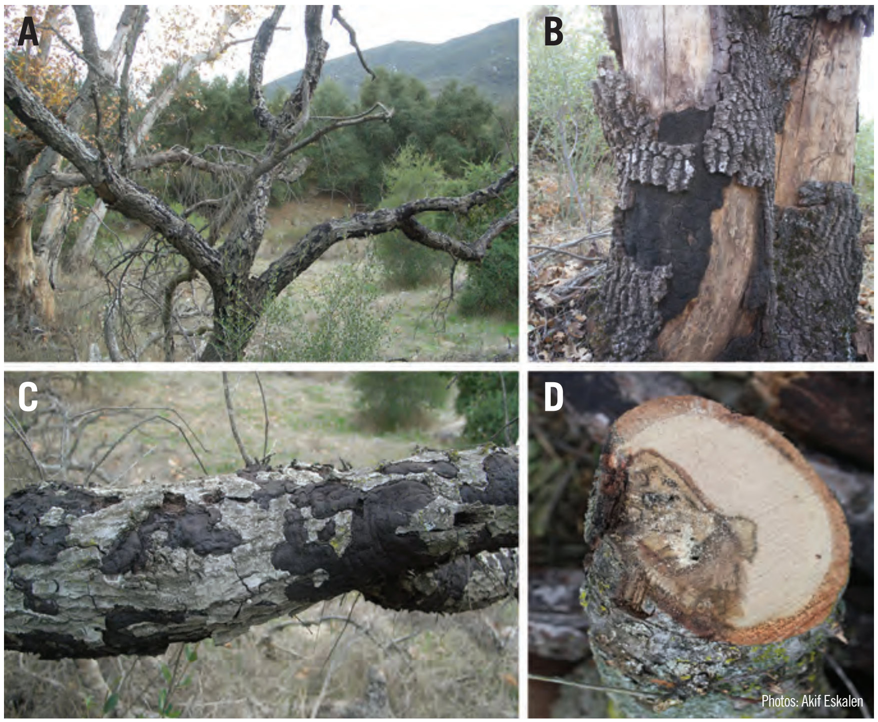


Fig. 9. *Biscogniauxia mediterranea* on a dead coast live oak (a); stromata growing in the cambial layer of California black oak (*Quercus kelloggii*), causing the overlying bark to break off (b); stromata developing within the bark tissue of a coast live oak branch, causing cracking and breakage of surrounding bark (c); necrotic sapwood of a coast live oak branch, caused by *B. mediterranea* (d).

Damage and Importance

The disease caused by *B. mediterranea*, commonly referred to as charcoal disease, is spread worldwide, and especially in the Mediterranean region. It affects mainly several species of *Quercus* (34,68,81) including *Q. suber, Q. cerris, Q. frainetto, Q. pubescens* (77), *Q. alba, Q. ilex, Q. imbricaria, Q. lusitanica, Q. palustris, Q. castaneifolia* (50), and *Q. pyrenaica* (32) in Europe, North America, Africa, New Zealand, Iran, and Asia (China and India). It is known to be found in close association with cork oak (*Q. suber*) decline, and is able to kill the host in a single growing season (50). Typical of other *Biscognauxia* species, this fungus occurs in healthy living bark as an endophyte, and under water stress conditions, its rapid growth destroys the stressed tissues of the host (55,76,78).

The occurrence of *B. mediterranea* with multiple pathogens and pests throughout declining oak stands is well documented (38,40,46). In California, it is likely that charcoal disease contributes to tree decline in association with other pathogens, but it is not a primary cause (46). It is present in both coastal and inland sites throughout the Nature Reserve of Orange County (43).

Management Strategies

There are currently no methods to control charcoal disease. Signs and symptoms of the disease indicate that the tree has undergone drought stress, and thus management suggestions on cork oak have been to employ practices that improve tree vigor and prevent trunk injuries (5). Because it can occur as an endophyte on multiple hosts, without causing visible symptoms, it is advised to utilize the sanitation methods recommended herein to prevent contamination onto other trees and hosts.

Botryosphaeria canker ('Bot canker')

Species recovered from coast live oak in southern California:
Diplodia agrifolia (Teleomorph unknown)
Diplodia corticola (=*Botryosphaeria corticola*)
Diplodia seriata (=*Botryosphaeria obtusa*)
Dothiorella iberica (=*Botryosphaeria iberica*)
Fusicoccum aesculi (=*Botryosphaeria dothidea*)
Neofusicoccum luteum (=*Botryosphaeria lutea*)
Neofusicoccum parvum (=*Botryosphaeria parva*)

Hosts

Quercus spp., avocado, grapevine, citrus, pistachio, walnut, and a wide range of annual and perennial hosts.

Symptoms

The disease is typically characterized by the presence of wedge- or pie-shaped perennial cankers in twigs, shoots, or branches when cut in cross section (85), but the shape of the canker varies (Fig. 10). Cankers are found in association with

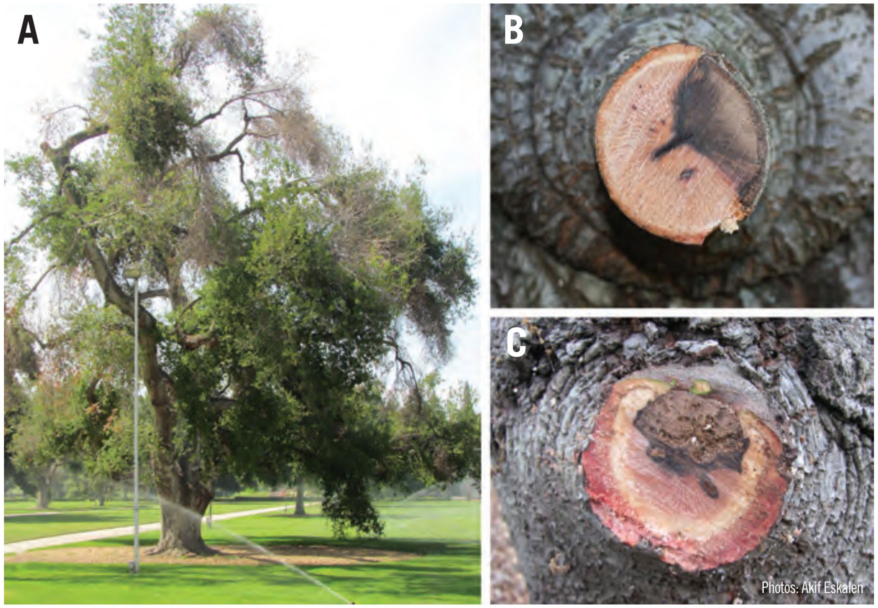


Fig. 10. Coast live oak tree showing symptoms of branch dieback caused by bot canker (a); cross section of a branch showing the classic wedge-shaped canker symptom caused by bot canker (b); cross section of a branch that is infected with bot canker (c).

dieback of limbs, where a dark sunken canker may be observed on the outer bark, girdling the limb (85). On recent infections, the dry and desiccated dead leaves remain on the infected limb. Symptoms also include a dark red oozing sap from the bark on the tree bole.

Diagnosis of disease caused by Botryosphaeriaceae can be difficult based merely on observations of vascular and external symptoms. Accurate diagnosis by means of isolations and/or molecular techniques is required to confirm the presence of these species.

Disease Cycle

Asexual (pycnidia) (Fig. 11a) and sexual (perithecia) (Fig. 12a) fruiting bodies are formed on the plant tissue, although pycnidia are more often observed in nature. Conidia (Fig. 11b-c) are produced in pycnidia (Fig. 11a). Asci (Fig. 12b) containing ascospores (Fig. 12c) are produced in perithecia (Fig. 12a). The size, shape, and color of spores differ among species in the Botryospaheriaceae (Fig. 11bc) (58).

Cankers develop primarily from pruning wounds, but also from natural openings, cracks, insect entry/exit holes, and other tissues damaged by mechanical injury, frost, or sunburn (12). These openings serve as points of entry for spores (12).

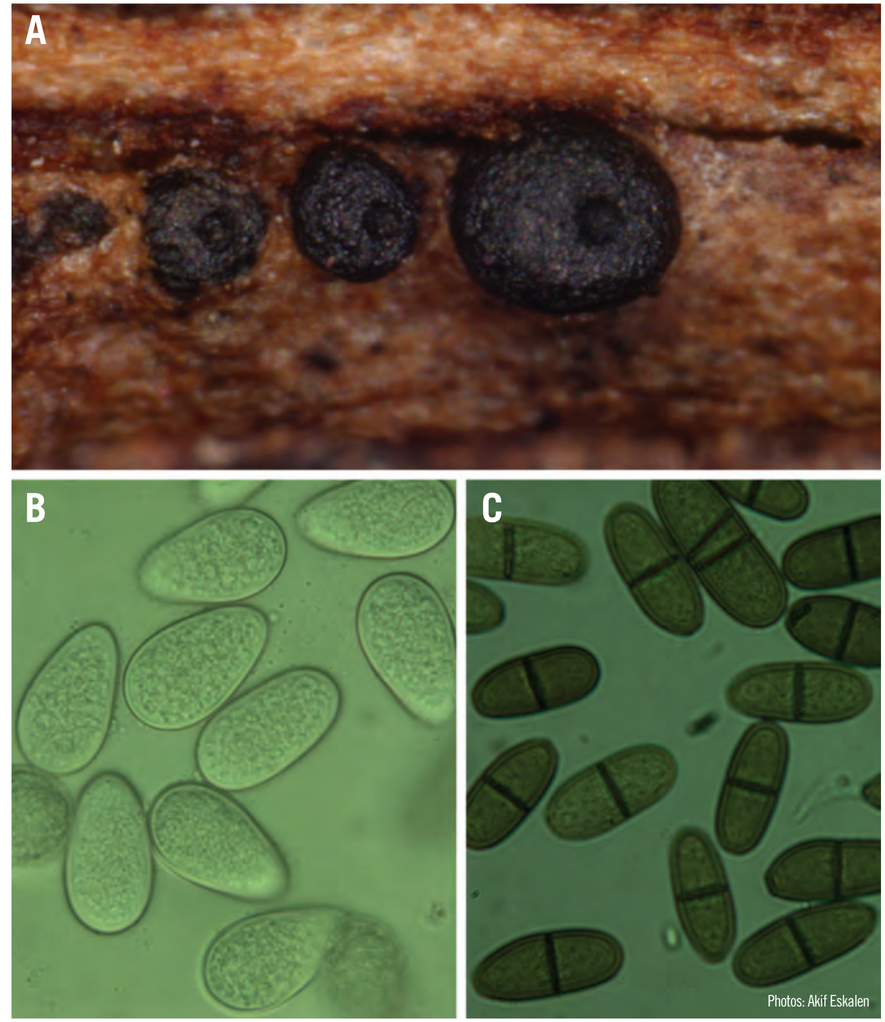


Fig. 11. Pycnidia of *Botrysphaeria* sp. on the surface of coast live oak (a); conidia of *Diplodia corticola* (b); conidia of *Dothiorella iberica* (c).

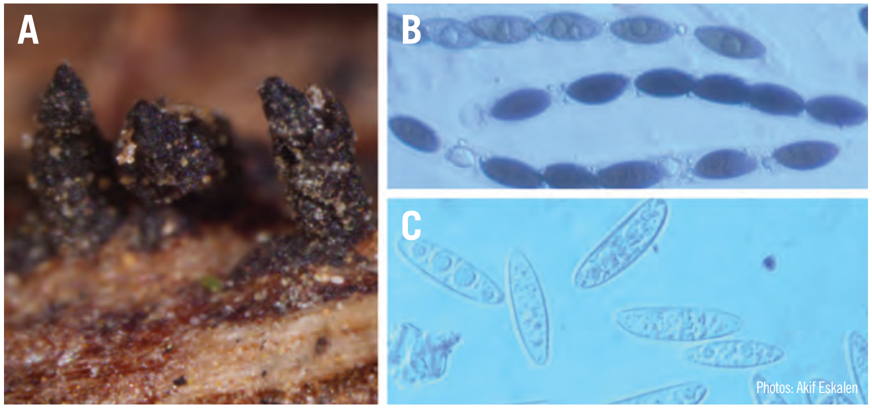


Fig. 12. Perethecia of *Botryosphaeria* sp. on the surface of grapevine (a); asci containing developing ascospores of Botryosphaeria sp. (b); mature ascospores of Botryosphaeria sp. after release from asci (c).

It has been documented for avocado and grapevine that these conidia are released from pycnidia during periods of high humidity, and are then spread by rain splash and wind, typically between November and April (21,84).

Damage and Importance

Species in the Botryosphaeriaceae have a cosmopolitan distribution (85). In California, the importance and diversity of species in the Botryosphaeriaceae associated with branch cankers on multiple hosts are becoming better understood (70).
Several species within this family are significant plant pathogens. They cause leaf spots, fruit rots, dieback, perennial cankers, and eventual death in economically important woody perennial crops and ornamental plants, as well as in both native and introduced forest tree species (22). Details for important pathogens in this family with respect to coast live oak are explained below.

Management Strategies

Given that botryosphaeriaceous taxa are only recently being recognized as important disease pathogens, few epidemiological studies have been conducted. Hence, the development and implementation of successful control methods have been limited, and this area of study is just beginning to be explored. Although great progress has been made throughout the last decade, management is still extremely difficult, due to the wide range of different species causing disease (85). Some suggestions follow.

It is recommended in all cases to conduct these activities during dry weather months of summer.

- Prune infected branches using recommended techniques described below.
- Prune dead limbs and twigs, and remove and destroy pruning waste from sites prior to periods of rain.
- Avoid conducting any cutting during and shortly after precipitation.
- Employ sanitation methods recommended herein.
- Remove and destroy diseased wood on the ground, to reduce inoculum sources and avoid new infections.
- Do not move plant material for use of firewood outside of local area. This is especially important because the assemblage of canker pathogens differs among locations. Please refer to www.dontmovefirewood.org for more information.

Diplodia agrifolia

Hosts

Coast live oak (*Quercus agrifolia*), black oak (*Q. kelloggii*).

Status

Occurs in Orange, Riverside, and San Diego Counties.

Symptoms

Symptoms are similar to those of *D. corticola*. While it aggressively colonizes host tissue, the disease does not progress as aggressively as *D. corticola* (44).

Disease Cycle

Conidia of *D. agrifolia* are hyaline, aseptate and pale-to-dark brown, and once-septate prior to, and after discharge from, conidiogenous cells (Fig. 13). The disease cycle is the same as other members in its family.

Damage and Importance

D. agrifolia is a newly described species, and little is known about the impact

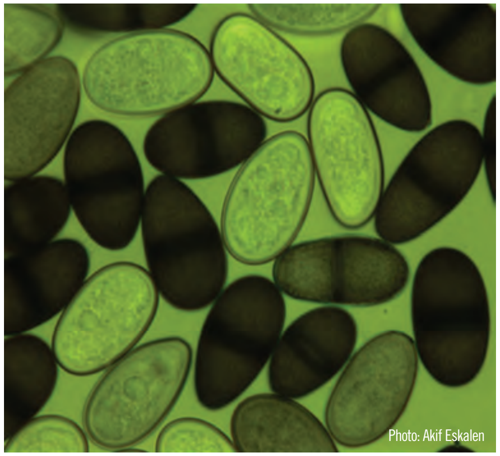


Fig. 13. Conidia of *Diplodia agrifolia*.

this pathogen will have throughout oak stands in California. Throughout the Nature Reserve of Orange County, it was recovered from more plots and in higher frequencies than *D. corticola* (43). It was also recovered from Limestone Canyon, one of the inland sites in Orange County, suggesting an ability to establish within a broader range of environmental factors (43). In addition, *D. agrifolia* occurs at higher frequencies throughout surveyed sites in Orange County compared to San Diego and Riverside Counties (43,46). However, incidences of *D. agrifolia* within the San Diego and Riverside sites increased up to 308% between 2010 and 2011, suggesting a recent establishment and ability to spread rapidly.

It is difficult to model which factors contribute to the presence of this pathogen at this time (44). Long-term monitoring and further genetic studies will determine its distribution and impact. Nevertheless, we know that in California it occurs more frequently in Orange County (43), that it aggressively colonizes coast live oak seedlings (44), that its incidence has increased in San Diego and Riverside Counties within one year (46), and that it co-occurs with aggressive pathogens such as *D. corticola*. To minimize its impact on coast live oak, management of this pathogen is important.

Management Strategies

Early detection and eradication will be the most important strategy for management of this new pathogen. Confirmation is essential for understanding the conditions that allow for establishment of botryosphaeriaceous taxa over time, and it will in turn contribute to the development of improved management techniques. Once confirmed, employ the recommended practices for Bot canker.

Diplodia corticola (=Botryosphaeria corticola)

Hosts

Grapevine in California (84), and species of *Quercus* including coast live oak (*Q. agrifolia*), black oak (*Q. kelloggii*), canyon live oak (*Q. chrysolepis*) (Úrbez Torres et al. 2010), and live oak (*Q. virginiana*) (15) in North America. Cork oak (*Q. suber*) (39), Holm oak (*Q. ilex*) (67), Kermes oak (*Q. coccifera*) (75), and Sessile oak (*Q. petraea*) (75) in Europe and North Africa.

Status

Occurs in the coastal sites of the Nature Reserve of Orange County, as well as in Riverside and San Diego Counties.

Symptoms

Symptoms of bleeding and pycnidia formation, leaf desiccation, epicormic shoot formation, and tree death within three to four weeks have been observed on seedlings artificially inoculated with *D. corticola* (44). *D. corticola* kills the xylem in advance of the living phloem and on inoculated seedlings, it moved into the taproot (44).

There is preliminary evidence that suggests the oak twig girdler (OTG) correlates to the presence of *D. corticol a* on live oaks (*Q. virginiana*) in Florida (15). In California, *D. corticola* has been recovered from symptoms caused by OTG, though not exclusively (43,44,46).

D. corticola is correlated with symptoms of severe shoot dieback and crown symptoms (43,46) (Fig. 14), but it is also associated with symptoms of bleeding cankers on the trunk (Fig. 15). Thus far, trunk symptoms are more often observed in Riverside and San Diego Counties.

Disease Cycle

Please refer to disease cycle description for ‘Bot Canker’.

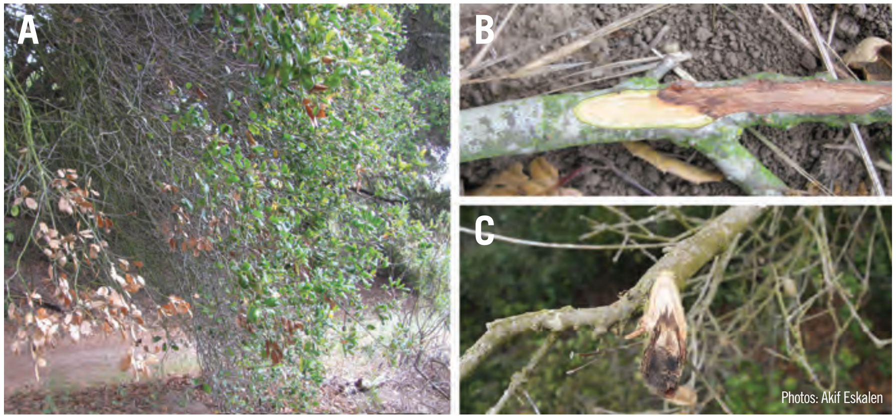


Fig. 14. Crown symptoms caused by *Diplodia corticola* on coast live oak, including shoot (a), twig (b), and branch (c) dieback.

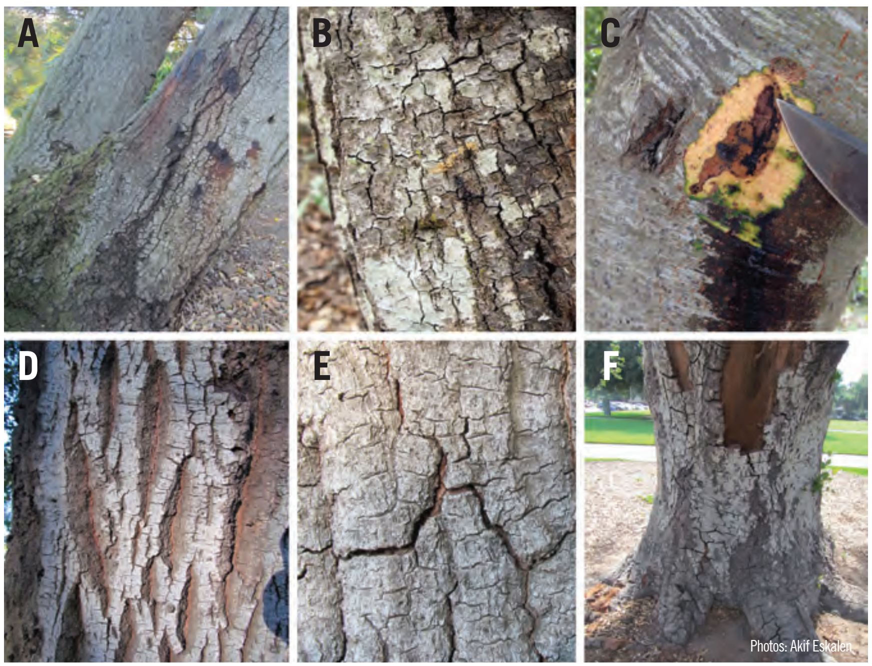


Fig. 15. Coast live oak trunks showing symptoms of bleeding caused by *Diplodia corticola* on the left (a-c), and healthy versus unhealthy bark cracking symptoms on the right (d-f). Necrotic tissue and healthy phloem separated by a black zone line is exhibited beneath the outer bark layer (c). Healthy bark cracking is a result of natural growth of the tree, and is usually indicated by pink phloem tissue within the bark furrows (d). Bark cracking caused by diseases or pests comes off in large, uneven pieces completely detached from the cambium (e-f).

Damage and Importance

Diplodia corticola is a known contributor to the decline of cork oak (*Q. suber*) and other oak species throughout Mediterranean Europe (4,39,40,41,66). Little is known of the origin of *D. corticola*, or its status as an exotic or overlooked native pathogen. There is evidence that suggests it is an exotic pathogen (44).

D. corticola occurs most frequently throughout regions of San Diego and Riverside Counties that are non-infested by the GSOB, though it is present within infested stands (42,44). Compared to more opportunistic members of this genus, *D. corticola* is significantly more aggressive; compared to *D. agrifolia* and *F. solani*, which are aggressive pathogens of coast live oak, *D. corticola* has been recovered at much higher frequencies in the field. It has been shown that this pathogen is correlated to coast live oak mortality (46).

D. corticola was recovered from a single staining sample collected from a tree in Aliso Wood Canyon; all other recovery was from cankered branch and shoot dieback tissues. At the time of this writing, Laguna Laurel had more dead trees and higher incidence of *D. corticola* than Aliso Wood Canyon (43).

Management Strategies

Early detection and eradication will be the most important strategies for management of this pathogen. Once species is confirmed, employ the recommended practices for Bot canker.

Dothiorella iberica (=Botryosphaeria iberica)

Hosts

Coast live oak (*Quercus agrifolia*), black oak (*Q. kelloggii*), grapevine, and avocado in California, and *Q. ilex*, and *Malus* spp. in Spain and Italy.

Status

Occurs in Orange, Riverside, and San Diego Counties.

Symptoms

D. iberica has been recovered from cankered tissues of trunk and crown symptoms, which include bleeding patches and/or insect entry/exit holes on the trunk, and branch/shoot/twig dieback (44,46). In pathogenicity tests, it caused mild necrosis in the xylem and produced pycnidia around the point of inoculation (44). A tree with the aforementioned symptoms combined with symptoms of heart rot is a good indication for the presence of *D. iberica* (46).

Disease Cycle

Conidia in *Dothiorella* are brown and one-septate early in their development, while still attached to conidiogenous cells (57,58). Conidia of some isolates of *Do. iberica* have been shown to be hyaline and aseptate when discharged from pycnidia (44). Differences for *D. iberica* may indicate differences between California populations and other populations of this species.

Damage and Importance

D. iberica is found in association with all types of symptoms, suggesting that it is an opportunistic pathogen that further alters the health of adult trees (46). However, its impact on coast live oak under natural conditions has not been tested. At the time of this writing, it occurs at lower frequencies in Orange County compared to the locations surveyed in San Diego and Riverside Counties; it occurs in Aliso Wood Canyon and Borrego Wash.

Management Strategies

Look for signs and symptoms of Bot canker, and note whether or not the tree has heart rot and signs of insect exit holes. Once species is confirmed, employ the recommended practices for Bot canker.

Neoscytalidium dimidiatum (teleomorph unknown)

Hosts

Woody plants in various families, including citrus, grapevine, Populus spp., English walnut, almond, and subtropical and tropical crops.

Status

Recovered from one tree in Limestone Canyon.

Symptoms

Symptomatology of *N. dimidiatum* is undetermined for coast live oak. It was recovered from cankered tissues of a branch from a single tree.

Disease Cycle

Conidia of *N. dimidiatum* are ellipsoid to ovoid, hyaline, with an acutely rounded apex, truncate base, and initially aseptate (65). Conditions for sporulation and transmission in coast live oak have not been explored.

Damage and Importance

N. dimidiatum has a cosmopolitan distribution, and is common in tropical countries (10,59,62,65). It causes gummosis, dieback, branch wilt, decline, leaf spot, tip rot, and canker on other woody hosts.

It occurs on citrus and grapevine in the Coachella Valley (65), the warmest growing area for these crops. In some cases, collapse of the entire grapevine in the middle of the growing season (a.k.a., apoplexia) has been observed (65). This pathogen has been identified in California in a walnut nursery, causing the death of trees due to the development of canker at the graft union (10). It has also been identified as the causal agent of shoot blight, canker, and gummosis on citrus in Italy (59), and dieback of mango in Australia (62).

Management Strategies

There is currently no information on the impact of this fungus on coast live oak. Therefore, early detection and an understanding of the factors for establishment will help to decide management activities. Look for signs and symptoms of Bot canker, and note any surrounding conditions (soil type, current management activities, temperature, presence of insect or animal damage, etc.). Once species is confirmed, employ the recommended practices for Bot canker.

Cryptosporiopsis querciphila (teleomorph unknown)

Hosts

Coast live oak (*Quercus agrifolia*), black oak (*Q. kelloggii*).

Status

Occurs in Riverside and San Diego Counties.

Symptoms

C. querciphila is associated with branch cankers. In GSOB-infested sites, it is also associated with GSOB exit holes on the tree bole (46). In pathogenicity tests, it caused mild necrosis in the xylem (44).

Disease Cycle
Species of *Cryptosporiopsis* are anamorphs of *Neofabraea* and *Pezicula*, and are characterized by extremely variable conidiomata (71,90). It has been determined that there are few reliable morphological characters to distinguish among taxa of *Cryptosporiopsis* species, though this genus characteristically has large, ellipsoid, aseptate conidia with a protuberant scar (71,86). Optimal temperature for sporulation has not yet been determined for this newly described species. Hence, specific details on the disease cycle remain to be investigated.

Damage and Importance
Little is known about this newly described weak pathogen. Studies of other *Cryptosporiopsis* spp. suggest associations with these fungi range from endophytic to symbiotic (1,11,29,37). *Cryptosporiopsis querciphila* was rarely recovered from asymptomatic plant tissues in Riverside and San Diego Counties (46). In addition, it is prevalent throughout GSOB-infested sites, and is associated with symptoms of GSOB (46). For these reasons, *C. querciphila* may contribute to the furthering of crown dieback on a tree (48,68). This pathogen was not recovered in the preliminary survey throughout the Nature Reserve of Orange County (43).

Management Strategies
The impact of *C. querciphila* is not known at this time, and thus control of the fungus has not been determined. It is advised to utilize the sanitation methods recommended herein to prevent contamination onto other trees, including those in different locations.

Diatrypella verrucaeformis

Hosts
Coast live oak (*Quercus agrifolia*), red alder (*Alnus rubra*), grapevine (*Vitis vinifera*).

Status
Occurs in Orange, Riverside, and San Diego Counties.

Symptoms
Diatrypella verrucaeformis has been recovered from cankered tissues of decaying branches on larger trees (46) (Fig. 16). In pathogenicity tests, it caused mild necrosis in the xylem (44).

Disease Cycle
Diatrypella verrucaeformis produces wart-like stromata that break through the bark of the host (Fig. 17). Its sexual (perethecia) fruiting bodies are 1-6-8 per pustule, and circular to ovoid (71). Asci within the perethicia are long-stalked, and contain multiple ascospores (72). Asexual spores (conidia) are hyaline, filiform, and are produced in masses in the mycelia (45,72).

Fig. 16. Cross section of a branch infected with *Diatrypella verrucaeformis*.

Damage and Importance
The fungus *D. verrucaeformis* is in the Diatrypaceae family, which is mostly regarded as saprobes, and commonly found on dead or declining wood of iosperms (27). Yet, interest in verifying the saprophytic vs. pathogenic habit of Diatrypaceous fungi has increased with the recent detection of some species on premium grapevines in California, Southern and Western Australia, and New South Wales (73). It was shown to be saprophytic on grapevine (74), and weakly pathogenic on artificially inoculated coast live oak seedlings (45).

Diatrypella verrucaeformis was recovered at all sites surveyed in Orange, San Diego, and Riverside Counties, but in higher frequencies in Orange County (43,46). It is likely that it is an underlying cause of background irritation or low-level stress to the trees.

Fig. 17. Stromata of *D. verrucaeformis*.

Management Strategies
Because little is known about the disease progress of this fungus under stress, it is suggested to employ the sanitation practices described herein.

Discula quercina (=Apiognomonia cinerescens)

Hosts
Coast live oak (*Q. agrifolia*), and occurs on valley (*Q. lobata*) and California black oak (*Q. kelloggii*) in California. In Europe, hosts include Turkey oak (*Q. cerris*), Hungarian oak (*Q. frainetto*), downy oak (*Q. pubescens*), English oak (*Q. robur*), cork (*Q. suber*), chestnut (*Castanea sativa*), and European oak (*Fagus sylvatica*).

Status
Occurs in Orange County.

Symptoms
In the crown, symptoms of leaf spotting or shoot dieback of smaller branches due to girdling by the pathogen can be observed (32,54,70) (Fig. 18). On twigs, the infection may begin at the leaf petiole in the shoots, advancing to the twigs to develop a sunken canker. This pattern of colonization leads to the death of a number of twigs, giving rise to the typical shoot dieback (54). The fungus may also enter through natural openings or wounds (70). Small black specks develop on the acorns and may also be observed (54).

Fig. 18. Symptoms of oak anthracnose on coast live oak leaves.

General crown thinning (especially from the bottom-up) and eventual tree death occurs when the fungus attacks repeatedly, and with a rapid development of symptoms over a number of years (33, 54).

Disease Cycle
D. quercina develops asexual fruiting bodies (acervula) on the shoots and twigs, which are round or elliptical, with a diameter often exceeding 250 µm (54). The conidia are one-celled, hyaline, ellipsoid, 3–6 x 8–15 µm. The sexual fruiting bodies (perethecia) are found on leaves, and are dark brown, measuring approximately 400 x 700 µm on average (54). Asci are evanescent and measure approximately 7 x 50 µm on average (54).

Oaks ranging from 15 to 40 years may become infected, primarily when temperatures reach 64-68° F (54). Infection may occur in coppices close to the time of the harvest, and in aging stands. It survives in cankers in the twigs and branches during colder temperatures, and as perithecia that form on leaves during moderate temperatures (54). Spores are dispersed by splash and wind-blown rain (68).

Damage and Importance:
Disease caused by *D. quercina*, or oak anthracnose, affects a number of hosts over extensive areas of the Northern Hemisphere (28,52,60,61,68).

Given that it produces a large inoculum load, is highly persistent within a diverse range of host tissues, can adapt to a wide variety of climates and environments, and has an extensive host range, this pathogen has a high rate of spread and survival capability (54).

D. quercina is endophytic in nature, and can turn into a pathogen in times of climatic stress (53). In California, it can cause considerable defoliation and dieback during periods of frequent and abundant rainfall (54), but is otherwise considered of minor importance to California native oaks. In Orange County, it was recovered from a single tree in Aliso Wood Canyon.

Management Strategies:
Natural antagonists to oak anthracnose are currently being explored (54). Because *D. quercina* has been recovered at very low frequencies, the best strategy for management is to monitor for outbreaks after periods of abundant rainfall, especially following drought.

In nurseries, urban parks and arboretums, the following practices have significantly reduced pathogen inoculum (54):

- Gathering up and burning infected plant residues such as fallen leaves, twigs, and branches.
- Pesticides were justified in exceptional cases on young trees in the field, when they grow in small and well-circumscribed areas.

Fusarium solani (=Nectria haematococca)

Hosts
Multiple plant families. Oak hosts include coast live oak, California black oak (*Quercus kelloggii*), cork oak (*Quercus suber*), and northern red oak (*Quercus rubra*).

Status
Occurs in Orange, Riverside, and San Diego Counties.

Signs and Symptoms
Associated primarily with bleeding trunk cankers. Affected trees will show symptoms of leaf wilt.

Disease Cycle
Fusarium solani produces asexual spores (microconidia and macroconidia). It produces chlamydospores, and overwinters as mycelium or spores in infected or dead tissues.

The fungus can persist in the soil for several years. Soil or plant material infested with spores and mycelium can be introduced into new locations via rain splash, equipment, transitory animals (birds and mammals), and human recreation.

Damage and Importance
F. solani is the most disease-causing fungus in its genus. It is known to occur and vary in severity on oak species throughout Europe, the eastern United States, and Canada (36,40,68,87). In pathogenicity tests of coast live oak seedlings, *F. solani* caused bleeding symptoms and aggressively colonized plant tissue, suggesting an ability to cause more severe damage on coast live oak than on other oak species (44, 45).

F. solani was recovered from a single staining sample and cankered branch and shoot dieback tissues of two trees in Aliso Wood Canyon (43). It was recovered at higher frequencies from locations surveyed in San Diego and Riverside Counties, and is mainly associated with trunk symptoms (46).

Management Strategies
Due to the fact that it is not a widespread threat for oak species, management of *F. solani* for these hosts has not been extensively explored. It is recommended to employ the sanitation practices described herein to prevent disease spread. Because it can persist in the soil for several years, and can affect a wide range of plant species, it is recommended not to move soil within and between locations.

Geosmithia pallida (Foamy bark canker)

Hosts
Coast live oak.

Status
Symptoms have been observed throughout California.

Signs and Symptoms
Symptoms occurring on the trunk include wet discoloration seeping through entry holes (Fig. 19) caused by the western oak bark beetle (*Pseudopityophthorus pubipennis*) (Fig. 35). Peeling back of the outer bark reveals phloem necrosis surrounding the entry hole (Fig. 19). Multiple entry holes may be observed on each tree (Fig. 19). In advanced stages, a reddish sap may ooze through the entry hole (Fig. 19), followed by a prolific foamy liquid (Fig. 19). This sap may run as far as 0.5 m down the trunk (Fig. 19).

Note: Symptoms may be confused with those caused by FD/PSHB.

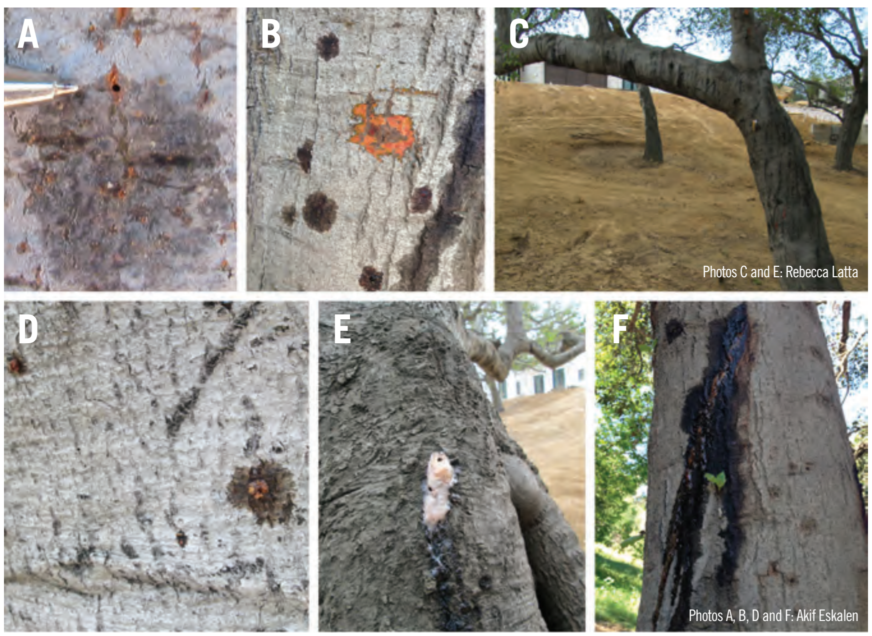


Fig. 19. Foamy bark canker symptoms caused by *Geosmithia pallida* and the western oak bark beetle on coast live oak.

Disease Cycle
The disease cycle is still not fully understood and is under investigation. In general, the beetles carry the fungus in their mouthparts and inoculate the plant tissue with the fungus. The fungus is a food source for the larvae and adults. The fungus infests the plant tissues, causing the trunk symptoms described above and branch dieback.

Damage and Importance
Foamy bark canker is a newly identified disease/pest complex that is currently under investigation (47). More studies are required to assess its distribution and impact.

Management Strategies
Given that very little is understood about this newly identified disease, the best current management strategies are early detection and comprehensive monitoring studies. Please contact your appropriate local authority if you see signs and symptoms consistent with what is described herein.

Phaeoacremonium mortoniae (=Togninia fraxinopennsylvanica)

Hosts
Coast live oak (*Quercus agrifolia*), ash (*Fraxinus latifolia*), grapevine (*Vitis vinifera*).

Status
Occurs in Orange, Riverside, and San Diego Counties.

Symptoms
Phaeoacremonium mortoniae has been recovered from cankered tissues of branches of coast live oak (46). In pathogenicity tests, it caused mild necrosis in the xylem (44).

Disease Cycle
The disease cycle for this pathogen is documented on esca-diseased grapevines and declining ash trees in California (19). Sexual fruiting bodies (perithecia, 183-276 µm) containing hyaline asci with hyaline ascospores can be found embedded in decayed vascular tissue and in pruning wounds, cordons, and trunks of these hosts. Spore trapping studies show that propagules of this fungus are present as airborne inoculum in infected vineyards during rainfall events (19), and are thus splash disseminated.

Damage and Importance

P. mortoniae is involved with the disease complex esca (black measles) and petri disease (young esca), which are two of the most destructive diseases of grapevines in California, United States, and in other grape-producing countries (19,25,60). It has been recovered at very low frequencies on coast live oak in Orange, Riverside, and San Diego Counties, and has thus far not been a problem for this host. *P. mortoniae* was recovered from a single tree each at Aliso Wood Canyon and Laguna Laurel Canyon.

Management Strategie

Given that it is a major disease of grapevine, and has been shown to occur on declining ash trees (19), close attention to this pathogen should be made over time. Look for signs and symptoms after precipitation.

Rots

Rots in the Basidiomycota (mushroom, puffball, stinkhorn, bracket fungi, jelly fungi, boletes, chaterelles, eath stars, smuts, bunts, rusts, and other polypores) tend to fall into two categories, white rots and brown rots, and are categorized by how they decay the wood tissue. White rots degrade lignin, cellulose, and hemicellulose, leaving behind a white residue (26). Brown rots degrade cellulose and hemicellulose, but not lignin. As a result, decayed wood breaks into cubical fragments, and the lignin becomes an important component of carbon sequestered in forest soil (26).

White Rots (See foldout for Table 1)

The following table is a summary of white rots that affect oaks. Please refer to Sweicki and Bernhardt (2006) (68) for more details on these organisms, including images of signs and symptoms. Images of those not listed in Sweicki and Bernhardt (2006) are provided herein.

Fig. 20. Fruiting body of *Abortiporus biennis*

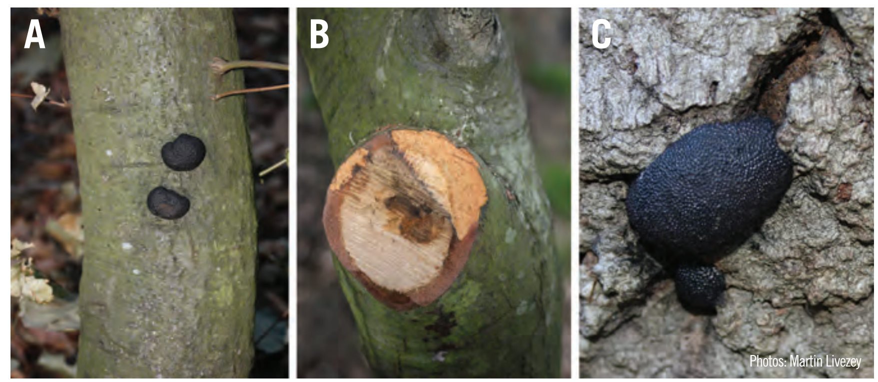


Fig. 21. *Annulohypoxylon thousarianum* fruiting bodies on coast live oak (a); cut branch showing necrotic tissue caused by *A. thousarianum* infection (b); close up of fruiting bodies of *A. thousarianum* on coast live oak.

Table 1. Rots that digest lignin, cellulose, and hemicellulose of plant tissue, leaving behind a white/off white residue (white rots)

		Tree Parts Affected					Plant Tissues Affected							
Fungal Species	**Common Name**	**Trunk**	**Branch**	**Tree Base**	**Root Crown**	**Root**	**Phloem**	**Cambium**	**Sapwood**	**Heartwood**	**Other Signs/Symptoms**	**Fruiting Body**	**Comments**	**Damage and Importance**
Abortiporus biensis		Living and dead	Dead									Annual, sessile, or sometimes with a lateral or central stalk, sometimes distorted with pores covering the entire surface[24]. Sometimes fruiting on the ground from subterranean roots[8] (Fig. 20).		
Annulohypoxylon thousarianum	Hypoxylon canker	x	x						x			Carbonaceous and hemispherically-shaped discs on bark or wood surface (Fig. 21)	Common on trees infected by *Phytophthora ramorum*	May become opportunistic pathogen when host is severely stressed[65]
Armillaria mellea	Armillaria root disease			Also causes canker rot	x	x	x	x	x	x	Bleeding sap through bark, with underlying mycelial fans, rhizomorphs, crown thinning and leaf browning. Infection centers usually begin around dead/dying oaks/other hosts. Look for individual or groups of trees in a given area showing signs/symptoms.	Gilled, light yellow mushrooms with a ring around stalk beneath the cap. In tight clusters of tree base in the fall.	A. mellea is the most widespread and aggressive of the four species in California[66].	Mostly problematc in well-irrigated orchards and vineyards. Does cause tree mortality, but large disease centers are rare[6,7].
Ganoderma applanatum	Artist Conk			x	x	x			x			Perenial, reddish brown surface with smooth white underside	Degrades lignin in advance of cellulose, creating a mottled appearance	Conk indicates advanced decay, and elevated risk of failure. Important roles in nutrient cycling throughout native forests.
Ganoderma brownii	Ganoderma root rot			x	x	x			x			Perennial, bright yellowish pore surface	Degrades lignin and cellulose at same rate	Conk indicates advanced decay, and elevated risk of failure. Important roles in nutrient cycling throughout native forests.
Ganoderma lucidum	Ganoderma root rot			x		x	Can kill		x	Mainly		Annual, leathery to corky when fresh, with creamy white surface, developing in single or overlapping clusters.	Degrades lignin in advance of cellulose, creating a mottled appearance	Conk indicates advanced decay, and elevated risk of failure. Important roles in nutrient cycling throughout native forests.
Hericium erinaceus	Hedgehog fungus			Pocket rot					x			Annual, solitary, 10-20 cm wide. Many closely-packed, icicle-like teeth (2-5 cm) bear spores[26].	Fire scars, stem cracks, and branch stubs serve as infection courts	Not common, but can increase failure in infected trees
Inonotus andersonii	Canker rot	x	x					Cankers from dead cambium cause dieback, failure and mortality[65].	Strips	x	Advanced decay appears bleached, is very light in weight, and crumbles easily[26,65]. Thinning, dieback, epicormic sprouts, branch or trunk failure[65].	A flat polyspore forming sheet-like fruiting bodies on dead wood beneath the bark and sometimes between outer layers of sapwood. Brown, becoming black with age.	Slow deline, often appearing to die from the top down[65]. Need microscope to confirm species.	Serious pathogen of California oaks, are associated with oak decline, failure, and mortality in many oak woodlands[65].
Inonotus hispidus		x						x	x	First infects heartwood, then begins to kill sapwood and cambium[64].	Large, elongate, bark-covered lesions, spindle-shaped swelling of trunk[64].	Annual, forming in summer to early autum[64]. Top is reddish orange, becoming reddish brown to nearly black with age. Many coarse hairs when young[26] (Fig. 22).	Enters through pruning wounds (less than 2.5 cm diam) within 5 m from ground.	One of the major trunk decay pathogens on shade trees in Europe[64].
Inonotus dryadeus	Weeping conk			x	x	Mostly larger roots, where infection begins.	x	x	Infection of bark and cambium precedes infection of sapwood[64].	At late stages of infection	Sparse foliage, poor color, and dieback, although may not show any aboveground symptoms until tree fails[64].	Annual conk, up to 24 inches wide. Tan, cushion-like conk, exuding a yellowish "weeping" liquid when fresh, and becoming blackish and cracked with age.	Slow developing. Spores enter through dead or wounded roots or basal fire scars. Need microscope to confirm species	May or may not kill the tree, but can adversely affect tree vigor over time. May have significant amount of root decay and elevated risk of windthrow[36,65]
Inonotus dryophilus	Canker rot							Develop from sapwood, killing cambium. Cankers from dead cambium cause dieback, failure and mortality[65].	Strips and sections	x	Advanced decay appears bleached, is very light in weight, and crumbles easily[26,65]. Thinning, dieback, epicormic sprouts, branch or trunk failure[65].	A flat polyspore forming sheet-like fruiting bodies on dead wood beneath the bark and sometimes between outer layers of sapwood. Brown, becoming black with age.	Slow decline, often appearing to die from the top down[65]. Need microscope to confirm species.	Serious pathogen of California oaks, are associated with oak decline, failure, and mortality in many oak woodlands[65].
Omphalotus olivascens	Western jack o'lantern fungus					x						At the tree base. Stalked, gilled mushrooms, usually in clusters on or near trunks, stumps, or buried wood in the fall and winter[65].	Pathogenicity not tested[65]	Can be an opportunistic pathogen[26].
Phellinus gilvus	Mustard Yellow Polypore	x								Living		Annual to perennial, shelf-like, corky, solitary or in overlapping clusters[68]. Variable in appearance. Reddish to dark purple brown poroid spore-bearing surface[26].	Uniform decay in dead wood	
Phellinus robustus				x		x						Perennial, very hard, sessile or effused-reflexed, mau ungulate or be flat. Upper surface brown to blackish with yellowish or grey-brown pore surface[26].		Often associated with tree failure on oaks in northern CA[26]. In northern CA, found high up on tree bole in association with heart rot[26].

Table 1.

Rots that digest lignin, cellulose, and hemicellulose of plant tissue, leaving behind a white/off white residue (white rots)

(fold out)

Fig. 22. Fruiting body of *Inonotus hispidus*.

Other White Rot Saprotrophs

The following fungi may be found on dead branches, boles, and woody debris, but can be opportunistic pathogens on stressed trees (26).

Fig. 23. Fruiting body of *Pleurotus ostraeus* (oyster mushroom).

Fig. 24. Fruiting bodies of *Schizophyllum commune* (split gill fungus).

Stereum spp.: Can be confused with turkey tail, but spore-bearing undersurface is smooth and lacks pores, gills, or other supporting structures (Fig. 25). Decays sapwood.

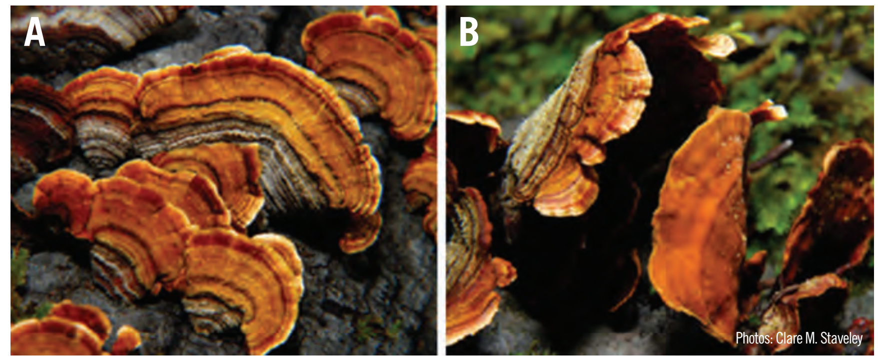


Fig. 25. Fruiting bodies of *Stereum* spp. showing the upper surface (a) and the smooth spore-bearing undersurface (b).

Trametes spp. (turkey tail): A polyspore with porous undersurface (Fig. 26). Decays sapwood; *T. versicolor* can attack and colonize cambium adjacent to dead wood and form cankers (26).

Management Strategies

Practice sanitation pruning because *Trametes versicolor* can colonize healthy tissue (38).

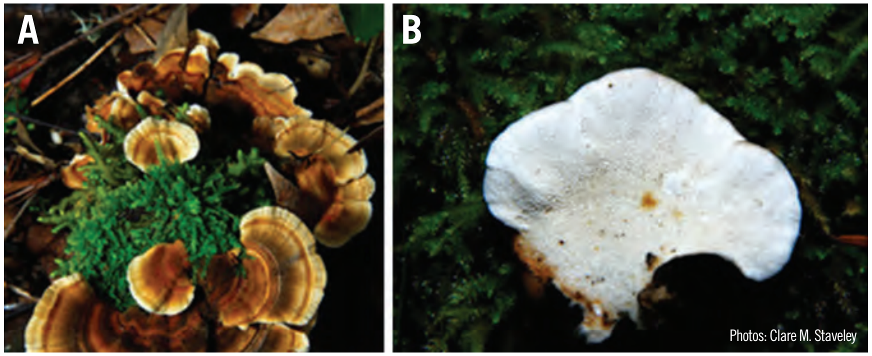


Fig 26. Fruiting bodies of *Trametes* spp. showing the upper surface (a) and the porous undersurface (b).

Brown cubical rot (chicken of the woods) *Laetiporus gilbertsonii*

Hosts
Oak species and several species of other hardwoods, including *Eucalyptus spp.* and *Prunus spp.*

Symptoms
Look for fleshy, soft, clustered, and shelf-like fruiting bodies (brackets) at or near the base of the tree, typically in late summer and fall (Fig. 27). Fruiting bodies are bright orange to red-orange above with a bright sulfur-yellow pore surface, becoming hard, brittle, and chalky white with age. Brown rots digest cellulose within the heartwood and occasionally the sapwood of the plant, and leave behind lignin. Thus, the wood breaks down into reddish-brown cubes in advanced decay, with areas of white mycelium visible in the cracks between the cubes (83). Decay most often occurs in the base of trees and occasionally in the trunk.

Disease Cycle
The fungus enters trees via windborne spores through basal fire scars or other wounds (83). Fruiting bodies are produced annually, after advanced decay development (83).

Damage and importance
This fungus causes brown cubical rot in many species. As a decaying fungus, it plays an important ecological role by opening up the canopy in mature stands, creating cavities for wildlife habitat, and breaking down wood into important components of carbon sequestered in forest soil to improve soil moisture and

Fig. 27. Fruiting bodies of *Laetiporus gilbertsonii* on California black oak.

nutrient availability (26). Standing dead trees with brown rot, or live trees with fruiting bodies indicate extensive decay and high potential for stem breakage and tree failure (70).

Management Strategies
Please refer to “Management of Rots and Decay Fungi” in the “Best Management Practices Section” for an explanation of management strategies for this fungus.

Other Diseases

Phytophthora root rot *(Phytophthora cinnamomi* and other *Phytophthora* spp.*)*

Hosts
Over 900 plant species, including coast live oak.

Status
P. cinnamomi was found in a native stand of coast live oak in San Diego County (70). It was not encountered during field surveys in Orange, Riverside, and San Diego Counties (43,45,46).

Symptoms
Fine root decay, bleeding cankers on the root crown and lower trunk. Removal of the outer bark layer reveals inner bark and cambium cankers, as seen with *P. ramorum* (see Sudden Oak Death) and other canker causing fungi (*D. corticola, F. solani*, etc.). Trunk cankers typically originate below the soil or occasionally at the soil line, as opposed to those caused by *P. ramorum* and other canker causing fungi (Bot canker, etc.). Crown thinning and leaf yellowing are also observed in the crown, especially from the top-down.

Disease Cycle
Phytophthora species are fungus-like organisms, related to algae, and produce structures only visible under a microscope. Species of *Phytophthora* can survive in the soil for many years, and can be transmitted via movement of infested soil on equipment and shoes, and in infected or infested nursery stock (68). During high levels of soil moisture, especially prolonged periods of soil saturation, dormant spores (chlamydospores or oospores) may either form sporangia, or germinate to produce hyphae that can directly infect roots (68) (Fig. 28). Zoospores released from sporangia in the presence of free water are spread with splashing or flowing water. Following a chemotaxic gradient to find the roots of host plants, zoospores encyst and germinate hyphae, which infect and kill root cells. Sporangia can initiate the next disease cycle within one to two days, and chlamydospres can serve as survival structures in the soil, as they may be formed in dead roots and tolerate drying (68). *P. cinnamomi* and *P. citricola* are mostly active when soil temperatures are 75-82 F, whereas *P. cactorum* causes disease at cool temperatures between 50-68 F (68).

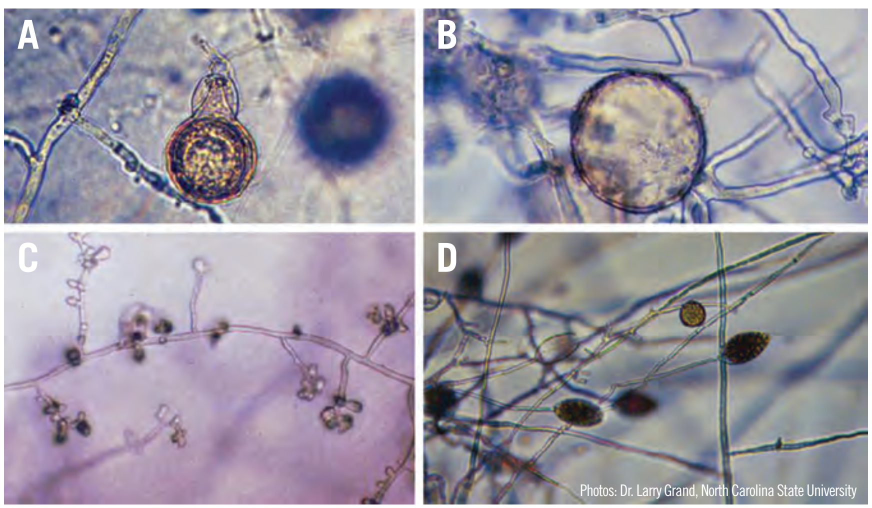


Fig. 28. Morphological structures of *Phytophthora cinnamomi* including an oospore (a), chlamydospore (b), hyphae with hyphal swellings (c), and sporangia containing zoospores (d).

Damage and Importance
P. cinnamomi is an important cause of root rot on avocado, and has been recovered from coast live oak trees in native stands adjacent to avocado groves in San Diego County (Eskalen *unpublished data*). Phytophthora root rots are most common on ornamental oaks in well-irrigated landscapes.

Management Strategies
The best management strategy is to prevent an introduction of these pathogens into non-infested areas. Maintain good sanitation practices described herein, especially when dealing with movement of soil. Know the source of nursery stock used in restoration projects, and screen soil for the presence of Phytophthora root rot, prior to deployment. Autoclave infested plant material for 20 min at 121°C (250 °F) and 15 psi over two consecutive dates, prior to disposal. Avoid overwatering of trees.

Powdery Mildews *(Brasiliomyces trina, Cystotheca lanestris, Microsphaera extensa curta, Phyllactinia angulata)*

Hosts
Most oak species and some in the Ulmaceae (for *P. angulata*).

Status
Found within the coastal sites of the Nature Reserve of Orange County.

Symptoms
Powdery mildew mainly prefers young leaves, creating distorted, “witches’ broom” symptoms. Symptoms of crown thinning may be observed as old leaves senesce and drop from the canopy. Dry, thin, powdery fungal spots on the leaf surface of mature leaves may be observed (Fig. 29).

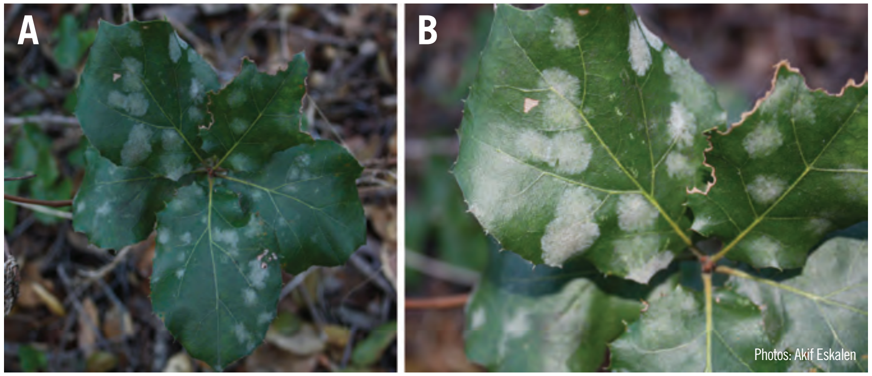


Fig. 29. Signs of powdery mildew on the surface of coast live oak leaves.

Disease Cycle

Oak powdery mildew is common in areas of high humidity and cool temperatures, especially near the coastline (17). Species are most easily identified by sexual fruiting bodies (cleistrothecia). Disease persists by production of asexual spores (conidia) during warm days and cool nights, and overwinters as cleistothecia or mycelium in infected buds (as with *C. lanestris*) (Sweicki and Bernhardt 2006). Ascospores produced in cleistothecia are released via wind during humid conditions. Host tissues are not killed as these fungi derive nutrition from living host cells via a fungal structure called haustoria (68). Dry conidia that form on superficial mycelium are dispersed via wind onto young shoots to initiate new infection (68). Infection by conidia is inhibited by wet conditions (68).

Damage and Importance

The impact of powdery mildew on adult trees is minimal. Small seedlings may be adversely affected. Stump or epicormic sprouts produced after heavy pruning may develop severe powdery mildew (68).

Management Strategies

Because infection by powdery mildew species can occur during either spring or late summer and fall (68), avoid pruning activities in the coastal locations that would yield stump or epicormic sprouting during these times.

Important Diseases in California

Fusarium Dieback/Polyphagous Shot Hole Borer (FD/PSHB)

Hosts

The following is a selective list from over 110 hosts: coast live oak (*Quercus agrifolia*), box elder (*Acer negundo*), castor bean (*Ricinus communis*), avocado (*Persea americana*), English oak (*Quescus robur*), valley oak (*Q. lobata*), California sycamore (*Platanus racemosa*), big leaf maple (*Acer macrophyllum*), mimosa/silk tree (*Albizia julibrissin*), American sweet gum (*Liquidambar styraciflua*), coral tree (*Erythrina corallodendon*), goldenrain (*Koelreuteria paniculata*), titoki (*Alectryon excelsus*), blue palo verde (*Parkinsonia florida*), palo verde (*Cercidium floridium*), tortuosa (*Salix matsudana*), weeping willow (*Salix babylonica*), red willow (*Salix laevigata*), trident maple (*Acer buergerianum*), Japanese maple (*Acer palmatum*), evergreen maple (*Acer paxii*), Chinese holly (*Ilex cornuta*), brea (*Cercidium sonorae*), black bean (*Castanospermum australe*), and camelia (*Camelia semiserrata*).

Status

Currently occurs in Orange, Los Angeles, Riverside, San Diego, and San Bernardino, and Santa Cruz Counties. *F. euwallaceae* was recovered from a roadside coast live oak 1/4 mile south of a Laguna Laurel Canyon entry gate on Laguna Canyon Road. In October 2013, the beetle infestation was found on sycamore, goldenrain, and red willow in Laguna Niguel Regional Park. The beetle was recovered from an entry hole on a sycamore, and the infestation into Laguna Niguel was a recent one. Between October 2013 and July 2014, the infestation expanded to Clark (Buena Park), Craig (Fullerton), Tri-City (Placentia), Aliso/Wood Canyons (Laguna Niguel), Carbon Canyon (Brea), Mason (Irvine), Mile Square (Fountain Valley), and George Key Ranch (Placentia) parks. There were also three facilities leasing OC Parks land that were found to be infested including Canyon RV (Yorba Linda), David Baker Gold Course (Fountain Valley) and Strawberry Farm Golf Course (Irvine) (Kabashima, personal communication).

Symptoms

Sycamore, maple, red willow, and castor bean are good trees to search for signs and symptoms of the beetle, as it tends to prefer to infest these hosts first (Fig. 30). Look for a single entry/exit hole (0.033 inch wide) surrounded by wet discoloration

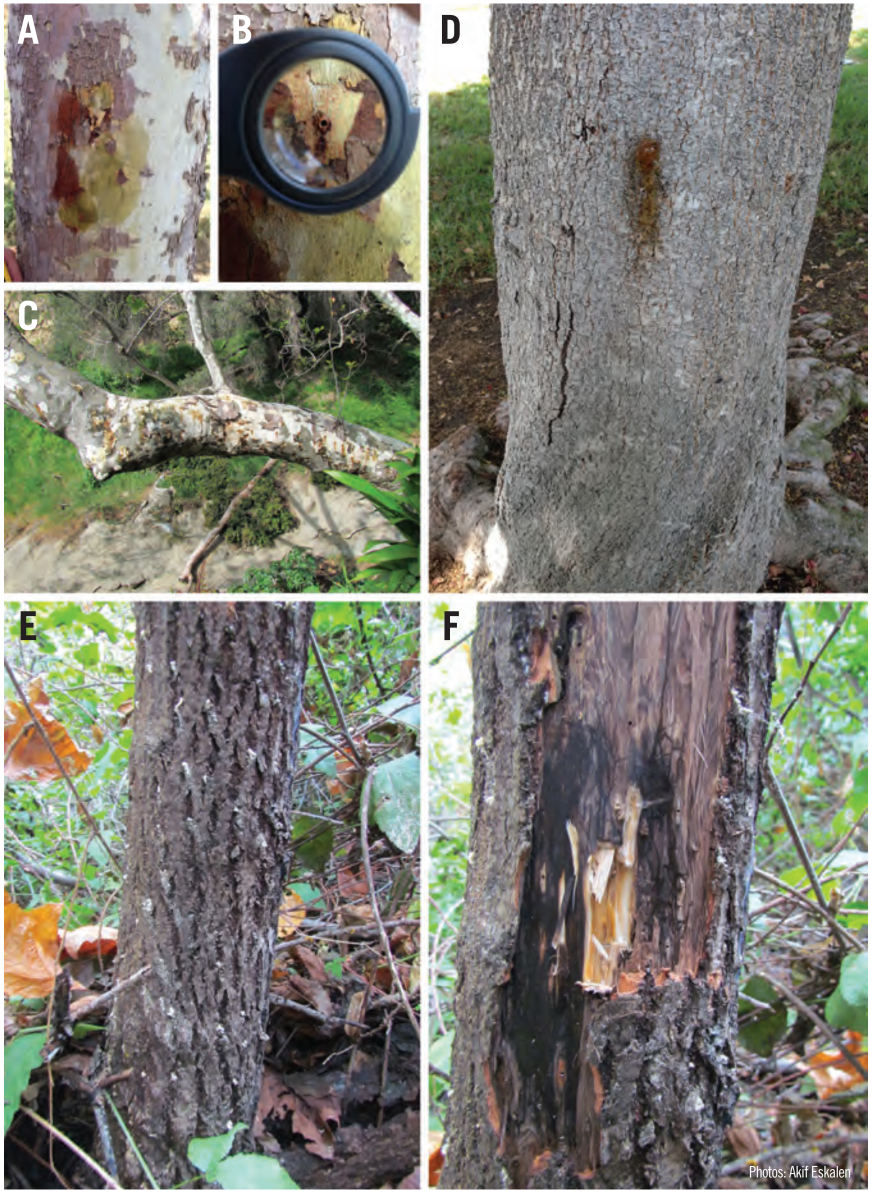


Fig. 30. Symptoms of Fusarium dieback (FD) on two California native hosts. Entry hole of polyphagous shot hole borer (PSHB *Euwallaceae* sp.) on California sycamore (*Platanus racemosa*), surrounded by wet discoloration (a), with the same symptom viewed through a hand lens (b); heavily infested sycamore (c); heavily infested red willow *(Salix laevigata)* with signs of frass exuding from exit holes (e), and necrotic cambium caused by *Fusarium* sp. (f).

Fig. 31. Symptoms of Fusarium dieback (FD) on coast live oak. Entry holes surrounded by wet discoloration on the trunk (a), and branches (b-c); large branch cut showing entry holes on the bark surface, and necrotic heart and sapwood due to fungal growth by *Fusarium euwallaceae* from the beetle galleries (d); branch dieback and crown thinning of two coast live oak trees (e-f).

of the outer bark (Fig. 30a-b; Fig. 31). At the advanced stage of infestation, there are often many entry/exit holes on the tree (Fig. 30c). Scrape off the bark layer around the infected area to look for brown discolored necrosis caused by the fungus. Necrosis can occur through the cambium (Fig. 30f) and into the xylem (Fig. 31d). Symptoms on other hosts may show gumming (Fig. 30d-e). Density of beetle exit/entry holes is highest at the base of the plant. PSHB is smaller than a sesame seed (Fig. 32acd).

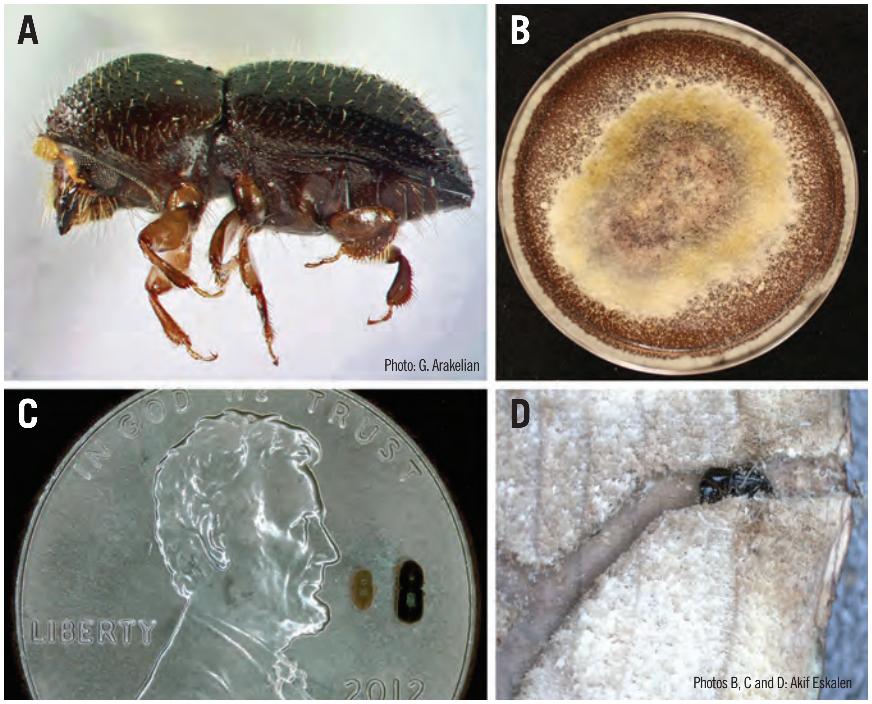


Fig. 32. Female polyphagous shot hole borer (PSHB) (*Euwallacea* sp.) (a); *Fusarium euwallaceae* (b); male (left) and female (right) PSHB on a penny (c); longitudinal section of a host tree showing a male within a gallery (d).

Coast live oak is a suitable host for reproduction, meaning the beetle is able to carry out its life cycle within the host. Therefore, coast live oak is highly prone to rapid dieback and tree death. Symptoms on coast live oak include entry holes surrounded by wet discoloration of the outer bark (Fig. 31a-c). Fungal infection spreads into the wood from the beetle galleries (Fig. 31d). Galleries produced by heavy infestation structurally weaken the plant, and this, combined with the plugging of xylem vessels by the fungus, results in the dieback of large branches and ultimately tree death (Fig. 31e-f).

Disease Cycle

The beetle and fungus have a symbiotic relationship. When the beetle burrows into the tree, it inoculates the host plant with the fungus, which is carried in the beetle's mouthparts in a structure called a mycangia. The fungus attacks the vascular tissue of the tree, blocking the transport of water and nutrients from the roots to the rest of the tree, and eventually causing branch dieback. The beetle larvae live in galleries within the tree and feed on the fungus.

Damage and Importance

This emerging disease/pest complex was discovered in California in 2012 on a backyard avocado tree (20), and has caused serious damage on avocado in Israel since 2009 (49). PSHB is a new species of ambrosia beetle in the Euwallaceae, and is closely related to the tea shot hole borer (an exotic Asian ambrosia beetle) (13,20). The disease/pest complex has been observed on more than 100 different plant species in California, including many species common in the urban landscape and on such agriculturally important species as avocado, olive, peach, and persimmon (20). The impact of this problem is under investigation.
The disease continues to spread. For updated information on disease distribution, please visit: http://eskalenlab.ucr.edu/avocado.html.

Management Strategies

The beetle is highly invasive and can establish quickly onto new hosts. Chipping infested wood and keeping the wood under a clear tarp for several months has been shown to kill the beetle, but this strategy is still being studied. It is imperative that infested wood not be moved for use of firewood. For more information please visit www.dontmovefirewood.org.

The best strategy for management at this point is early detection. Look for signs and symptoms. If you suspect that you have found this beetle or have seen symptoms of FD, please contact your known local authority (page 6).

For updated information, including newly infested locations, please visit www.eskalenlab.ucr.edu.

Sudden Oak Death

Hosts

Coast live oak, black oak, tanoak, California bay laurel, rhododendron, camellia, and a wide range of woody species and perennials.

Status

At present, does not occur in southern California.

Symptoms

Coast live oak trees will exhibit bleeding cankers on the bark of larger trees (> 4 inches in diameter at breast height) (14) (Fig. 33), as seen with other pathogens such as *D. corticola, D. agrifola*, and *F. solani* (44,45). Removal of the surface bark reveals necrotic, dead phloem tissue, separated from healthy bark by a distinct, black zone line (Fig. 34). This pattern is also observed for the aforementioned pathogens.

The disease was named sudden oak death because the browning of leaves in the entire crown can appear suddenly, within several days to weeks. However, these symptoms usually occur after an extended period of disease, perhaps more than 2 years from the onset of infection of the trunk.

Fig. 33. Bleeding canker on the bark surface of a coast live oak tree infected with *Phytophthora ramorum*.

Disease Cycle

During periods of rain and high humidity, *P. ramorum* produces sporangia that contain motile spores called zoospores. Either hyphae, sporangia, zoospores, or chlamydospores (survival structures) move through water, wind-driven rain, plant material, or on animals (via soil or plant material) to infect a new host through natural openings. The pathogen typically "girdles" the tree by killing the conductive tissues around the trunk. It is able to persist in the system by surviving in the tissues of other host species.

Damage and Importance

Sudden oak death currently occurs in coastal California counties from Monterey to Humboldt and in a small portion of southwest Oregon (http://www.oakmapper.org). It is estimated to have killed more than 1 million oak and tanoak trees during the last decade. 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 (14,56,64).

Fig. 34. Phloem canker of a tanoak (*Notholithocarpus densiflorus*) tree infected with *Phytophthora ramorum*, showing necrotic and healthy tissue separated by a black zone line.

Management Strategies

Management options include treatment with phosphonate compounds and selective plant removal, but once sudden oak death infects oak trees, there is no known way to cure them. Therefore, most of the management practices are directed at preventing the spread of the disease to new plants or areas, and protecting susceptible trees before they are infected.

This may be achieved through:

- Proper diagnosis of infected trees.
- Outreach and education to the public on SOD awareness and proper sanitation practices, should individuals recreate in infested locations.
  - Individuals who have recreated (mountain biking, hiking, etc.) in infested areas should sterilize shoes and tires after visiting an infested area and prior to entering uninfested areas.
- 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.
- Employ sanitation practices described herein.
- A quarantine is in place in the infested counties. It is required by law to contact your agricultural commissioner for a permit before moving regulated plant material out of quarantined areas.
- For more information visit http://www.suddenoakdeath.org.

Insect References

Bark Beetles

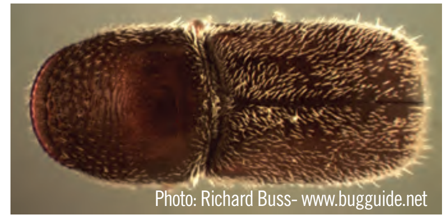


Fig. 35. Western oak bark beetle, *Pseudopityophthorus pubipennis*

Wood Boring Insects

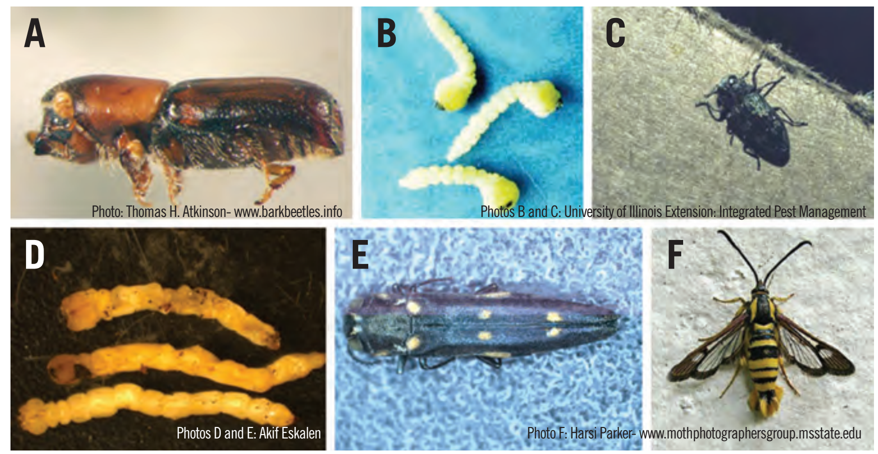


Fig. 36. Ambrosia beetle *Monarthrum dentiger* (a); flat-headed apple tree borer *Chrysobothris femorata* larvae (b) and adult (c); goldspotted oak borer *Agrilis auroguttatus* larvae (d) and adult (e); western sycamore borer *Synanthedon resplendens* and adult (f).

Twig Girdlers

Fig. 37. Oak twig girdler, *Agrilus angelicus*

Acknowledgements

We thank the Nature Reserve of Orange County (NROC) and Milan Mitrovich for funding and coordinating the production of this manual. Dr. John Kabashima UCCE Orange County Farm Advisor and Monica Dimson provided information on FD/PSHB distribution throughout OC Parks.

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