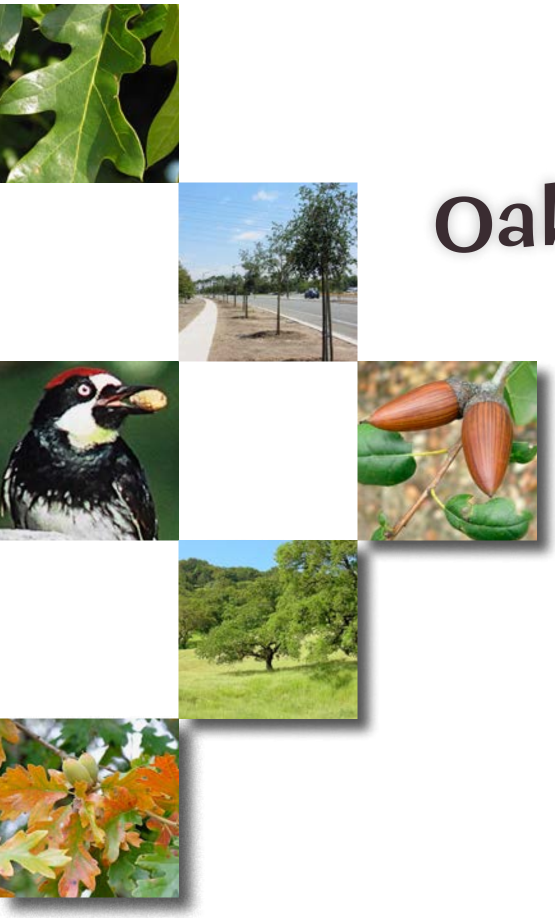

Oaks in the Urban Landscape
Selection, Care, and Preservation

Chapter 7

Biotic and Abiotic Disorders

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Chapter 7

Biotic and Abiotic Disorders

Although oaks are noted for being tolerant of adverse conditions, they can be damaged by a number of biotic and abiotic agents. Many biological organisms, such as insects, fungi, and bacteria, cause injury, dieback, or decline (biotic disorders) (fig. 7.1). Similarly, environmental factors, such as water deficit, aeration deficit, and soil disturbance can injure oaks (abiotic disorders) or predispose them to injury from biotic agents (fig. 7.2). Damage from both types of disorders can range from slight to severe, and virtually all parts and life stages of oaks can be affected.

To manage biotic and abiotic disorders, the causal agent must first be identified. This is accomplished through the diagnostic process, a series of steps used to determine a probable cause. This chapter focuses on the diagnosis of oak disorders by providing a general review of the diagnostic process, a diagnostic guide to identify possible causes from injury symptoms, and descriptions and photos of disorders and specific causal agents. By reviewing key factors to consider when diagnosing problems and then using the diagnostic guide and descriptions, a determination of the cause and significance of most oak disorders can be achieved.

Although the management of oak pests is an important topic, it is not addressed in this chapter because it is covered extensively in other publications: see *Pests of Landscape Trees and Shrubs* (Dreistadt and Flint 2004) for detailed information. Although some discussion of the management of abiotic disorders is included, more detailed information can found in *Abiotic Disorders of Landscape Plants* (Costello et al. 2003). Also, see online resources at the UC Statewide Integrated Pest Management Program (www.ipm.ucdavis.edu). Further information on preventing disorders can be found in chapter 5; for a discussion of general considerations regarding oak pest management, see the last section of this chapter.

Figure 7.1. Many biotic agents can impair the health of oaks. Here, mushrooms indicate that the tree has been infected by oak root fungus *(Armillaria mellea)*. B. Hagen

Figure 7.2. The decline of many oaks can be attributed to abiotic factors. Mechanical injury to roots, soil compaction, and diversion of rainwater likely led to the decline of these valley oaks. B. Hagen

The Diagnostic Process

Considering the large number of agents that can damage oaks, it can be challenging to determine the cause of injury. The diagnostic process is employed to meet this challenge. This is a systematic evaluation of the problem and identification of potential causal agents. It is vital that sufficient time be taken for the diagnostic process to be thorough and accurate. If the process is hurried or steps are missed, then ineffective, unnecessary, expensive, and potentially harmful treatments may be prescribed. The following ten investigative steps assist in systematically diagnosing disorders.

1. ***Identify the oak species.*** If the oak species is not known, see chapter 1 for assistance with identification. If more that one oak species is present, note which species are affected and whether some individuals are injured to a greater or lesser extent than others.
2. ***Locate the damage.*** Inspect the entire tree to determine which parts are affected: acorns, leaves, twigs, branches, trunk, root collar, and roots.
3. ***Identify the symptoms.*** Identify specific symptoms on the affected plant parts, such as bleeding on the trunk, bark loss on branches or marginal necrosis on leaves (see the "Diagnostic Guide," below, for symptoms linked to plant parts). Inspect the entire tree and identify general symptoms, such as shoot growth, foliage color and density, and dieback in upper crown.
4. ***Look for patterns of occurrence.*** Note whether the symptoms are scattered or spread uniformly throughout the crown, limited to the lower or upper part of the crown, or to one side. (fig. 7.3). When did the symptoms begin relative to the season or a particular cultural activity? Did symptoms appear suddenly or are they chronic? Are they increasing or decreasing in severity? Is the problem more severe in some regions or localities than in others, or limited to a particular environmental zone? Are species other than oaks affected?
5. ***Look for signs of pests.*** Signs are evidence of a biotic agent, such as the pest itself or pest-produced materials. Signs of insect pests include frass (fecal pellets or boring dust), honeydew (a sugary solution excreted by sap-feeding insects), sooty mold (a black, sooty-like fungus growing on leaves covered by honeydew), webbing, tunnels under the bark, exit and entry holes, galls (abnormal swellings or structures on a plant), insect eggs, cast larval skins, and pupal cases (fig. 7.4). Signs of fungal pathogens include fruiting bodies (conks, mushrooms), mycelia, and rhizomorphs.
6. ***Assess environmental factors and site conditions.*** Environmental conditions unfavorable to oaks can cause stress, leading to increased susceptibility to pests. Environmental factors can also favor pest development, resulting in injury to the host. Consider the topography (ridge, slope, valley bottom), exposure to sunlight, soil conditions (depth, texture, moisture content), climate (average rainfall, mean summer and winter temperatures), and recent events such as floods, droughts, hail storms, and temperature extremes.

Figure 7.3. Recognizing patterns of symptom distribution is an important step in diagnosing oak disorders. Dieback of the entire crown of a coast live oak (A) suggests a belowground cause, such as Armillaria root disease. Dieback in this coast live oak (B) is restricted largely to the lower and midcrown zones, suggesting an aboveground cause such as twig blight *(Cryptocline cinerescens).* L. Costello

Figure 7.4. Look for signs of pests. An accumulation of frass (pelletized fecal matter, granular, or sawdustlike boring material) indicates that a boring insect is present (A); in this case, the pest is carpenterworm *(Prionoxystus robiniae)*. The sticky, glistening appearance of this black oak leaf (B) resulted from honeydew drip, which typically is a sign of sap-feeding insects such as aphids, scales, or whiteflies. B. Hagen

7. ***Consider cultural practices.*** How has the oak been managed? What are the current tree care practices? Is there turf or other vegetation requiring irrigation in the root zone? Is the soil close to the trunk kept moist by irrigation? Has fill soil been placed against the trunk? What is the pruning history? Is the natural leaf litter allowed to remain or is it regularly removed?
8. ***Determine whether there have been disturbances in the root zone.*** Disturbances such as trenching, excavation, soil compaction, paving, fill soil installation, and changes in drainage patterns can cause significant injury to oaks. Determine whether roots have been cut or otherwise damaged. Has the tree been transplanted?
9. ***Consider multiple causes.*** Keep in mind that multiple factors or causal agents may be involved. In some cases, one agent may be abiotic and the other biotic; for instance, bark beetle injury often occurs when trees experience prolonged water deficit. Typically, one agent is the primary cause of injury, while the other is secondary to it. In this case, water deficit is primary and bark beetles are secondary.
10. ***Consider cumulative effects.*** Note that while most biotic agents of oaks cause minor injury, cumulative effects can occur. For example, infections by foliar pathogens generally do not cause significant injury, but if infection follows extensive root damage from construction, dieback or decline may follow.

In the process of conducting diagnoses, it is useful to list suspected agents and rank them from most to least likely. After this process, the highest-ranked (most plausible) cause or causes should be further assessed for their potential role in the disorder. Although this may take some time and effort, it substantially increases the potential for arriving at an accurate diagnosis.

Diagnostic Guide

The following diagnostic guide will aid in the identification of biotic and abiotic agents that injure oaks. The guide is organized by the plant part affected (acorns, leaves, twigs, branches, trunk or scaffold branches, root collar, and roots) and symptoms associated with specific causes. To use the guide, follow this four-step process:

1. Identify the plant part or parts affected.
2. Review the symptoms listed in the guide and determine the set of symptoms that align with those of the injured plant part. If the plant part has no symptoms, skip to the next plant part listed.
3. Review the list of possible causes given after each symptom and select those considered most likely to be involved. If you are not familiar with the cause listed, refer to the pest and disorder descriptions and photos following the guide. Although causal agents are listed by common name, in a few cases only the scientific name is given because no common name exists. Also, note that agents that appear in bold are serious pests that should be closely monitored and managed.
4. After reviewing possible causes and descriptions, determine the likely primary agent and consider the involvement of secondary agents. In some cases, this determination may remain tentative until further information is collected, such as laboratory confirmation of a suspected pathogen.

* Note that herbicide toxicity (marked with an asterisk in the diagnostic guide) is discussed in detail on pages 188–198 in *Abiotic Disorders of Landscape Plants* (Costello et al. 2003).

A. Acorns

A1. Holes in acorn shell, tunnels and boring material within. **Page**

Cause	Page
Filbert (acorn) weevil	143
Filbertworm	143
Acorn moth	143

A2. Clear, sticky fluid dripping or bubbling from acorns; large, sticky droplets falling from tree (acorns).

Cause	Page
Drippy nut disease	170

B. Foliage

B1. Foliage missing, chewed, gouged, or skeletonized (loss of green leaf tissue between the veins, leaving a network of brown veins).

Cause	Page
California oak moth, oakworm	149
Fruittree leafroller	149
Oak weevil	151
Tent caterpillars	151
Western tussock moth	151
Oak ribbed casemaker	150

B2. Leaves ragged, tattered, or torn.

Cause	Page
Wind	185
Hail	185

B3. Leaves or portions thereof scattered throughout much of the crown or portions of the crown appear dead and brown (“blighted”). Blighting may affect entire leaves or the leaf margins and/or leaf tips, or it may occur as spots, blotches, angular areas, mines, or blisters.

Cause	Page
Twig blight	160
Oak anthracnose	158
Oak leaf blotch miner	150
Two-horned oak gall wasp	152
Pumpkin gall wasp	153
California gall wasp	152
Powdery mildew	159
Oak leaf blister	158
Water deficit	172
*Herbicide toxicity	185

B4. Leaves throughout entire tree or much of the crown are dead and brown (necrotic). In some cases, wilting may precede leaf necrosis. Affected trees may have been declining for some time or may have died suddenly.

B5. Leaves on twigs and small branches scattered throughout the crown are dead and brown.

B6. Lower leaf surfaces are dotted by small, white, cottony tufts or small, black, oval, flat spots surrounded by a ring of white, waxy, or clear gelatinous material.

B7. Leaves sticky, glistening, blackened, or yellowed; mistlike drip or large droplets of honeydew falling from tree. Honeydew, a sugary liquid excreted by many sap-feeding insects, creates a sticky coating on the leaves and branches, and vegetation or objects below the tree. Leaves coated with honeydew often glisten but eventually turn black as sooty mold fungi grow on the sugary substance. Heavily infested leaves can wilt or turn yellow because of excessive sap loss. (fig. 7.5).

Figure 7.5. The blackened or sooty appearance of these oak leaves is caused by sooty mold (fungi) growing opportunistically on honeydew produced by aphids.
J. K. Clark

Page

B8. Yellow or brown spotting or stippling on leaves.

Oak leaf phylloxera 150
Powdery mildew 159
Brown blister leafminer 148
Oak anthracnose 158
Oak leaf blister 158
Spider mites 151
Air pollution 185
*Herbicide toxicity 185

B9. Leaves covered by a dry, white to gray powdery material.

Powdery mildew 159

B10. Leaves appear blistered or distorted.

Oak leaf blister 158
Powdery mildew 159
Live oak erineum mite 149

B11. Leaves with abnormal, often brightly colored or unusually shaped growths (galls).

Gall-forming insects 152

B12. Leaves in abnormally dense clumps, atypically shaped, and smaller than normal.

Powdery mildew 159
Oak mistletoe 171

B13. Leaves are sparse and often smaller than normal. Affected trees appear to be declining. Symptoms may also include poor growth, branch dieback, and epicormic shoots along the trunk and main branches.

Phytophthora root rot 165
Armillaria root rot (oak root fungus) 164
Ganoderma root rot 166
Oak pit scale 155
Canker rots 163
Water deficit 172
Aeration deficit 176
Low temperature 185
*Herbicide toxicity 185
Salinity 179
Specific ion toxicity 179

B14. Leaves yellow (chlorotic, entire leaves or interveinal areas).

Soil aeration deficit 176
Mineral deficiency 183
Low temperature 185
*Herbicide toxicity 185
Soil pH–related problems 183
Specific ion toxicities 179
Salinity 179
Leaf senescence (natural) .... NA
Sap-feeding insects 154
Phytophthora root rot 165

C. Twigs

Page

C1. Often a noticeable pattern of small, dead, brittle twigs in the outer canopy.

C2. Twigs and small branches appear swollen or have abnormal growths (galls) on them.

D. Branches

D1. Branch dieback in the upper crown. Often associated with other symptoms of decline, e.g., wilting, sparse foliage, and epicormic sprouting on the bark of the trunk and older branches.

D2. Underside of branches appears whitewashed, or covered by circular, white, cottony patches.

E. Trunk or Scaffold Branches

E1. Areas of bark dead, sunken, cracked, missing, lifted, or bleeding (a thick, dark exudate or fluidlike discharge).

E2. Bleeding, oozing, or wet spots on bark surface — **Page**

- **Canker-causing pathogens** 159
- Boring insects: 143
- **Carpenterworm** 144
- **Oak bark beetles** 146
- **Oak ambrosia beetles** 146
- **Pacific flatheaded borer** 147
- **Flatheaded appletree borer** 147
- **Goldenspotted oak borer** 145
- Nautical borer 145
- Lead cable borer 145
- **Western sycamore borer** 148
- **Armillaria root rot** 164
- **Phytophthora root rot** 165

E3. Pronounced swelling of the trunk base.

- **Phytophthora root rot** 165
- **Basal (butt) rot** 166

E4. Scattered holes in the bark of the trunk and larger branches; sawdustlike or pelletized fecal or boring material (frass) may be found in bark crevices and on the ground; tunnels under the bark and/or in the wood; wet or frothy spots or a dark brown to black exudate on the bark surface.

- **Carpenterworm** 144
- **Oak bark beetles** 146
- **Oak ambrosia beetles** 146
- **Pacific flatheaded borer** 147
- **Flatheaded appletree borer** 147
- **Goldenspotted oak borer** 145
- Nautical borer 145
- Lead cable borer 145
- **Western sycamore borer** 148

E5. Shallow holes in bark, uniformly and horizontally arranged.

- Sapsuckers 170

E6. Deep holes, up to 1 inch wide, which often contain acorns.

- Acorn woodpeckers 170

E7. Patches of bark appear very roughened or eroded and riddled with 1/8-inch-wide tunnels.

- **Western sycamore borer** 148

E8. Bark appears patchy or spotty as the corky, outer bark exfoliates (flakes off) in small patches.

- Kuwana oak scale 154

E9. Areas of bark covered by circular or irregular-shaped patches of varying size of a gray, gray-green, occasionally yellow (or other color) leafy, filamentous, pendulous, shrubby, netlike, sheetlike, or crustlike growth, or large, dense mats of lush, green fernlike vegetation.

- Lichen 170
- Moss 171

E10. Fleshy, leathery, or hard shelflike, bracketlike, or dome-shaped structures (fungal fruiting bodies) growing on the bark or exposed wood of trunks, large branches, or near branch stubs and old wounds. Trees with fungal fruiting bodies, indicating wood decay, should be evaluated for risk potential.

	Page
Ganoderma root rot	166
Canker rots	163
Phellinus robustus	166
Hedgehog fungus	167
Sulfur fungus	167
False turkey tails	168
Hypoxylon canker	168
Oyster mushroom	169
Phellinus gilvus	169
Split gill fungus	169
Turkey tails	169

E11. Mushrooms or conks growing on or near the trunk base or on large roots.

Armillaria root rot	164
Jack-o'-lantern fungus	168
Oyster mushroom	169
Ganoderma root rot (occasionally found on trunk)	166

E12. Trunk and larger branches with large, nearly hemispherical swellings (galls) on the bark surface.

Mistletoe galls	171
Unknown causes	172

E13. Basal scars and seams indicate where bark wounds or cankers have closed (compartmentalized). They also may be associated with decay or indicate cracks.

See "Other Biotic Disorders" ... 170

F. Roots and Root Collar

F1. Areas of the root collar have dead, sunken, cracked, missing, or loose bark, usually accompanied by bleeding through small bark fissures. Vigorous callusing may be seen at canker margins, sometimes with adventitious roots growing from the callus (woundwood) into the soil.

Armillaria root rot (oak root fungus)	164
Phytophthora root rot (crown rot)	165

F2. Fleshy, leathery, or hard shelflike or bracketlike structures known as conks (fungal fruiting bodies) or mushrooms growing through the bark near the soil line or on the root flare or large support roots.

Ganoderma root rot	166
Weeping conk	167
Phellinus robustus	166
Sulfur fungus	167
Jack-o'-lantern fungus	168

F3. Bark on large supporting roots just below the soil line appears decayed or girdled by large tunnels.

California prionus	143
Lower trunk and root decay	164

Biotic Disorders

At least 850 insects and more than 380 disease agents are known to occur on oaks in California (Swiecki 2002). While few of these pests cause serious damage in undisturbed oak woodlands, some can be destructive in the urban landscape.

Insects and Mites

Five groups of insects and mites are active on oaks: acorn feeders, borers, defoliators, gall-formers, and sap-feeders. Of these, the defoliators (particularly moth larvae) cause the most noticeable injury. Their outbreaks are typically sporadic and short-lived, but total or significant defoliation can slow growth, retard wound closure, impair response to wood decay pathogens, and increase susceptibility to secondary pests (Wargo 1978). Repeated defoliation can affect tree survival, particularly when combined with severe drought (fig. 7.6).

Sap-feeding insects often occur in abundance on oaks, especially on the new growth. Symptoms may include sticky, blackened, curled, folded, distorted, yellowed, or spotted foliage, as well as branch dieback and decline. Among the sap-feeding insects, oak pit scale (an introduced pest) is the most destructive, particularly during drought years in urban landscapes (fig. 7.7).

Boring insects attack stressed trees, girdling branches, killing areas of the trunk, and facilitating infection by decay-causing pathogens. Some (such as oak twig girdler and Pacific flatheaded borer) feed mostly in the phloem (inner bark), cambium, and outer sapwood (fig. 7.8). Others (such as carpenterworm and oak ambrosia beetle) bore deeper into the wood, weakening tree structure. By comparison, feeding by oak bark beetles is restricted to the phloem and cambial layer.

More than 200 species of gall-forming insects on native oaks have been described (Russo 2006). Galls are abnormal growths that vary greatly in size, shape, color, and location, and can be found on leaves, flowers, acorns, buds, twigs, branches, and roots. They develop from plant tissue that has been "reprogrammed" by the gall-forming organism, usually tiny wasps. Galls provide both food and shelter for the organism. Although certain species of gall-forming pests can kill branches or portions of leaves (fig. 7.9).

For more detailed information regarding oak pests, see *A Field Guide to Insects and Diseases of California Oaks* (Swiecki and Bernhardt 2006).

Figure 7.6. Coast live oak can be extensively defoliated by the California oakworm *(Phryganidia californica)*, as shown here in Woodside, California. After defoliation, trees can recover, but overall growth may be stunted, particularly if defoliation is repeated in subsequent years. These trees developed a new set of leaves the following spring. B. Hagen

Figure 7.7. The pitting and rough appearance of this twig was caused by oak pit scale (*Asterolecanium* spp.), a sap-feeding insect. Golden-brown adults are visible in many of the pits. B. Hagen

Figure 7.8. Serpentine galleries (oval tunnels) just under the bark and into the wood surface of this oak indicate that the Pacific flatheaded borer *(Chrysobothris mali* or *C. femorata)* is present. B. Hagen

Figure 7.9. Gall-forming insects are common on oaks. These spherical, reddish orange growths are caused by the clustered gall wasp *(Andricus brunneus)*. B. Hagen

Acorn Feeders

Filbert (acorn) weevil *Curculio* spp.

Filbertworm *Cydia latiferreana*

Acorn moth *Valentinia glandulella*

The developing larvae of these pests feed inside acorns, damaging the cotyledons (embryos) (figs. 7.10, 7.11) . Infested acorns are usually unable to sprout. Larvae (grubs) of the filbert weevil are legless, c-shaped, stout, and slightly less than ⅜ inch long (fig. 7.12). By comparison, the larvae (caterpillars) of both the filbert weevil and the acorn moth have distinct legs. The adult filbertworm is about ¾ inch long (fig. 7.13). The acorn moth is reported to favor damaged acorns.

Figure 7.10. The pinhole-sized puncture in this acorn was made by a female acorn weevil inserting an egg. It is not unusual to find several puncture wounds (and as many larvae) within acorns.
B. Hagen

Figure 7.11. Filbert weevil (*Curculio* spp.) larvae on this leaf emerged from a black oak acorn. Normally the larvae emerge, drop to the soil, and pupate into adult snout beetles.
B. Hagen

Figure 7.12. A filbertworm larva that recently emerged from a black oak acorn.
B. Hagen

Figure 7.13. An adult filbert weevil next to the emergence hole of a larva.
J. K. Clark

Borers

Borers can kill patches of bark and cause bleeding. Look for bleeding (fig. 7.14), frass (fig. 7.15), bark cracks, and exit holes. Borers typically colonize drought stressed trees, dying and recently killed trees, and bark tissue damaged by fire or sunburn injury (fig. 7.16).

Figure 7.14. Bleeding (wet spots) on the bark of this coast live oak is an indicator of boring insects.
B. Hagen

Figure 7.15. The reddish brown frass (fecal pellets and boring dust) collecting on bark plates indicates that a boring insect (carpenterworm, *Prionoxystus robiniae*) is present.
B. Hagen

Figure 7.16. Boring insects are considered secondary pests that often invade stress-weakened hosts. Borers typically kill branches or bark patches of varying size on the trunk and large branches. The damage to this red oak was caused by the Pacific flatheaded borer *(Chrysobothris mali)*.
B. Hagen

California prionus *Prionus californicus*

The larvae of this roundheaded beetle feed in living and dead roots of stressed trees, just below the soil line (fig. 7.17). Feeding can completely girdle trees. This is one of the largest beetles attacking oaks in California and is commonly called the giant root borer.

Figure 7.17. This roundheaded borer, California prionus *(Prionus californicus)*, emerged from a decaying root.
B. Hagen

Carpenterworm
Prionoxystus robiniae

Carpenterworm infestations are characterized by abundant frass—coarse "sawdust" and dark brown fecal pellets—expelled through ½-inch-diameter tunnel openings in the bark (figs. 7.18, 7.19). The bark of affected trees often appears quite roughened, and the wood below is riddled with large, oval tunnels. Larvae, which are off-white and up to 2½ inches long, tunnel extensively in the phloem (inner bark) and wood (fig. 7.20). Brown, papery pupal cases are often visible projecting from tunnel openings (fig. 7.21). Tunneling may introduce decay-causing pathogens and weaken tree structure (fig. 7.22). Heavy infestations can severely damage trees, lead to decline and increase susceptibility to other secondary pests (fig. 7.23).

Figure 7.18. A large quantity of frass (fecal pellets) and boring dust (frass) has accumulated around this oak (arrow), indicating an infestation of carpenterworm (*Prionoxystus robiniae*). Root injury due to sidewalk repair likely predisposed the tree to infestation. B. Hagen

Figure 7.19. Tunnel openings of carpenterworm (*Prionoxystus robiniae*) larvae may exceed ½ inch in diameter. Note frass in bark crevices. B. Hagen

Figure 7.20. Larvae of carpenterworm (*Prionoxystus robiniae*) are up to 2½ inches long and range from pinkish to off-white. B. Hagen

Figure 7.21. These empty pupal cases of carpenterworm (*Prionoxystus robiniae*) were extracted from separate tunnels. Their presence can be used to identify the causative agent. B. Hagen

Figure 7.22. Large tunnels riddling the wood of this coast live oak were caused by larvae of carpenterworm (*Prionoxystus robiniae*). B. Hagen

Figure 7.23. Repeated infestation by carpenterworm (*Prionoxystus robiniae*) can cause severe bark damage and may kill very old or severely stressed trees. B. Hagen

Goldenspotted oak borer
Agrilus coxalis

This flatheaded borer (Buprestid) was first detected in San Diego County in 2004. Bark of affected trees bleeds heavily, causing dark staining, and red, blistered patches often develop (fig. 7.24). Symptoms include crown thinning, branch dieback, and tree death. Other indicators include dark, frass-filled meandering larval galleries up to ⅛ inch wide on the surface of the sapwood, and woodpecker foraging damage to the bark (bark flecking). Mature larvae are slightly less than ¾ inch long and about ³⁄₃₂ inch wide (fig. 7.25). Sinuous larval galleries are black, frass-filled and about ⅛ inch wide. Adult exit holes in the bark of the trunk and larger branches are D-shaped and approximately ³⁄₃₂ inch wide (fig. 7.26). Bark beetles and other boring insects may be associated with this new pest.

Figure 7.24. Extensive bleeding, dark staining, and red-blistered patches are indicative of an infestation by goldenspotted oak borer *(Agrilus coxalis)*. Courtesy USDA Forest Service

Figure 7.25. Larvae of the goldenspotted oak borer *(Agrilus coxalis)* extracted from an infested oak. Courtesy USDA Forest Service

Figure 7.26. Adult of the goldenspotted oak borer *(Agrilus coxalis)*. The adults are black with orange to golden spots, less than ⅓ inch long, and narrow. Courtesy USDA Forest Service

Figure 7.27. Adult female lead cable borers *(Scobicia declivis)* tunnel through the bark into the wood to lay their eggs. The developing larvae riddle the wood, and their frass is tightly packed within the tunnels. B. Hagen

Lead cable borer
Scobicia declivis

The larvae of these beetles (Bostrichids—false powderpost beetles) burrow in dead and seasoned wood and occasionally dying branches. They do not feed under the bark like many other borers. Adults are about ⁵⁄₁₆ inch long, brown, cylindrical, slender, and the head is projected downward (fig. 7.27). They are similar in appearance to bark beetles, but much larger. Tunnels in the wood are round, less than ⅛ inch wide, frass-filled, and run mostly parallel to the axis of the limb or trunk.

Nautical borer
Xylotrechus nauticus

These roundheaded (Cerambycid) borers commonly attack the trunks and branches of stressed, dying and recently killed trees, fallen and dying branches, and recently cut firewood. After emerging from eggs laid on the bark, the developing larvae tunnel through the outer bark and begin burrowing within the phloem and later the wood. The phloem and wood surface is riddled with coarse, frass-filled oval galleries (fig. 7.28). Boring can girdle branches or kill large patches of affected tissue. The larvae tunnel deeply into the heartwood to complete their development. Larvae range from about ½ inch to ¾ inch long and their "heads" are prominent and mostly rounded (clublike), not wide and flattened like those of the Pacific flatheaded or appletree borer. Boring activity is indicated by round exit holes, slightly larger than ¼ inch in diameter (fig. 7.29). A few other less-common borers, such as western ash borer *(Neoclytus conjunctus)*, can cause similar damage.

Figure 7.28. Larval galleries of the nautical borer *(Xylotrechus nauticus)*. The granular frass was removed to show the pattern of the oval mines. Larval galleries appear to radiate outward from a common point. Like other wood-boring beetles, the eggs are deposited on the bark surface, not under it as with bark beetles. B. Hagen

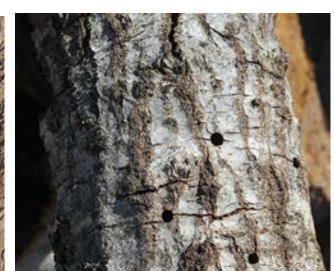

Figure 7.29. The exit holes of nautical borer *(Xylotrechus nauticus)* are mostly round, not oval as are those made by the Pacific flatheaded borer. The holes are about ¼ inch in diameter. B. Hagen

Oak ambrosia beetles
Monarthrum scutellare, M. dentiger

Adult beetles (Scolytids) burrow through the bark into the sapwood and heartwood of severely stressed, dying, recently dead trees, broken branches, windfall, and cut firewood. Trees affected by sudden oak death are also colonized by oak ambrosia beetles. Look for small piles of fine, light-colored frass and accumulations on the bark surface and ground below (figs. 7.30, 7.31). Black-stained pinholes (tunnels) in the wood are also characteristic (fig. 7.32). In cross-section individual tunnels can be seen branching (forking) into several or more tunnels (fig. 7.33).

Figure 7.30. These small, conelike piles of light-colored frass (boring dust) were expelled by oak ambrosia beetles *(Monarthrum scutellare* or *M. dentiger)* tunneling through the bark and into the wood of a recently cut oak. B. Hagen

Figure 7.31. Frass produced by the oak ambrosia beetles *(Monarthrum scutellare* or *M. dentiger)* and oak bark beetles *(Pseudopityophthorus pubipennis* or *P. agrifolia)* can be seen accumulating on the bark of this dying oak. The light-colored frass is that produced by the ambrosia beetle, and the reddish brown frass is that produced by the oak bark beetle. Note the lichen on the trunk. Large amounts of frass often accumulate on the ground around affected trees. J. K. Clark

Figure 7.32. When the bark is removed, tunnels of ambrosia beetles *(Monarthrum scutellare* and *M. dentiger)* appear as small, black-stained holes in the wood. Staining is caused by a fungus that the beetles introduce and feed on. B. Hagen

7.33. In this cross-section of a coast live oak killed by sudden oak death, the black-stained tunnels of adult ambrosia beetles *(Monarthrum scutellare* or *M. dentiger)* can be seen extending into the wood. B. Hagen

Oak bark beetles
Pseudopityophthorus pubipennis, P. agrifolia

These small beetles (Scolytids) colonize severely stressed, dying, or recently dead trees. Attacking beetles burrow through the bark and cause a frothy liquid to bubble or bleed from entry tunnels (fig. 7.34). In this manner, the vascular tissue is girdled and affected trees die and turn brown relatively quickly. Bleeding ceases as affected trees decline, and granular, reddish brown frass (fecal pellets), expelled from the tunnel openings, collects in the bark crevices (fig. 7.35). Colonizing beetles excavate shallow tunnels under the bark, across the grain of the wood, engraving the outer surface of the wood. Female beetles lay their eggs in these tunnels; the developing larvae tunnel at right angles to these, but mostly within the phloem (inner bark) close to the surface. Consequently, a gridlike pattern can be seen on the inner surface of the bark (fig. 7.36). White, legless larvae (grubs) can be found under the bark unless they have completed development and emerged. The adult beetles are small (1/25 to 1/10 inch long), dark brown, and shiny. Trees affected by sudden oak death are commonly colonized by oak bark beetles.

Figure 7.34. Oak bark beetles *(Pseudopityophthorus pubipennis* or *P. agrifolia)* have burrowed through the bark of this coast live oak to lay eggs, causing sap to flow from small wounds that wets small areas of the bark. The fluid is usually clear and may bubble from the tunnels that penetrate through the bark. B. Hagen

Figure 7.35. Once bleeding stops, small piles of coarse, reddish brown boring dust and frass accumulate on the bark beneath tunnel entrances and on the ground around the tree colonized by oak bark beetles *(Pseudopityophthorus pubipennis or P. agrifolia).* UC IPM

Figure 7.36. With the bark removed from this dead branch, the characteristic gallery pattern of oak bark beetles is visible. The shallow tunnels engraved into the surface of the wood across the wood grain are made by adult females to lay their eggs. The smaller larval tunnels, which are made mostly in the inner bark, run at right angles to those of the adult. B. Hagen

Oak twig girdler
Agrilus angelicus

Twigs and small branches up to about ½ inch in diameter, scattered throughout the crown, are killed by this flatheaded borer, causing the leaves to turn brown. Females lay a single egg on selected twigs, and after hatching, the developing larva tunnels spirally around the twig, girdling it and killing the leaves (fig. 7.37). The developing larva tunnels toward the base of twig, progressively girdling more of the twig. Shallow, spiraling tunnels can be found just under the bark of affected twigs (fig. 7.38). Toward the end of its development, the larva begins to tunnel down the center of the twig back to where it first began. Larvae are off-white, flattened, legless, and up to 1 inch long. Outbreaks typically occur during periods of subnormal rainfall.

Figure 7.37. Oak twig girdler *(Agrilus angelicus)* damage is typically characterized by many small, dead branches with brown leaves scattered throughout the outer canopy. Damage can be extensive during droughts. B. Hagen

Figure 7.38. Shallow, spiraling larval tunnels of an oak twig girdler revealed by peeling or cutting away the bark. Toward the end of their development, larvae tunnel back down the center of the twig (pith) toward the far end where they began. B. Hagen

Figure 7.42. The oval holes seen in the bark of this coast live oak were made by Pacific flatheaded borer *(Chrysobothris mali)* adults. After pupating, the adult beetles tunnel outward, exiting through the bark to emerge and disperse. B. Hagen

Pacific flatheaded borer
Chrysobothris mali

Flatheaded appletree borer
Chrysobothris femorata

These beetles (Buprestids) are secondary pests, attacking dying and drought-stricken trees, dying branches, and fire-damaged and sunburned bark tissue. They are also problematic on transplanted trees and newly planted trees when soil moisture deficits are allowed to develop. Bleeding (wet spots) may occur as the larvae, developing from eggs laid on the bark surface, begin to burrow through the outer bark to feed in the phloem. The larvae are off-white with wide, flattened, amber-colored "heads," and are said to resemble "horseshoe" nails (fig. 7.39). They are about ¾ inch long and found in shallow, oval tunnels (galleries) packed with coarse boring dust. The tunneling engraves the surface of the wood, leaving a characteristic serpentine or sinuous pattern (figs. 7.40, 7.41). Boring damage is typically characterized by cracking and loosening of the bark and 3⁄16-inch oval exit holes. The larvae burrow in the wood to pupate and then exit through the bark (fig. 7.42). Frass is retained within the galleries.

Figure 7.39. Pacific flatheaded borer *(Chrysobothris mali)* larva in manzanita (*Arcostaphylos* spp.), one of many hosts. Note that the larva's head (prothorax) is wide and flattened, the body (abdomen) appears beadlike, and there are no legs (prolegs). B. Hagen

Figure 7.40. Pacific flatheaded borer *(Chrysobothris mali)*, flatheaded appletree borer *(C. femorata)*, and goldenspotted oak borer *(Agrilus coxalis)* larvae make shallow galleries in the cambial zone between the phloem (inner bark) and the surface of sapwood. Galleries are oval, frass-filled, and serpentine. The galleries in this photo were made by the Pacific flatheaded borer or the flatheaded appletree borer. B. Hagen

Figure 7.41. Frass-filled oval tunnels of the Pacific flatheaded borer *(Chrysobothris mali)* viewed in cross-section of an oak stem. B. Hagen

Figure 7.43. Larva of a roundheaded oak twig borer *(Styloxus fulleri)*. This minor pest feeds in the center of small twigs, not between the wood and bark. Only a few dead branches were seen in the affected tree. B. Hagen

Roundheaded oak twig borer
Styloxus fulleri

Larvae of this Cerambycid beetle burrow longitudinally down the center of twigs up to ½ inch in diameter, consuming the wood. Affected twigs die back (fig. 7.43). Larvae are off-white, legless, and up to ¾ inch long. Look for an oval, frass-filled tunnel down the center of the twig. The larvae are mostly round in cross-section and stouter than those of the oak twig borer.

Western sycamore borer
Synanthedon resplendens

These "clearwing" (Sesiid) moth larvae burrow extensively in the phloem (inner bark), sometimes causing conspicuous damage to the bark and cambium. (fig. 7.44) Stressed trees are usually at greater risk to severe infestations, which may result in mortality. Symptoms include bleeding (a thick, dark exudate on the bark), patches of roughened, tunnel-riddled bark, round exit holes in areas where the bark is still intact, and copious amounts of reddish brown fecal material (frass) in bark crevices and on the ground below the tunneling. Larvae (fig. 7.45), when fully grown, burrow to the outer bark to pupate. Brown, papery pupal cases are often visible projecting from ⅛-inch-wide exit holes (fig. 7.46). Heavy infestations can cause considerable damage (fig. 7.47).

Figure 7.44. The roughened appearance of the bark on this coast live oak indicates that it was damaged by the western sycamore borer *(Synanthedon resplendens)*. The bark in affected areas appears riddled with ⅛-inch-wide tunnels. Damage may be quite severe and can extend down to the cambium. B. Hagen

Figure 7.45. A western sycamore borer *(Synanthedon resplendens)* larva, removed from a burrow in the bark and placed on a piece of wood. Three pairs of jointed legs and four pairs of rudimentary prolegs can be seen on the ventral surface. The head capsule and segment just behind the head is reddish brown. B. Hagen

Figure 7.46. The presence of ½-inch-long, brown, papery pupal cases extending out of tunnel openings is a sign confirming the presence of western sycamore borer *(Synanthedon resplendens)*. B. Hagen

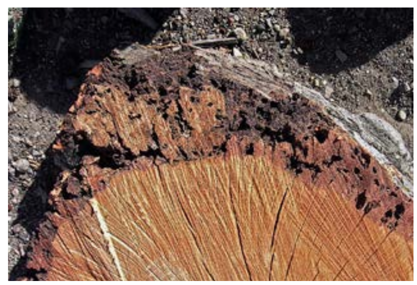

Figure 7.47. Cross-sectional view of western sycamore borer *(Synanthedon resplendens)* injury to the bark of coast live oak. B. Hagen

Defoliators and Other Leaf Feeders

Brown blister leafminer
(Thought to be caused by an Agromizid moth)

Brown, circular spots up to 5/16 inch across on affected leaves (fig. 7.48).

Figure 7.48. Typical symptoms of brown blister leafminer (unidentified species). Note the circular brown leaf spots on this black oak leaf. Some of the spots are so close that they have coalesced. The small dark speck in the center of each lesion is the likely exit hole for the pest. B. Hagen

California oak moth, oakworm *Phryganidia californica*

This serious defoliator occurs on most oak species in the coastal mountain ranges from Del Norte County to San Diego County. After hatching, the young larvae begin skeletonizing small patches on the underside of leaves as they feed. Older larvae, however, consume entire leaves, leaving only the major leaf veins. The larvae are yellow to olive with black, longitudinal stripes running the length of the body (fig. 7.49). When fully developed, they are about 1¼ inch long. The pupae (fig. 7.50) are off-white with black marking. They can be on the leaves, twigs, branches and trunk of infested trees. The adult, called an oak moth, is a uniform tan to gray or silvery color and is distinguished by its prominent wing veins. The body is about ½ inch long, and the wingspread is about 1¼ inches. Unlike females, males have feathery antennae. Typically, there are two generations per year; however, a third generation may occur in southern California. The first (spring) generation develops from eggs laid in the fall of the previous year by the second (summer) generation. The larvae that develop from these eggs overwinter on the underside of leaves. They begin feeding in the late spring and early summer. The resulting adults give rise to the second (summer) generation. Feeding damage is usually less serious on deciduous oaks because eggs and inactive larvae are shed in the fall with the leaves. The second generation is generally responsible for most severe defoliation.

Figure 7.49. The California oakworm *(Phryganidia californica)* larva has a large brown head, a black, relatively hairless body with yellow stripes. J. Neve

Figure 7.50. California oakworm *(Phryganidia californica)* pupa. Pupae are off-white, yellowish to pinkish, and have distinct black markings. J. K. Clark

Fruittree leafroller *Archips argyrospila*

The larvae fold, roll, and tie developing leaves together with silken threads, then feed within the leaf shelters. Affected leaves appear skeletonized, tattered, and chewed (fig. 7.51). The larvae are up to ¾ inch long, light green to brownish green, and have dark heads (fig. 7.52). When disturbed, they drop and wriggle on silken threads. When populations are high and trees are nearly defoliated, larvae may drop to the ground and feed on other vegetation. Pupae are about ½ inch long, amber colored to dark brown. Pupation generally occurs within the leaf shelters.

Figure 7.51. Fruittree leafroller larval feeding damage. Developing leaves are rolled up or tied together with silk, and areas of the leaves are skeletonized or entirely consumed. High populations can defoliate trees. The pupa is just under ½ inch long, light to dark brown, and is usually formed within the rolled leaf shelter. Silk webbing lines the area around the pupa. Unlike California oakworm *(Phryganidia californica)*, fruittree leafroller produces noticeable silk threads but not the large masses of silk formed by tent caterpillars. B. Hagen

Figure 7.52. At maturity the larvae of the fruittree leafroller *(Archips argyrospila)* are green and ¾ to 1 inch long. The head and segment just behind it (prothoracic shield) are brownish. Larvae wriggle vigorously when disturbed and often drop to the ground on silken threads. This leafroller is a destructive defoliator of deciduous and evergreen oaks. B. Hagen

Live oak erineum mite *Eriophyes mackiei*

These nearly microscopic Eriophyid mites cause the formation of numerous raised green blisters on the upper leaf surface (fig. 7.53). Blister depressions on the lower leaf surfaces are filled with a tan to brown feltlike material in which the wormlike mites can be found (fig. 7.54).

Figure 7.53. Live oak erineum mite *(Eriophyes mackiei)* on coast live oak. Note blisters on upper leaf surface caused by mites on the underside. B. Hagen

Figure 7.54. Live oak erineum mite *(Eriophyes mackiei)* on a lower leaf surface. Note depressions filled with rusty, brown material. The color is variable and can be orange, yellow, or whitish. B. Hagen

Oak leaf blotch miner
Lithocolletis agrifoliella

Signs of oak leaf blotch miner (fig. 7.55) are tan-colored mines, initially narrow and serpentine, becoming broad and irregularly-shaped (blotches) (figs. 7.56, 7.57). Feeding occurs just beneath the upper leaf surface, leaving the membranous cuticle intact. Although damage is seldom significant, outbreaks can cause partial defoliation.

Figure 7.55. Larva of the oak leaf blotch miner (*Lithocolletis agrifoliella*), exposed when the membranous leaf surface was removed. B. Hagen

Figure 7.56. Oak leaf blotch miner (*Lithocolletis agrifoliella*) larval mine. Note the initial serpentine pattern of the gallery. With time, the mines widen and become blotched or blisterlike. B. Hagen

Figure 7.57. Multiple leaf blotches on a valley oak leaf caused by the oak leaf blotch miner (*Lithocolletis agrifoliella*). B. Hagen

Oak leaf phylloxera
Phylloxera spp.

These tiny, yellow, aphidlike insects on the underside of leaves cause yellow spotting on the upper surface (figs. 7.58, 7.59). When numerous, yellow spots may coalesce into irregularly shaped brown spots. Spotting may be fairly random or primarily along the leaf veins.

Figure 7.58. Oak leaf phylloxera (*Phylloxera* spp.) feeding on the underside of this valley oak leaf causes yellow and brown leaf spotting on the upper surface. B. Hagen

Figure 7.59. A close-up of oak leaf phylloxera (*Phylloxera* spp.) on the lower leaf surface of a valley oak leaf. This minor pest is minute, yellow, and aphidlike. J. K. Clark

Oak ribbed casemaker
Bucculatrix albertiella

The larvae of this very small moth initially mine (burrow) within the leaf. After molting under circular, white, silken shelters, they begin skeletonizing small patches on the underside of leaves. Look for distinctive white, longitudinally ribbed, cigar-shaped pupal cases that are about ¼ inch long on leaves, bark, and other plants (fig. 7.60). Larvae seldom cause serious defoliation but can diminish appearance of the tree (fig. 7.61).

Figure 7.60. Distinctive cigar-shaped pupal cases of the oak ribbed casemaker (*Bucculatrix albertiella*) on coast live oak. B. Hagen

Figure 7.61. Feeding damage (skeletonized patches) on coast live oak caused by the oak ribbed casemaker. Heavy infestations can cause the leaves to appear brown and resemble damage caused by twig blight or certain leaf galls. B. Hagen

Oak weevil
Deporaus glastinus

Feeding damage by this weevil is characterized as "leaf-gouging." Tissue on the underside of young leaves is eaten in small oval to rectangular patches. When extensive, feeding injury may cause leaves or portions of leaves to turn brown and the leaf edges to curl. Heavy feeding may cause trees to brown perceptibly. Weevils also clip the petiole, causing leaves to fall. Feeding usually is restricted to only one portion of the tree, but it may spread to new areas. Damage may diminish appearance of the tree. Coast live oak and Engelmann oak are the primary hosts. Adult beetles are metallic blue-green with long, curved snouts to ¼ inch long. Although the live oak weevil is a common pest in Southern California, it is not a serious pest.

Spider mites
Various species in family Tetranychidae

Spider mites are tiny, eight-legged organisms that generally feed on the undersides of leaves. They spin protective silk webbing and feed on the contents of living leaf (epidermal) cells. This results in the leaf having a stippled (spotted) appearance. High populations cause bronzing and bleaching of the affected leaves (fig. 7.62). This minor pest is generally uncommon, unless the population of predatory mites has been disrupted by pesticide sprays intended for other pests.

Figure 7.62. The bronzed appearance of this valley oak leaf was caused by spider mites. An outbreak occurred after carbaryl insecticide was applied during hot weather to manage an infestation of fruittree leafroller *(Archips argyrospila)*. Ostensibly, the pesticide application reduced the population of predatory mites and allowed spider mites to proliferate. J. K. Clark

Tent caterpillars
Malacosoma spp.

Infestations are characterized by silken tents and brown, hairy caterpillars. Larvae are dark bodied and covered by orange to brown hairs and orange to white tufts of hairs, depending on the species (fig. 7.63). Coloration and markings depend on the species and locality. Typically, a row of light blue spots or linear markings can be seen along each side of the upper surface of both the western and Pacific tent caterpillars. The western tent caterpillar *(M. californicum)* has orange hairs and orange tufts. By comparison, the Pacific tent caterpillar *(M. constrictum)* has orange hairs and off-white tufts of hairs along the sides. The forest tent caterpillar *(M. disstria)*, however, has white "key-hole"-shaped markings along its back and a wide dark-blue stripe on either side. The hairs are light brown. Length can reach 2 inches. Tents of the western tent caterpillar are relatively large—up to 12 inches across. Those of the Pacific tent caterpillar are much smaller or rudimentary. Forest tent caterpillars construct flattened mats where the larvae congregate. Larvae feed communally and can defoliate branches, rarely entire trees.

Figure 7.63. Western tent caterpillars *(Malacosoma californicum)* in a large silken tent. The caterpillars have dark bodies with light blue spots along the sides and are covered with orange hair. Typically, defoliation is restricted to individual branches. B. Hagen

Western tussock moth
Orgyia vetusta

The larvae of this common pest are distinctive and colorful. The body is gray with red, blue, and yellow spots and covered with tufts (tussocks) of hairs ranging from white to silvery to golden (fig. 7.64). A pair of black tufts of bristlelike hairs project laterally and forward like horns from the head area, and a single tuft projects backward from the posterior area. Larvae may reach 1 inch in length. Look for clusters of tan, hairy cocoons and eggs masses on the bark (fig. 7.65).

Figure 7.64. Larvae of the western tussock moth *(Orgyia vetusta)* have four distinct tufts or tussocks of light-colored hair on their backs, two black tufts near their heads, a single posterior black tuft, numerous long, stiff bristles along their sides, and a series of red and yellow spots on their bodies. B. Hagen

Figure 7.65. Western tussock moth *(Orgyia vetusta)* cocoons on coast live oak. B. Hagen

Gall-Forming Insects

Over 200 species of gall wasps are known to cause galls (abnormal structures) on the leaves, flowers, buds, acorns, and twigs of oaks. Although produced by the host plant, these galls are initiated by gall wasps. Galls are stimulated to grow when female gall wasps lay their eggs on their preferred host when the plant is in a specific stage of development. This may be one of the reasons why population levels are variable. Individual larvae develop within a cavity or multiple cavities inside each gall, feeding on the materials lining the cavity. Formation of galls may be within or on the affected plant part. Galls may contain one to many larvae. At maturity, the larvae pupate and chew their way out. Each species of gall wasp produces a gall of a particular size, shape, and color. In some species, alternating generations form different galls on different plant parts. For more information see *Field Guide to Plant Galls of California and Other Western States* (Russo 2006).

California gall wasp, oak apple gall wasp, or California oak gall wasp *Andricus quercuscalifornicus*

Galls produced by this wasp form externally to the twig and are detachable. Initially they are small and green but change to round, reddish, or brown (and sometimes black) as they mature and grow to as much as 4 inches in diameter (fig. 7.66).

Figure 7.66. California oak gall *(Andricus quercuscalifornicus)*, formerly called oak apple gall *(Andricus californicus)*. These "detachable" galls are borne on the outer surface of the twigs. They occur singly or in clusters. Larvae can be found in separate chambers at the center of each gall. B. Hagen

California jumping gall wasp *Neuroterus saltatorius*

Affected leaves, particularly those with numerous galls, have a blighted or scorched appearance. Tiny, round galls (about 1⁄16 inch in diameter) can be found on the underside of affected leaves (fig. 7.67). The galls, which can be quite numerous, drop to the ground in the fall and the larvae within pupate. Movement of the larvae within fallen galls causes them to jump or hop about. Members of the white oak section, such as valley, blue, and Oregon white oak, are affected.

Figure 7.67. Leaf scorch symptoms caused by the California jumping gall *(Neuroterus saltatorius)* on valley oak. Note the small round galls on the underside of affected leaves. B. Hagen

Oak gall wasp or two-horned oak gall wasp *Dryocosmus dubiosus*

Affected leaves appear scorched (blighted) at their tips and along their margins (fig. 7.68). Occasionally, entire trees are affected. Small, oval galls with a hornlike projection at each end can be found on the underside of leaves along the leaf veins (fig. 7.69). This is a common pest on coast live oak and interior live oak.

Figure 7.68. Leaf scorch symptoms on coast live oak leaves caused by two-horned oak galls *(Dryocosmus dubiosus)*. B. Hagen

Figure 7.69. Two-horned oak galls *(Dryocosmus dubiosus)* on the underside of coast live oak leaves. Galls are typically oval with hornlike projections at either end. Note the necrosis that the galls have caused. Many galls eventually drop but often leave a raised scar on the leaf vein. B. Hagen

Pumpkin gall wasp
Dryocosmus minusculus

This gall wasp forms a tiny pumpkin-shaped gall that can cause symptoms similar to those of the live oak gall (fig. 7.70). Species within the black oak group are affected.

Figure 7.70. The pumpkin gall wasp *(Dryocosmus minusculus)* occasionally causes noticeable marginal leaf scorch on coast live oak. B. Hagen

Honeydew gall wasp
Disholcaspis eldoradensis

A light colored, cylindrical (¼ inch in diameter), flat-topped gall caused by a cynipid gall wasp (fig. 7.71) . This gall can be confused with kermes scale. The honeydew that drips from these galls attracts ants and yellow jackets.

Figure 7.71. Honeydew gall *(Disholcaspis eldoradensis)* on valley oak. While gall wasp larvae are developing within the galls, a phloem exudate is released that attracts ants and yellow jackets. B. Hagen

Red cone gall wasp
Andricus kingii

Galls caused by this wasp are white to reddish while forming and are found on both leaf surfaces. At times the galls can be so numerous as to give the leaves a reddish appearance (fig. 7.72). Galls form on blue, valley, and Oregon white oak.

Figure 7.72. Galls of the red cone gall wasp *(Andricus kingii)* are white to bright red, distinctively shaped, and are found on the upper and lower leaf surface. They can be so numerous as to make the leaves appear red. Galls form on blue, valley, and Oregon white oak. B. Hagen

Internal (Integral) Galls

The galls in this group, caused by gall wasps, form within the stem, rather than externally to it. This may cause branch swelling, distortion or dieback (figs. 7.73, 7.74).

Figure 7.73. Unknown gall wasps have deformed this small black oak branch, causing integral swellings. Note the numerous exit holes where the gall wasps have emerged. B. Hagen

Figure 7.74. Larval capsules of an unidentified integral gall wasp with larvae within, revealed when the gall was dissected. B. Hagen

Tapered stem gall wasp
Andricus spectabilis

Galls formed by this wasp occur on canyon live oak and are characterized by abrupt spindle-shaped swellings up to 2½ inches long and 1 inch across (fig. 7.75). The portion of the branch beyond the gall appears normal. Larval chambers can be seen when galls are dissected.

Figure 7.75. Tapered stem gall *(Andricus spectabilis)* on canyon live oak. The holes indicate where an individual gall wasp within the twig emerged. B. Hagen

Gouty stem gall wasp
Callirhytis quercussuttoni

This potato-shaped gall may cause twig dieback of coast live, interior live, and black oaks (fig. 7.76). Galls form internally in the branch and cannot be detached.

Figure 7.76. Gouty stem gall *(Callirhytis quercussuttoni)* on coast live oak. These galls are best described as round (potato-shaped) abrupt swellings of twigs, usually 1 to 2 inches wide (occasionally larger). Old galls are riddled with gall wasp exit holes. B. Hagen

Ruptured twig gall wasp
Callirhytis perdens

Galls formed by this gall wasp are characterized as spindle-shaped swellings, up to 3 inches long, with splits (ruptures) in the outer surface where larval "capsules" are expelled (fig. 7.77). Affected twigs typically die back or break just beyond the gall once the gall wasps have completed their development. Black oaks are commonly affected.

Figure 7.77. Ruptured twig gall *(Callirhytis perdens)* on black oak. These galls are tapered (torpedo-shaped), up to 3 inches long, and have splits or fissures on the surface. B. Hagen

Sap feeders

Black-punctured kermes
Kermes nigropunctatus and *K. cockerelli*

Large (up to 5/16 inch long), brown, immobile, and nearly spherical scales that can be confused with stem galls (fig. 7.78). The upper surface of the scale body is bumpy and there are two black spots near the base.

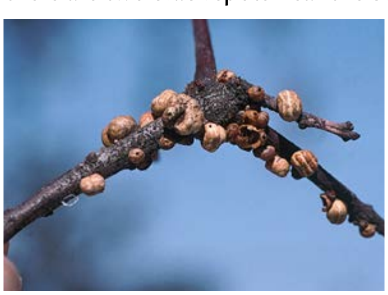

Figure 7.78. These scalelike insects are black-punctured kermes *(Kermes nigropunctatus, K. cockerelli)*. They are brown, bumpy, and nearly round, but slightly flattened. They are often mistaken for twig galls. B. Hagen

Ehrhorn's scale
Mycetococcus ehrhorni

Minute, red, pear-shaped, soft-bodied insects about 1/32 inch long concealed by white, fluffy secretions and gray-white fungal mycelial mats (fig. 7.79).

Figure 7.79. Ehrhorn's oak scale *(Mycetococcus ehrhorni)*. Affected branches within the canopy appear whitewashed or covered by a fluffy, white to gray diffuse spotting. B. Hagen

Kuwana oak scale
Kuwania quercus

Bark on the trunks of trees affected by these sap-feeding insects has a checkered appearance (fig. 7.80). Small, red, aphidlike insects can be found feeding under loose bark plates. Their feeding causes small flakes of outer bark to loosen and fall away. Adults are oval, bright red, and about 3/32 inch long. The immature stages are partially covered by white, waxy, filamentous material. Look for waxy tufts under the bark plates. The exposed areas where pieces of bark flake off are darker than the surrounding area. During the summer and fall only the residual white waxy material can be found in infested bark.

Figure 7.80. Kuwana oak scale *(Kuwania quercus)* on blue oak. Infestation causes the bark to become patchy or spotty as the corky outer bark exfoliates in small patches. The exposed areas below are darker than the surrounding bark. B. Hagen

Oak aphid
Myzocallis spp.

Green to yellowish aphids clustered on the underside of leaves of eastern oaks such as pin oak and red oak, and occasionally California native oaks (fig. 7.81). Large colonies can cause leaf distortion, yellowing, and heavy honeydew drip.

Figure 7.81. Oak aphid (*Myzocallis* spp.). These aphids are not associated with any white, cottony material as with wooly oak aphids (*Stegophylla* spp.). Oak aphids are typically yellow to greenish or brownish with a pair of cornicles (tubelike protuberances) and dark blotches on the abdomen. B. Hagen

Oak lecanium scale
Parthenolecanium quercifex

Mature female scales are dark, reddish brown, smooth, nearly hemispherical, and up to ¼ inch long. They occasionally have a dusty coating. These scale insects are often quite numerous and can be found clustered on twigs (fig. 7.82). Nymphs (the immature stage) are smaller, flattened, and orange, yellow, or mottled. Honeydew drip and sooty mold is a concern when populations are high.

Figure 7.82. Oak lecanium scale (*Parthenolecanium quercifex*) clustered on an oak twig. B. Hagen

Oak pit scale
Asterolecanium spp.

These scale insects are small, immobile, and firmly attached to the plant on which they feed (fig. 7.83; see also fig. 7.7). Their soft bodies are protected by the hard, waxy, scalelike covering that they secrete. They have long, threadlike mouthparts (stylets) and feed on plant sap. Their feeding slowly reduces plant vigor. Heavily colonized plants grow poorly and may suffer dieback of twigs and branches. Oak pit scales are round, convex, about the size of a pinhead, greenish to golden yellow, and surrounded by a distinct swollen and raised ring, giving them the appearance of being in pits. The bark of affected branches appears roughened, dimpled, or pitted. Dieback of small twigs throughout much of the outer crown is symptomatic. Infestations are usually restricted to 1-year-old twigs, often resulting in brooming (a dense cluster of shoots) due to shoot dieback. Affected trees may appear sparse and unhealthy. Leaf flush in spring may be delayed, and dead leaves of affected deciduous species may persist through the winter. Heavy infestation can cause severe stress, slowing growth and leading to increased susceptibility to other more serious pests. Valley oak is attacked more frequently and severely than other species. Damage can be severe in oaks along the central coast as well in the Central Valley. Heavy infestations over several years can kill young trees and weaken older ones. This pest is the most serious sap-feeding pest of oaks. Twig blight (*Cryptocline cinerescens*) is often associated with oak pit scale.

Figure 7.83. Oak pit scale (*Asterolecanium* spp.). The bark surface of affected twigs is pitted and rough. Note the yellow lichen growing on the twig. B. Hagen

Oak tree hopper
Platycotis vittata and *P. vittata quadrivittata*

Damage is minor and consists of small, spirally arranged punctures in the bark from feeding and slitlike punctures in the bark from egg laying. Adults are up to ⅜ inch long, off-white to olive-brown with red-orange stripes, and have two big red eyes, and a keel-like extension arising from their "backs" (pronotums) (fig. 7.84). Immature hoppers are black with red spots and white stripes, and have two divergent spines on their backs.

Figure 7.84. Adults and nymphs of the oak tree hopper (*Platycotis* spp.; perhaps *P. vittata* or *P. vittata quadrivittata*) feeding on coast live oak. B. Hagen

Crown whitefly
Aleuroplatus coronata

Stanford whitefly
Tetraleurodes stanfordi

Gelatinous whitefly
Aleuroplatus gelatinosus

Adult whiteflies are small, soft-bodied, powdery-white flying insects. The nymphs (immature stage between the egg and adult) are immobile, flattened, oval, and small (less than 1/16 inch long) (fig. 7.85). Crown whitefly is covered by a tuft or "crown" of white, waxy plates that project upward and outward (fig. 7.86). Nymphs of Stanford whitefly are black with a narrow, white outer ring of waxy material. Nymphs of the gelatinous whitefly are also black but surrounded by a clear, gelatinous ring (fig. 7.87). The nymphs of both crown and gelatinous whitefly are found only on the lower leaf surface. Stanford whitefly, by comparison, usually is found on the upper surfaces. Whiteflies are sap-feeding insects, but seldom cause harm. Populations of crown whitefly, however, can reach levels that create a nuisance because of the honeydew drip and sooty mold on the foliage.

Figure 7.85. Nymphs of crown whitefly *(Aleuroplatus coronatus)* on coast live oak, before they have developed their distinct white, waxy crowns. At this stage, they closely resemble Stanford whitefly *(Tetraleurodes stanfordi)*. The latter are surrounded by a narrow, white ring of waxy material and are typically found on the upper side of leaves. B. Hagen

Figure 7.86. Immature (nymphal) stage of crown whitefly *(Aleuroplatus coronatus)*. Note the white fringe or "crown" of a waxlike material projecting from the nymphs. B. Hagen

Figure 7.87. The immature stage of gelatinous whitefly *(Aleuroplatus gelatinosus)*. The waxy material surrounding the nymphs appears gelatinous and is nearly transparent. B. Hagen

Woolly oak aphid
Stegophylla spp.

Aphids are small, soft-bodied, pear-shaped sap-feeding insects. Depending on species, the color of woolly oak aphid ranges from bluish green to yellowish blue to olive (fig. 7.88). They are covered by tufts of white, waxy, filamentous material. The underside of leaves with colonies of these aphids may be nearly covered by the dense, woolly material that the aphids secrete (fig. 7.89). The wingless form of this aphid produces "pseudogalls" by causing the edges of the leaves to fold over, forming protective shelters (fig. 7.90).

Figure 7.88. Wooly oak aphids (*Stegophylla* spp.). J. K. Clark

Figure 7.89. Heavy infestations of woolly oak aphid (*Stegophylla* spp.) produce profuse white, waxy secretions that can cover the underside of colonized leaves. B. Hagen

Figure 7.90. The wingless generation of wooly oak aphid forms "pseudogalls" by causing the leaf edges to fold over. The aphids then develop within the protected space. B. Hagen

Other Insects

Cicadas

Look for egg-laying punctures that are regularly spaced and linearly arranged, giving affected twigs a "serrated" appearance (fig. 7.91). Affected twigs may die.

Figure 7.91. Cicada egg-laying damage is characterized by small bark splits with splintered wood projecting out. B. Hagen

Pathogens

Fungal diseases play a major role in the growth, survival, and regeneration of oaks throughout California. Pathogens causing wood decay, cankers, canker rots, and root diseases are important agents of mortality in natural oak stands (Swiecki, Bernhardt, and Arnold 1990).

Most wood decay pathogens can be divided into three groups: heart rots, sap rots, and canker rots. Heart rot pathogens are primarily restricted to the heartwood, decaying trees from the inside outward. Sap rot pathogens, by comparison, decay trees from the outside inward. They colonize the sapwood of dead and dying trees or branches and can invade the living sapwood of severely stressed trees. Trees with extensive wood decay should be evaluated for risk potential.

Canker rot pathogens initially decay the heartwood, but then spread outward into the sapwood, killing patches or strips of cambium and bark (fig. 7.92). In this manner, affected stems and branches are often girdled or completely decayed (fig. 7.93). Consequently, canker rot pathogens are associated with tree decline, branch and trunk failure, and mortality. Environmental stress, species susceptibility, and tree age and health undoubtedly play a role in how rapidly the pathogen spreads and how quickly the wood decays.

Most canker-causing fungi typically kill patches or elongated strips of the bark and cambium of affected trees, without directly causing decay. Symptoms usually appear as dead branches or localized areas of dead, diseased, or discolored bark tissue (lesions) on the trunk or large branches. With time, most cankers appear as sunken areas in the bark, surrounded by raised callus (woundwood) tissue (fig. 7.94).

There are two basic types of wood-rotting pathogens: those causing white rots and those causing brown rots. White rot fungi, the most common wood decay pathogens on oaks and other hardwoods, ultimately degrade all the major structural components of the cell wall: cellulose, hemicellulose, and lignin (fig. 7.95). The lignin, however, is typically degraded first, and the cellulose and hemicellulose are degraded in later stages. Some species, though, break down all cell wall components simultaneously. Affected wood tends to be moist, spongy, stringy, or laminated, and lighter in color than sound wood because of the persistence of cellulose fibers. Eventually all of the wood is degraded, leaving behind a void (fig. 7.96). With brown rot fungi, cellulose and hemicellulose are quickly degraded, while the lignin remains relatively unchanged. Affected wood tends to be dry, crumbly, and blocky (cubical) in structure due to longitudinal and transverse cracking. The color is typically rusty brown (fig.

Figure 7.92. A canker rot pathogen has decayed much of the heartwood in this branch of coast live oak. The pathogen has spread outward from the heartwood to the sapwood, cambium, and bark. B. Hagen

Figure 7.93. In this cross-section of coast live oak, decay caused by a canker rot pathogen has spread from heartwood into the bark, causing a large dead area (canker). B. Hagen

Figure 7.94. A large stem canker caused by a canker rot pathogen (probably *Inonotus dryophilus*). Note that the bark within the canker is still intact and surrounded by callus (woundwood) tissue. The pathogen probably spread downward into the trunk from the decayed branch stub visible near the top of the canker. B. Hagen

Figure 7.95. White rot decay in the trunk of blue oak. The cavity is where the wood has totally disintegrated, while the surrounding zone is still undergoing decay. Note the remaining thin shell of sound wood on the right side of the stem. B. Hagen

Figure 7.96. Wood decayed by a white rot pathogen. Decayed wood feels soft and spongy and appears stringy and bleached. B. Hagen

7.97). Brown rot of the heartwood of oaks in California is caused primarily by sulfur fungus *(Laetiporus gilbertsonii)*. *Daedalea quercina*, another brown rot pathogen, is occasionally found on decaying wood on oaks in California, but it is generally not a concern.

The single most important root disease of landscape oaks is Armillaria root rot caused by *Armillaria mellea* (fig. 7.98). Phytophthora root rot, caused by several species of *Phytophthora*, is also a destructive root disease, primarily affecting landscape oaks in irrigated settings (fig. 7.99). Natural oak stands in riparian settings and poorly drained or regularly flooded areas are commonly affected as well. Trees receiving frequent irrigation and those where soil aeration is poor are most susceptible.

Although foliar diseases (e.g., anthracnose and powdery mildew) have little impact on natural stands of oaks, they are important in the urban landscape. Damage ranges from leaf spotting to killing of leaves and shoots. Foliar diseases commonly affect healthy plants, causing damage only when the foliage is succulent and environmental conditions are favorable, such as during mild, wet weather or dry, warm conditions during the day followed by humid evenings during periods of active growth. Mature foliage is resistant.

Leaf Pathogens

Oak anthracnose *Apiognomonia errabunda*, [sexual stage]; *Discula umbrinella*, [asexual stage]; Septoria quercicola and other pathogens may also be involved

These pathogens cause leaf necrosis in small spots, irregular areas, or entire leaves. Occasionally entire trees are affected. Infected leaves often fall prematurely, particularly if the petiole is damaged. Spores produced in the spring are spread by splashing and wind-blown rain. Infections occur during prolonged, wet weather, and new succulent shoots and leaves are most susceptible (figs. 7.100, 7.101, 7.102).

Oak leaf blister *Taphrina caerulescens*

Infection by the pathogen causes raised, wrinkled, light green to yellow blisters, which eventually turn brown on both leaf surfaces. Blisters on the lower side of affected leaves appear as grayish to brown depressions (fig. 7.103).

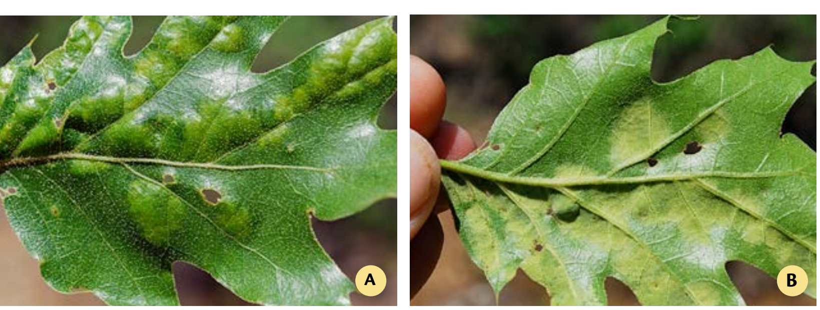

Figure 7.103. Blistering and yellowing on the upper (A) and lower (B) surface of a black oak leaf caused by oak leaf blister *(Taphrina caerulescens)*. The blisters ultimately turn brown. B. Hagen

Figure 7.97. Brown rot caused by sulfur fungus *(Laetiporus gilbertsonii)* in black oak. In the advanced stage of infection, wood affected by the pathogen is dry, rusty brown, crumbly, and blocky. B. Hagen

Figure 7.98. Girdling of the stem of this young coast live oak resulted from an infection by *Armillaria mellea.* Adventitious roots (arrow) have developed from healthy tissue above the infection. B. Hagen

Figure 7.99. The death of this cork oak was caused by crown rot (*Phytophthora* spp.). Factors thought to have contributed to infection of this tree include frequent irrigation, poor drainage, and fill soil placed against the lower trunk. B. Hagen

Figure 7.100. Oak anthracnose can cause large, angular, necrotic lesions on the leaves, as seen on this black oak leaf. B. Hagen

Figure 7.101. Extensive leaf spotting on black oak in response to oak anthracnose. The infestation caused significant leaf drop. B. Hagen

Figure 7.102. Leaf spotting and necrosis on valley oak caused by oak anthracnose. B. Hagen

Powdery mildew
Cystotheca lanestris; Brasiliomyces trina; Phyllactinia angulata; Microsphaera extensa var. *curta*

Leaves appear to be covered by a white to grayish powdery material (fungal mycelium) that may occur in discrete patches or over the entire upper or lower leaf surface, or occasionally both (fig. 7.104). Extensive infections can result in leaf discoloration and distortion. Powdery mildew fungi typically penetrate the leaf surface (epidermal cells), generally without killing the cells, to obtain nutrition. In this manner, affected cells usually remain functional. Most of the fungal mycelium grows externally to the leaf (figs. 7.105, 7.106, 7.107). *Cystotheca lanestris*, however, invades more deeply, causing greater damage, such as blistering, chlorosis, and leaf stunting and induces the formation of bushy shoot tips known as witches' brooms (fig. 7.108). Powdery mildew spores can germinate under dry conditions and are generally inhibited by wet conditions. Infection occurs during periods of active growth when the shoots and leaves are expanding and environmental conditions are favorable: warm, humid conditions, particularly warm days followed by cool, humid evenings. Developing foliage is most susceptible, and practices that stimulate new growth later in the growing season promote this disease, particularly on coast live oak (fig. 7.109), and should be avoided. Mature foliage is resistant.

Figure 7.104. Powdery mildew (*Microsphaera extensa* var. *curta*) beginning to develop on a young black oak leaf. Note the white, powdery patch near the center of the photo.
B. Hagen

Figure 7.105. Powdery mildew (*Microsphaera extensa* var. *curta*) on bur oak is usually present on the upper leaf surface, forming a thin powdery film.
B. Hagen

Figure 7.106. Powdery mildew (*Cystotheca lanestris*) on valley oak causes chlorosis, blistering, and distortion of affected leaves. It is reported on most California oak species and grows primarily on the lower leaf surface.
B. Hagen

Figure 7.107. Powdery mildew (*Brasiliomyces trina*) on coast live oak, causing round or irregularly shaped white patches.
B. Hagen

Canker-Causing Pathogens

Pathogens often colonize and kill bark tissue, causing branch and trunk cankers of varying size and shape. Bleeding often occurs as the inner bark is killed or colonized by fungal, bacterial, and other pathogens that enter through wounds. Most cankers show strong callusing (woundwood) along their margins (fig. 7.110).

Figure 7.110. Target canker on blue oak. Note the unique concentric and overlapping rings of callus (woundwood) encircling the center of the wound. Only the outer callus ring is alive. The pathogen was able to colonize the healthy tissue that formed at the margin of the canker, and it progressively killed each new ring of callus after it was formed. In this manner, the canker gradually increases in size. Depending on the pathogen and tree vitality, cankers may girdle and kill the trunk or branches.
B. Hagen

Figure 7.108. Witches' broom caused by powdery mildew (*Cystotheca lanestris*) on coast live oak.
B. Hagen

Figure 7.109. Distorted, stunted leaves of coast live oak covered with powdery, whitish fungal mycelia of powdery mildew (*Cystotheca lanestris*).
B. Hagen

Twig blight
Cryptocline cinerescens

This leaf and canker disease is characterized by dieback of developing leaves and shoots scattered throughout much of the mid and lower crown (figs. 7.111 and 7.112). Small black pustules (fruiting bodies) erupt through small fissures in the bark of dead twigs. Symptoms typically appear from mid-summer to fall. Spores produced in the spring are spread by splashing and wind-blown rain (fig. 7.113). Infections occur during prolonged wet weather, and new succulent shoots and leaves are most susceptible. Twig blight is often found in association with pit scale, and trees under stress are more likely to be affected than trees growing vigorously.

Figure 7.111. Twig blight (*Cryptocline cinerescens*) on coast live oak is usually most severe in the middle and lower parts of the crown.
B. Hagen

Figure 7.112. This small coast live oak twig was killed by (*Cryptocline cinerescens*). The twig is dry and brittle and the leaves have a bleached appearance.
B. Hagen

Figure 7.113. Fruiting bodies (acervuli) of *Cryptocline cinerescens* erupting through the bark of a twig killed by the pathogen. This pathogen is often associated with pit scale. Note the orange colored pit scales to the right side of the twig. B. Hagen

Diplodia canker
Diplodia quercina

This disease is characterized by scattered dead branches in the crown, with dead, brown foliage attached (fig. 7.114). Generally, branches less than ¾ inch in diameter are affected, but branches up to 4 inches in diameter may be killed (fig. 7.115). The fungus girdles affected branches at the point of infection, causing the distal portions to die. Cankers (dead, usually sunken areas of bark) or swollen areas with cankers or callusing fissures form at infection sites. Occasionally, cankers remain small and localized and may eventually close (compartmentalize). Infected bark tissue appears dead and brown, and the wood below is stained brown (fig. 7.116). The pathogen produces small, raised, black fruiting bodies on the dead tissue during wet weather (fig. 7.117). The spores produced in these fruiting bodies can be spread by rain onto healthy branches nearby. Spore production and germination are favored by wet conditions. Drought stress and other adverse conditions are thought to predispose trees to infection.

Figure 7.114. Diplodia canker is characterized by scattered, dead branches of varying size (not just shoot tips) in the crown. Most of the affected branches in this coast live oak were about ½ to 1 inch in diameter. B. Hagen

Figure 7.115. In some cases, Diplodia canker kills branches up to about 4 inches in diameter, as seen in this coast live oak. Like most canker fungi, Diplodia thrives on stressed trees.
L. Costello

Figure 7.117. Fruiting bodies (pycnidial stromata) of Diplodia canker.
B. Hagen

Figure 7.116. A small branch girdled by a Diplodia canker. Note the distinct demarcation between the living and dead tissue that was revealed when the bark was cut away.
B. Hagen

Figure 7.118A. The canker on the trunk of this coast live oak was caused by bacterial wetwood, a condition caused by microorganisms (usually bacteria) that invade cracks or small wounds. The formation of this canker was preceded by copious bleeding (fluxing) through a small fissure in the bark (note the dark staining). Wetwood infections are characterized by a thin, watery, malodorous exudate. However, when colonized by other microorganisms, the exudate may thicken, become slimy (slime flux), and change color. B. Hagen

Figure 7.118B. Foamy canker appears as a white, foamy fluid exuding from small cracks or holes in the bark, as shown on this oak. K. Phillips

Bacterial wetwood
Various anaerobic bacteria

Foamy canker (Alcoholic flux)
Causal agent unknown

Bacterial wetwood infections are characterized by a copious, wet, foul-smelling exudate (fermented sap) flowing from wounds and cracks in the bark. The exudate, which is initially clear, gradually darkens and thickens or becomes slimy. On drying, the exudate leaves a conspicuous, light-colored to brown encrustation on the bark below the lesion (fig. 7.118A). Bleeding may continue for several years. The pathogen kills the cambium and phloem tissue, often forming elongated or elliptical cankers with callusing (woundwood formation along their margins).

Foamy canker is characterized by white, foamy fluid exuding from small fissures in the bark (fig. 7.118B). Unlike the sour or rancid odor associated with bacterial wetwood, foamy canker has an alcohol or fermentative odor. Localized areas of bark and underlying cambium may be killed. Although the cause has not been identified, bacteria, yeasts, or other microorganisms are thought to be involved.

Sudden oak death
Phytophthora ramorum

This pathogen causes bleeding cankers on the lower 6 to 8 feet of the trunk and scaffold branches (fig. 7.119). Bleeding typically appears as droplets or short "streamers" of a thick, reddish brown to nearly black exudate (fig. 7.120). Cankered areas often appear uniformly stained. Bleeding is associated with large patches (up to 3 feet across) of discolored or dead phloem (inner bark) and cambium. The sapwood below is stained dark as well (fig. 7.121). Trees decline and ultimately die as cankers enlarge and coalesce.

In some cases, cankers remain small, and, in time, become inactive. Oak bark beetles and ambrosia beetles and the black, dome-shaped fruiting bodies of *Annulohypoxylon thouarsianum*, a wood-rotting pathogen, are commonly associated with the disease. *Phellinus gilvus*, another decay-causing fungus, commonly colonizes dead and dying trees, particularly those affected by *Phytophthora ramorum*. The decay caused by these fungi often leads to tree failure (fig. 7.122). Although affected trees may decline due to extensive death of bark tissue on the lower trunk, death occurs when developing cankers completely girdle the trunk. When affected trees die suddenly, their leaves turn brown and remain attached to dead limbs (fig. 7.123).

Figure 7.119. Bleeding and diffuse staining on the bark of this coast live oak was caused by *Phytophthora ramorum*, the pathogen responsible for sudden oak death. This disease causes bleeding cankers on the lower trunk and scaffold branches to a height of about 6 feet, occasionally higher. Cankers seldom extend below the soil line. B. Hagen

Figure 7.120. Bleeding in sudden oak death *(Phytophthora ramorum)* often consists of a few discrete droplets or short streamers of thick black to mahogany red exudate on the bark. Moss near cankers is usually killed. B. Hagen

Figure 7.121. The inner bark of sudden oak death–infected trees can appear to be either watersoaked and reddish brown or dead, dry, and dark brown. Note the boundary between healthy and diseased tissue (arrows). B. Hagen

Figure 7.122. Oaks killed by sudden oak death *(Phytophthora ramorum)* are prone to rapid wood decay and structural failure. This coast live oak failed less than a year after it was killed by the disease. Fruiting bodies of a wood decay fungus (probably *Phellinus gilvus*) can be seen growing on the trunk. B. Hagen

Figure 7.123. Coast live oaks killed by sudden oak death *(Phytophthora ramorum)*. B. Hagen

Ten Important Facts about Sudden Oak Death (SOD)

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1. SOD is caused by an introduced pathogen (*Phytophthora ramorum*) that requires the presence of water and mild temperatures to infect plants.
2. Infection rate on oaks is not the same every year: in dry years very few oaks are infected, but in wet years, and especially when precipitation occurs between April and June, large numbers of oaks can be infected. These are called "wave years." An El Niño year is a wave year of potential high intensity resulting in a truly epidemic spread of the deadly tree disease.
3. SOD kills oaks and tanoaks by colonizing and destroying the phloem and cambium, effectively girdling trees. It is believed that most trees (> 90%) inevitably die 1 to 3 years after infection. The most obvious symptom of SOD, the sudden browning of the entire tree crown, is chronologically one of the last symptoms to occur in the development of the disease. Bleeding of viscous sap through intact bark is the only other symptom that may be visible. Green and apparently healthy trees may be infected without the presence of obvious symptoms.
4. The SOD pathogen does not infect only oaks; it can infect over 100 plant species, including many landscape plants and most understory species of the California coastal forests. Coast live oak, black oak, Shreve oak, and tanoak are most susceptible. Species in the California white oak group appear to be resistant: valley oak, blue oak, and Oregon white oak. While infection of oaks is exclusively limited to stems and large branches, twigs and leaves of other species are more commonly infected.
5. The disease does not typically spread from oak to oak: foliar infections on California bay laurel are mostly responsible for transmission to oaks. Tanoak leaves and many landscape plants can also be infectious. SOD often does not kill or seriously injure these infectious hosts.
6. In an SOD-infected area, and especially during the rainy season, it should be assumed that leaves and wood of many host species, soil, and water are infectious. Movement of any of these substrates or use of recycled water without chemical treatment should be avoided in order to prevent further spread of the disease. When entering an SOD-free area, take care not to bring plant material and soil (e.g., on shoes, tools, or tires) from SOD-infested areas.
7. To actively combat the disease, keep in mind the following:
   - Although SOD will never disappear, it is still patchy in distribution. It is important to verify the presence and significance of the disease in each area. If you suspect that a tree has become infected, contact your county agricultural commissioner's office or your UC Cooperative Extension office. For information regarding disease symptoms, distribution, and management, see the following SOD Web site, *www.suddenoakdeath.org*.
   - It is not possible to save entire forests, but it may be possible to reduce infection on a number of selected oak trees. Consider protecting trees of high value and those that may cause property damage or personal injury if they fail.
   - Candidate trees for protection must be healthy and without any SOD symptoms. For information regarding chemical treatments and other management practices, see *www.suddenoakdeath.org*.
8. If a tree is infected by SOD, it is subject to rapid decay and structural failure even before the crown turns brown. If you live in an SOD-infested area, carefully monitor oaks and tanoaks that may represent a hazard to people and property. Look for hard, black, charcoal-like, hemispherical fungal fruiting structures growing on the bark (*Hypoxylon* fruiting bodies) and sawdust produced by bark beetles that are indications the tree is dying. Consult a certified arborist or consulting arborist to determine whether SOD is present and whether removal of such trees is appropriate. Note that SOD-killed trees are prone to failure and removals should be handled by tree care professionals.
9. Horticultural and sanitation practices should be followed to reduce risk of infection. In an infested area
   - minimize horticultural and construction activities during the rainy season.
   - because SOD does not blanket the entire landscape, schedule work in uninfested areas first before moving to areas that are infested. This applies even when working in a single property.
   - do not prune large oak branches or stems between December and June, as large pruning cuts are extremely susceptible to infection.
   - infected plant material should not be removed from the property unless the material is properly disposed of following state and federal regulations for SOD-infected material. Burning SOD-infected plant material, if possible, will kill the pathogen. Do not pile, tarp, or cover plant debris following trimming or removal of infected or dead trees. Instead, chip or split plant material and broadcast locally in a sunny area, as rapid drying of infected plant material will kill the pathogen.
   - composting of infected plant material following EPA guidelines for commercial composting will kill the pathogen.
10. Although researchers are trying to find natural resistance to the disease among California oaks and tanoaks, preventive treatments applied in the fall are currently the only way to slow the spread of the disease. Early detection of the pathogen is pivotal. In order to learn how to identify SOD symptoms on California plant species, how to apply treatments against SOD, and how to schedule applications, see *www.suddenoakdeath.org*.

Figure 7.124. The fungus *Inonotus andersonii* caused white rot decay in the trunk of this Oregon white oak. B. Hagen

Figure 7.125. *Inonotus andersonii* produces a crustlike, rusty to golden brown, porous, spore-bearing layer that spreads over the wood surface under dead, loose bark. It consists of a series of tubes with angular openings (pores). In this case, its surface is white. Note the yellow, spore-covered bark below. B. Hagen

Figure 7.126. The characteristic chrome-yellow spore print of *Inonotus andersonii* found on the inner surface of a piece of bark that was covering the fruiting body. B. Hagen

Figure 7.127. An older, inactive fruiting body of *Inonotus andersonii.* Note that it forms broad peglike extensions that hang down, resembling icicles or stalactites. B. Hagen

Figure 7.128. *Inonotus dryophilus* conks (fungal fruiting bodies). Note that the pores in the lower (spore-bearing) surface are irregularly shaped, unlike those of *Phellinus* species, which are predominantly round. B. Hagen

Figure 7.129. A large canker associated with *Inonotus dryophilus* on Oregon white oak. The conks are old and beginning to disintegrate. B. Hagen

Figure 7.130. A target canker associated with *Inonotus dryophilus.* The pathogen likely entered a dying branch stub (out of view). B. Hagen

Figure 7.131. The failure of this branch was associated with the canker rot pathogen *Inonotus dryophilus.* The decay may have entered through the lower dead branch, spread into the heartwood, and then progressed outward into the sapwood. B. Hagen

Canker Rots

Canker rot pathogens (*Inonotus* spp.) are an important cause of mortality in oaks, particularly in more arid areas and drier sites. These wood decay pathogens typically enter through wounds, dying branches, broken branch stubs, fire scars, and similar wounded or damaged tree parts. Initially, the pathogens decay the heartwood and then spread outward into the sapwood, killing the cambium and phloem (inner bark) in irregular, localized patches or elongate strips, resulting in the formation of cankers. These pathogens, however, do not always produce a recognizable conk (fruiting body). Cankers may appear as sunken areas of intact bark surrounded by strong callusing, concentrically ringed target cankers, or cankered areas where the bark appears tattered or torn and pushed outward, exposing the wood below. Wood with advanced decay is lightweight, crumbly, and has a bleached appearance (fig. 7.124).

Trees with canker rots are very prone to trunk and branch failure. Affected branches gradually die, typically resulting in limb failure. Affected trees often appear to be declining. Symptoms of decline may include poor growth, thinning foliage, epicormic sprouting, and branch dieback. Trees seem to be falling apart branch by branch. *Inonotus andersonii*, a common canker rot pathogen, produces spores in a porous, rusty to golden brown, sheetlike annual fruiting body that forms under dead, loose bark. The fruiting bodies, which form only on dead wood, have an irregular surface comprised of a series of tubes with angular openings (pores). They often form broad, peglike extensions that hang down, resembling stalactites (figs. 7.125, 7.126, 7.127). Bright yellow spores produced by the fruiting bodies collect on the inner surface of the bark. This is a major wood rot pathogen that often leads to trunk and branch failure. In addition, it may be associated with large, target cankers. *Inonotus dryophilus*, another common canker rot pathogen, forms cankers of varying size and width with strong callusing along the margins and may produce distinctive hooflike conks, or fruiting bodies. The conks of *I. dryophilus* form on living stems and are persistent. They begin to develop in the fall and mature by spring and then the outer surface begins to darken and erode. In some cases, a large area of bark tissue is killed before callus forms at the margins, and in others, a small amount of necrosis develops before callus forms. Depending on environmental conditions or host resistance, the new callus is attacked and killed, causing the canker to enlarge concentrically forming a target or bull's eye pattern (figs. 7.128, 7.129, 7.130). Weak host resistance to the pathogen may explain this pattern of disease symptoms. Affected trees decline gradually as the trunk or branches decay. This wood-decay pathogen invades its host through large wounds, causing extensive decay of the heartwood, and ultimately invades the sapwood and bark of the trunk and larger branches. It causes a white rot of the wood. The annual conks are woody and hooflike. Once formed, they darken with age and the surface begins to erode. This major wood rotting pathogen often leads to trunk and branch failure (fig. 7.131).

Figure 7.132. Oak root fungus (*Armillaria mellea*) mushrooms growing at the base of this valley oak typically appear in late November and December. B. Hagen

Figure 7.133. *Armillaria mellea* mushrooms occur in clusters and grow directly on the lower trunk or lateral roots of infected trees. B. Hagen

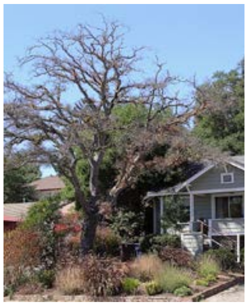

Figure 7.134. After years of decline, this coast live oak finally succumbed to oak root fungus (*Armillaria mellea*). The leaves turned brown within a few weeks as the pathogen finally girdled and killed the tree. Note that a number of disturbances and environmental changes have occurred around the tree. An irrigated lawn existed prior to the installation of this landscape. B. Hagen

Figure 7.135. *Armillaria mellea* was responsible for the death and sloughing of bark tissue on the root collar (trunk flare) of this valley oak. B. Hagen

Figure 7.136. In cases where an oak root fungus infection is suspected, conduct a root collar excavation and examination. In this case, the presence of *Armillaria mellea* was confirmed. Note the bark lesion (arrow). B. Hagen

Figure 7.137. Although this large coast live oak appeared relatively healthy before it failed, nearly all of the large supporting roots were decayed by oak root fungus (*Armillaria mellea*). T. Young

Figure 7.138. White mycelial fans or mats such as those seen here are diagnostic for *Armillaria mellea*. They are found growing between the bark and wood of the lower trunk and large roots of affected trees. The pathogen also invades and decays the wood. B. Hagen

Figure 7.139. Masses of tough black rhizomorphs (rootlike structures) on black oak at Yosemite National Park. B. Hagen

Root Pathogens

Armillaria root rot (oak root fungus)
Armillaria mellea, Armillaria spp.

Tan (honey-colored) to brown mushrooms may appear at the bases of affected trees in winter (fig. 7.132). Cap diameter ranges from about 2 to 5 inches. These mushrooms always occur in clusters, never singly, and grow directly on the lower trunk or large support roots of infected trees (fig. 7.133). They also have the unmistakable smell of common edible mushrooms. The presence of an annulus, a ring of membranous tissue around the stem of the mushroom, is characteristic of this fungus. The annulus marks where the outer edge of a mushroom's cap was originally attached before it opened and expanded. In addition, spores leave a white print on the surface below.

This is a serious root disease pathogen of stressed and aging trees, and it is most problematic in irrigated landscapes and poorly drained sites. Water and soil aeration deficits, root loss, and repeated defoliation predispose trees to this disease. The pathogen commonly occurs in oak woodlands and areas where oaks have been cleared. This disease typically causes a general decline characterized by crown thinning, defoliation (fig. 7.134) and branch dieback in the upper crown. In addition, cankers may develop at or below the soil line and occasionally several feet above (figs. 7.135, 7.136). The pathogen invades the roots and slowly progresses toward the trunk, killing the bark and cambium, and decaying the wood. Seriously affected trees gradually decline as large roots are killed. Relatively healthy-appearing trees, however, may die suddenly if the pathogen girdles the root collar. Infected trees often fail due to root decay (fig. 7.137).

Bleeding may occur on infected oaks when cankers develop, but bleeding cankers are more commonly associated with Phytophthora root disease. The bleeding associated with *Armillaria mellea* is characterized by wet spots on the bark and occasionally a dark, viscous exudate. Look for distinctive thin, white mycelial fans (fungal material) growing between the bark and wood and mushrooms at the tree's base in winter (fig. 7.138). *Armillaria mellea* attacks the roots and root collar of host plants, killing the cambium and phloem and decaying the woody tissues. Decayed wood is initially wet but becomes spongy or stringy and light-colored as decay progresses. Black rootlike structures (rhizomorphs) can be seen under the bark, on the roots, and in the soil (fig. 7.139). The disease is more prevalent in riparian areas, poorly drained sites, heavy soils, irrigated settings, and areas where oaks have been cleared. Dead roots of plants killed by the pathogen serve as a reservoir for the pathogen. Spread to uninfected trees occurs via root-to-root or rhizomorph contact.

Figure 7.140. *Phytophthora* spp. infections can cause bleeding (streak stains) and basal cankers, as seen on coast live oak. B. Hagen

Figure 7.141. Bleeding and staining caused by Phytophthora root rot. Note that the bark in the affected area appears to be stained brown, and the more recent exudate is thick, dark brown, reddish black to black, and shiny. B. Hagen

Figure 7.142. This cork oak declined and died rapidly, likely due to Phytophthora root disease. Excess irrigation and poor drainage undoubtedly favored the development of the disease. B. Hagen

Figure 7.143. Phytophthora root rot was suspected as the agent causing bleeding, basal cankers, and bark cracking and sloughing on this coast live oak. Cankers caused by this disease typically extend below the soil surface. B. Hagen

Figure 7.144. Heart rot decay caused by a white rot pathogen has destroyed much of the heartwood in the lower trunk of this coast live oak. B. Hagen

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

These pathogens cause bleeding cankers (areas of dead bark and cambium) on the lower trunk, root collar, and large support roots of affected trees. Bleeding is a red-brown, dark brown, or nearly black viscous exudate. Bleeding or staining may also appear as dark to rusty brown “streak stains” on the lower trunk (figs. 7.140, 7.141). Symptoms include general decline, reduced growth, twig and branch dieback, leaf yellowing, sparse foliage, and bleeding canker on the lower trunk (fig. 7.142), and occasionally, pronounced basal swelling. The swelling appears to be the result of callus (woundwood) production in response to tissue damage caused by the pathogen. Shaving the corky outer bark near bleeding cankers often reveals discolored (reddish brown) patches of phloem with dark zone lines delimiting diseased tissue from the healthy, surrounding tissue. (Note that bleeding is similar to symptoms of sudden oak death.) The surface of the wood where cankers are developing appears wet and slimy. In addition, the outer sapwood is discolored but not decayed.

The pathogen decays fine roots and invades the bark and cambium of the larger roots and the root collar, killing the infected tissues (fig. 7.143).

Trees decline and die as cankers expand and girdle the trunk. Some trees survive for many years with multiple small cankers on the lower trunks. The pathogen moves readily in water and is easily introduced to noninfected sites in nursery stock. It can also be moved about in soil or on shoes and equipment. This is a serious root disease in poorly drained and heavily irrigated sites. Aeration deficits stemming from high soil moisture levels due to restricted drainage or excess irrigation favor development of this disease. Planting trees too deeply or burying the root collar with fill soil or mulch, and keeping the surrounding soil moist also favors the pathogen and disease development.

Wood Decay Fungi

Heart rots

Heart rot pathogens decay the heart wood, or central core, of branches, trunks, and large supporting roots of living trees, but they also decay dead trees. The pathogens generally enter through wounds (mechanical and pruning), broken branches, branch stubs, and other damaged tree parts (fig. 7.144).

Figure 7.146. Cavity and basal decay resulting from fire damage to the lower stem of a valley oak. B. Hagen

Figure 7.145. Pronounced swelling of the root collar (trunk flare) of this old Oregon white oak suggests extensive root and basal rot. B. Hagen

Figure 7.147. *Ganoderma applanatum* conks are fan-shaped, hard, woody, and perennial. Note the rusty-brown spores (spore print) on the bark below the conk. The upper surface is gray-brown, hard, and has concentric furrows and ridges. B. Hagen

Figure 7.148. A large *Ganoderma applanatum* conk on the base of a black oak. Note that the lower, spore-bearing surface is bright white and the pores are very small. B. Hagen

Figure 7.149. *Ganoderma lucidum* occasionally occurs on oaks. The upper surface of this conk has a shiny red to orange-brown varnishlike appearance. This pathogen also decays the roots and lower trunk, increasing potential for failure. Conks typically indicate extensive decay. B. Hagen

Figure 7.150. The white rot that developed in the roots and lower trunk of this coast live oak was caused by *Ganoderma applanatum.* The pathogen killed the tree and caused it to fail. Note the old conk on the left of the tree base. The pathogen causes a white rot of the roots and lower trunk. B. Hagen

Figure 7.151. These perennial hard conks of *Phellinus robustus* were found growing on a blue oak. They may occur in clusters and can become quite large and hooflike. The top of the conks are usually dark brown, deeply cracked, and concentrically zoned. B. Hagen

Basal (butt) rot
Various wood-rotting fungi

Look for basal wounds, cavities, fungal fruiting bodies or an exaggerated trunk flare (figs. 7.145, 7.146). The latter condition is often referred to as "bottle butt."

Ganoderma root rot
Ganoderma applanatum, artist's conk; *G. brownii* and *G. lucidum*

These pathogens cause extensive decay of the large supporting roots and occasionally lower trunk, affecting health and stability. Infected trees usually decline slowly, however, obvious symptoms may be lacking unless there is extensive root decay. This disease is best identified by the large, distinctive conks growing at the soil line or on the root collar (fig. 7.147, 7.148). The conks are perennial, woody, semicircular, quite large, and usually found on the lower trunk near the soil line. This disease is often associated with old wounds. The upper surface of the conk is relatively smooth, often concentrically furrowed, somewhat cracked, brown to gray above (*G. applanatum* and *G brownii)* or shiny, rusty to reddish brown (*G. lucidum)* (fig. 7.149). The lower spore-bearing surface, which is smooth and white to off-white, is easily bruised, and marks made on the surface quickly darken, hence the common name, artist's conk. Spores are rusty brown and often coat the soil and bark below. An off-white lip or margin is often visible from above. The pathogen commonly enters through basal wounds and causes a white rot of both the sap and heartwood (fig. 7.150). It is not uncommon to find conks on trees associated with damage to their root collars from Armillaria root rot. Extensive decay of the roots and lower trunk (butt) leads to increased failure potential. This root rotting pathogen typically causes a slow decline of affected trees. Many infected trees show no obvious symptoms until decay becomes extensive or the tree fails. Trees with conks should be carefully evaluated to determine risk potential because conks may indicate extensive decay and increased potential for failure.

Phellinus robustus

The conks (fruiting bodies) of this wood decay pathogen are large, perennial, semicircular, bracketlike, or hoof-shaped. They can be clustered and overlapping and quite large (fig. 7.151). The lower spore-bearing surface is tan to golden-brown, becoming dark brown with age. The pores are round and fairly uniform in size. The top surface is usually dark brown and concentrically furrowed and deeply cracked. This pathogen causes a white rot of the sapwood and heartwood of the trunks, large branches, and roots of living trees. Initially the heartwood is decayed, but the pathogen can spread out to sapwood, often causing cankers. Infection by this pathogen greatly increases the risk of branch and trunk failure.

Figure 7.152. The fleshy, bright yellow conk of sulfur fungus (*Laetiporus gilbertsonii* = *L. sulphureus*). B. Hagen

Figure 7.153. Within a few weeks of developing, the annual (short-lived) conks of sulfur fungus turn pale, chalky, and light yellow to tan, and then begin to disintegrate. ©M. Wood, Mykoweb.com, reprinted with permission

Figure 7.154. "Weeping conk" produced by *Inonotus dryadeus* growing at the base of a declining Oregon white oak. This pathogen causes a white rot of the roots and basal area of the tree. B. Hagen

Figure 7.155. Close-up of a recently formed *Inonotus dryadeus* conk. Note the golden droplets that form on the conk's surface, hence the name "weeping conk." With time, conks darken, turn brown, and begin to degrade. B. Hagen

Figure 7.156. Fruiting bodies of hedgehog fungus (*Hericium erinaceus f. erinaceus*) on black oak. Fruiting bodies consist of a mass of overlapping, slender, pendant, fleshy, fingerlike projections up to 2 inches long. They form annually and degrade quickly. J. R. Clark

Sulfur fungus
Laetiporus gilbertsonii = *L. sulphureus*

This is one of the few pathogens that cause brown rot in oaks. It can be found in decaying heartwood in the trunks and large branches, and occasionally extends into the large supporting roots of living trees. It can also be found on stumps and dead trees. The decayed wood is rusty brown, dry, crumbly, and cubical due to horizontal and vertical cracking. In cross-sections of decaying trunks or branches, white mycelial masses (felts) can be found in shrinkage cracks that form in the decayed wood. The fruiting bodies (conks) are soft, fleshy, and yellow to yellow-orange (or salmon) above and yellow below (fig. 7.152). With time, the conks dry, crumble, and turn a chalky, off-white color (fig. 7.153). They appear during the summer usually after years of infection. Trees with conks should be carefully evaluated for risk potential because conks are generally associated with extensive decay.

Weeping conk
Inonotus dryadeus

The annual woody conks are irregularly shaped, variable in size, and found at ground level (fig. 7.154). Initially buff-colored to tan, the developing conks are usually covered by golden droplets of liquid (fig. 7.155). They may occur singly or in clusters. In addition, conks quickly darken and the surface becomes quite roughened and cracked as they begin to break down. The pathogen causes a moderately slow white rot of the roots and lower trunk (butt) of both living and dead trees, often leading to tree failure.

Hedgehog fungus
Hericium erinaceus f. erinaceus

The annual fruiting bodies of this fungus are quite distinct—the outer spore-bearing surface is covered by soft, pendulous "teeth" or fingerlike projections. The conks typically occur in the fall near wounds. Fire damage, stem cracks, branch stubs, etc., are common sites of infection (fig. 7.156). This pathogen causes a white pocket rot of living trees, eventually resulting in cavities. It can also cause butt rot in affected trees.

Sap rots

Sap rots include fungal pathogens that decay dead and dying branches, the sapwood of dead and dying trees, and areas of sapwood injured by fire, sunburn, or mechanical damage. Once established, they can actively invade and kill living bark and cambium nearby. Decay progresses from the outside toward the center of the tree. The fruiting bodies of these pathogens are typically smaller and more numerous than those of heart rot pathogens. Furthermore, they are usually persistent and leathery.

Hypoxylon canker or cramp ball *Annulohypoxylon thouarsianum*, syn. *Hypoxylon thouarsianum*

This sap rot fungus is characterized by multiple black, dome-shaped fungal fruiting bodies up to 2 inches in diameter on trees it has colonized. They are hard and have a warty appearance and the consistency of charcoal. Fruiting bodies typically appear on the trunk and larger branches of dying and dead trees, particularly those killed or damaged by *Phytophthora ramorum*, the pathogen that causes sudden oak death (fig. 7.157). This pathogen is normally a saprophyte on dead and dying trees, where it causes a white rot of the sapwood, but on severely stressed trees it acts as a pathogen.

Figure 7.157. Fruiting bodies of *Annulohypoxylon thouarsianum* are black, hemispherical, and often erupt from multiple locations on the bark surface of dead and dying oaks. B. Hagen

False turkey tails *Stereum hirsutum*

This fungus colonizes the sapwood of dead and dying trees, dying branches and stumps, areas of dead or dying bark, and large wounds, causing a white rot. It may also invade the heartwood through large pruning cuts or broken branch stubs. The annual fruiting bodies are thin, pliant and bracketlike or partially flattened (spreading along the woody substrate) (fig. 7.158). Fruiting bodies are up to 2 inches across, but they are often smaller and the margins may appear fluted. They typically occur in dense, overlapping clusters. The upper surface is light orange-brown, obviously hairy, with alternating light and dark concentric stripes (zones). The lower surface is orange to pale-colored and smooth (lacking pores). The color of fruiting bodies can be variable and, with time, they harden and become grayish (fig. 7.159).

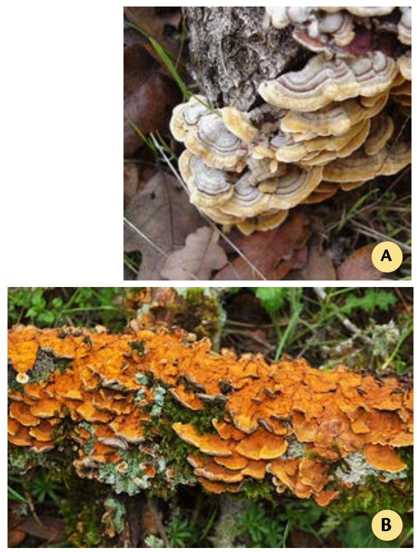

Figure 7.158. Fruiting bodies of *Stereum hirsutum* (false turkey tails) are thin, pliable, hairy on the upper surface, and concentrically marked (A). Their color can be quite variable, ranging from buff-orange to orange (B). Note the sheetlike (spreading) appearance of a colony. The log on which these fruiting bodies were growing was rolled over to take the photo. This lower, spore-bearing surface appears smooth and without pores. B. Hagen

Figure 7.159. The caps of the *Stereum hirsutum* conks may be very fluted or wavy-edged and turn grayish or brownish. Decay due to *Stereum* species often develops in the heartwood exposed by large pruning wounds and stem failures. B. Hagen

Jack-o'-lantern fungus *Omphalotus olivascens*

Fruiting bodies of this pathogen can be found on living and dead trees, generally growing in clusters at the soil line or nearby on shallow roots (fig. 7.160). Fruiting bodies are large mushrooms up to 10 inches tall with gills running from the edge of the cap down the stalk. Color ranges from a bright yellowy-gold to a yellowy-orange to olive (green-gold). The caps are initially convex, becoming depressed with a fluted margin with age.

Figure 7.160. Mushrooms of Jack-o'-lantern fungus *(Omphalotus olivascens)* are occasionally found growing on stumps and from the bases of living oaks. This fungus is sometimes called false chanterelle because of its yellowish color and the gills running up the stem. The color ranges from olive-yellow to a yellow with reddish tinge. ©F. Stevens, Mykobweb.com, reprinted with permission

Oyster mushroom
Pleurotus ostreatus

Fruiting bodies are mushroomlike and relatively large, up to about 6 inches wide. The gills on the bottom sides of the caps extend completely down the stems. The caps are hairy, white, and rounded (fig. 7.161). The pathogen typically invades the trunk and larger branches of living and dead trees through wounds or dying tissue after fire, sunburn, or mechanical injury. In addition, the pathogen can colonize trees in an advanced stage of decline, causing a white rot of the sapwood. Once established, it can actively invade and kill adjoining bark and cambium

Figure 7.161. Oyster mushrooms *(Pleurotus ostreatus)* on a dead log. The upper surface is smooth and white, cream colored, or taupe. The lower surface is gilled, and the gills run down the stem. ©F. Stevens, Mykoweb.com, reprinted with permission

Phellinus gilvus

This fungus produces solitary or clustered and overlapping, perennial, woody fruiting bodies (conks) (fig. 7.162). The lower spore-bearing surface, which is initially buff-colored to reddish brown, darkens with age. The pores are round and fairly uniform is size. The upper surface is typically a dark reddish brown with a light golden-brown velvety growing margin. It is roughened, bumpy, and concentrically furrowed. This pathogen commonly colonizes dead and dying trees and causes extensive white rot of the sapwood, often leading to branch or trunk failure. It is often associated with oaks killed by *Phytophthora ramorum*, the pathogen causing sudden oak death.

Figure 7.162. *Phellinus gilvus* conks on a large cut branch (A). Conks are usually rough and dark brown above and lighter below. The color ranges from buff to golden or rusty brown. *P. gilvus* is typically found on dead trees or dead portions of living trees (B). Fruiting bodies are often overlapping and interconnected. B. Hagen

Split gill fungus
Schizophyllum commune

The fruiting bodies of this fungus are small (up to 2 inches wide), rounded (parachutelike), white, and very hairy (shaggy) above, and they usually grow in clusters (fig. 7.163). The lower surface is light gray with well-spaced and longitudinally split gills (fig. 7.164). It occurs as a saprophyte on dead tissue or as an opportunistic pathogen on dying or injured tissue, such as that damaged by fire or sunburn. Once established, it can actively invade and kill adjoining bark and cambium, and it causes a white rot of the sapwood. The fungus can also colonize trees stressed by heat, drought, or major wounds. It generally occurs on cut and fallen wood and dead parts of living trees. Fruiting bodies generally persist for a year or more.

Figure 7.163. Fruiting bodies of the split gill fungus *(Schizophyllum commune)* on a dead tree. Fruiting bodies are leathery, fan-shaped, and bracketlike, and 1 to 1½ inches wide. The upper surface is shaggy (densely hairy) and ashy gray to white. B. Hagen

Figure 7.164. The lower surface of the split gill fungus *(Schizophyllum commune)* is light gray to taupe with well-spaced longitudinally split gills. ©M. Wood, Mykoweb.com

Turkey tails
Trametes versicolor

This common fungus is a saprophyte on dead trees or branches, and an opportunistic pathogen on severely stressed trees or areas of injured or dying bark. Once established in dead, dying, or injured tissue, it can actively invade and kill living bark and sapwood. It causes a white rot of the sapwood. The fruiting bodies are leathery, velvety, concentrically striped (alternating light and dark zones), and 1 to 4 inches across. The lower surface is nearly white and covered by small pores (fig. 7.165).

Figure 7.165. The underside of turkey tails *(Trametes versicolor)* fruiting bodies is white to pale yellow and has noticeable, but small, round pores. B. Hagen

Other Pathogens

Drippy nut disease

Drippy nut disease is caused by a bacterium that produces a dripping exudate from acorns (fig. 7.166). It may result from infestations of acorn-feeding insects.

Bark rot *Perenniporia medulla-panis* and other species

This fungus is occasionally found growing on the bark of oaks in California. It decays the outer corky layer bark in small patches that are white or cream-colored and angular, resembling thick white paint splashes on the bark plates and within the fissures. The damage appears to be insignificant.

Other Biotic Disorders or Pests

Acorn woodpeckers *Melanerpes* spp.

These birds gather acorns and insert them in holes made by pecking into the bark of living and dead trees (fig. 7.167). In this manner they create granaries for the safe storage of a food source.

Sapsuckers *Sphyrapucys* spp.

This type of woodpecker makes shallow holes in the bark of oaks and other trees to feed on the sap that collects in the wounds. The holes, made by pecking, range in size from about ¼ to about ⅜ inch in diameter and are uniformly spaced horizontally around the stem (fig. 7.168). A feeding site may have several rows of holes. Some trees become favorite feeding sites, and the holes may extend well up and down the tree trunk or branch. Extensive wounding can injure trees by killing the bark in and around the wounds and allowing the entry of stain- and decay-causing fungi.

Basal scars and seams

Scars and seams on the trunk of an oak indicate sites where bark wounds or cankers have closed (compartmentalized). These sites may indicate cracks or may be associated with decay and therefore should be evaluated. Sounding with a mallet can determine whether there is a hidden cavity. Seams near the soil line may indicate root disease. Longitudinal and linear seams may also indicate cracks.

Lichen

These plantlike organisms are comprised of a fungus and a green algae or cyanobacterium in a symbiotic relationship (figs. 7.169, 7.170, 7.171). They are harmless to oak trees. A few white to gray-white lichen form circular crustlike patches on branches and trunks of oaks.

Figure 7.166. The clear, sticky exudate caused by drippy nut disease becomes a nuisance when it drops onto cars, outdoor furniture, decking, etc. B. Hagen

Figure 7.167. A "granary" tree with acorns stored for future use. Acorn woodpeckers drill (peck) holes into the bark of living and dead trees and then insert acorns into them for later retrieval. B. Hagen

Figure 7.168. Sapsucker damage. Note the regularity of the holes, which the birds may arrange horizontally or vertically, depending on species of sapsucker. B. Hagen

Figure 7.169. A lichen, the light gray-green leafy material, covers the limb of this oak. Lichens are comprised of a fungus and a photosynthetic partner, usually a green algae, living together in a symbiotic relationship. B. Hagen

Figure 7.170. A bright yellow lichen (probably *Xanthoria parietina*) sometimes seen on oaks in irrigated landscapes or moist habitats. B. Hagen

Figure 7.171. Fishnet lichen *(Ramalina reticulata)*, mistakenly called Spanish moss, on valley oak. This lichen can grow profusely on oaks, usually in moist sites. B. Hagen

Oak mistletoe
Phoradendron villosum

Leafy mistletoe is a parasitic plant that obtains water and minerals from its host but produces most of its own carbohydrates. The leaves of this parasitic flowering plant are green, thick, and slightly oval, and the stems are smooth and green (fig. 7.172). Clusters of white, pearl-like berries can be seen in the late summer. These berries are an important food source for numerous birds. Mistletoe is spread when birds deposit seeds in the trees where they roost. The seeds can pass through their digestive systems intact. Seeds that land on oaks germinate and penetrate branches and occasionally the trunk.

Older mistletoe plants appear as round to oval clumps up to 3 feet or more in diameter in the crowns of affected trees (fig. 7.173). Healthy trees tolerate a few mistletoe branch infections, but individual branches may be weakened or sometimes killed. Heavy infestations may affect tree health, stunt growth, and cause stress or contribute to mortality. Trees experiencing drought stress are more likely to be damaged by mistletoe. Heavily infested tree branches often die because they are unable to regulate water loss from the mistletoe.

Large swollen areas (galls) often develop on infected branches and trunks (fig. 7.174). Cankers often result when mistletoe plants die, opening the stem immediately around the dead mistletoe plant to boring insects and wood decay pathogens (figs. 7.175, 7.176). In fact, mistletoe cankers are often associated with limb dieback and failure, particularly on black oak in Yosemite National Park and on blue oak in the Central Sierra foothills. John Kipping reported (personal communication, 2006) that mistletoe causes a significant amount of branch dieback in blue oak in the Sierra Nevada foothills region east of Sacramento. Furthermore, mistletoe can be destructive to non-native oaks in other parts of the state. For further information on mistletoe biology and management, see Mallams and Mathiasen (2010).

Figure 7.172. Oak mistletoe (*Phoradendron villosum*) leaves are thick, green, and slightly oval. B. Hagen

Figure 7.173. Valley oak with mistletoe (*Phorodendron villosum*). Mistletoe can be a serious problem for urban oaks and should not be ignored. B. Hagen

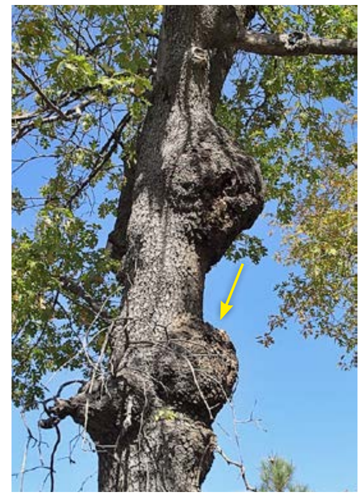

Figure 7.174. Mistletoe infections on the stem or large branches can result in the formation of large hemispherical galls (arrow). B. Hagen

Figure 7.175. Stem cankers caused by oak mistletoe (*Phoradendron villosum*). Note the dead, sunken areas where the wood is exposed and the canker margins show strong callusing (arrows). In this case, the mistletoe plant has died. Significant wood decay is often associated with mistletoe cankers. B. Hagen

Figure 7.176. Oak mistletoe resprouting from the area where a mistletoe plant had been pruned out a year or two earlier. Note the branch cankers nearby. Non-native oaks such as this red oak appear to be quite susceptible to mistletoe. B. Hagen

Moss

A harmless green, leafy, primitive plant that grows on tree bark as well as other surfaces. Moss typically forms lush, green and dense mats in damp or shady locations (fig. 7.177).

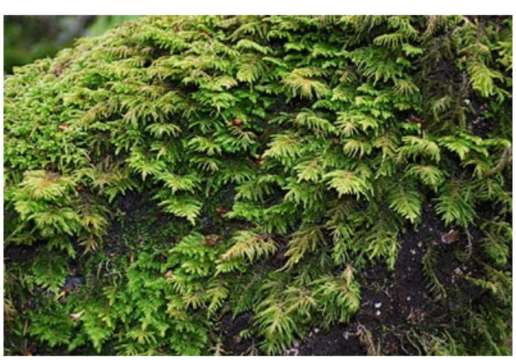

Figure 7.177. Mosses are nonflowering nonvascular plants that grow on the ground, rocks, and plants in damp and shady locations. They are commonly found on oaks, such as the one shown here. B. Hagen

Unknown causes

Large galls or swellings can be caused by bacteria, fungi, and cellular mutations of the plant (fig. 7.178). Galls are produced by excessive division and enlargement of cells due to abnormal cambial activity. The bark covering the galls often degrades allowing the wood below to decay.

Figure 7.178. Large galls, such as this one on a valley oak, may occur on both urban and woodland oaks. They typically occur on the trunk near the soil line but are occasionally seen higher in the tree. The cause of such galls is not known. B. Hagen

Abiotic Disorders

Abiotic disorders are caused by environmental factors such as insufficient water (drought), too much water, lack of essential elements, and excess salts. They can be as common as biotic disorders and cause injuries ranging from mild to severe.

This section describes the more commonly occurring abiotic disorders of oaks: water deficit, aeration deficit, mineral deficiency, salt injury, specific ion toxicity, and sunburn injury. Symptoms, causes, and remedies for each disorder are given with applications to oaks as appropriate.

Although some disorders are not common in oaks in woodland areas (e.g., salt injury and mineral deficiency), they can be found in urban areas. Such cases typically result from unfavorable changes in soil conditions following development. In addition, some disorders (e.g., water deficit) can occur more frequently and severely in newly planted oaks than in mature trees.

Disorders other than the six described in this section do occur but are less common. Although these are noted at the end of this section, see *Abiotic Disorders of Landscape Plants: A Diagnostic Guide* (Costello et al. 2003) for complete details.

Water Deficit

Although California native oaks are well recognized for tolerating extended periods without rainfall or irrigation, they do incur water deficits and can be injured.

Water deficits occur when water loss exceeds water supply, that is, when transpiration is greater than water absorption. A number of factors affect water supply, absorption, and loss, and the response of oaks varies depending on the severity and extent of a deficit.

Symptoms

Water deficit injury can range from a small reduction in growth rate to death of a whole tree. The level of injury depends on the severity and duration of the deficit and the sensitivity or tolerance of the species. Common symptoms include the following, listed in order of increasing severity:

- wilt in young seedlings or young (nonwoody) shoots, particularly during the warmest part of the day
- reduction in growth rate (growth may cease)
- early fall color and early leaf drop in deciduous oaks or partial defoliation in evergreen oaks
- tip dieback and marginal necrosis on leaves
- branch dieback
- secondary pest attack
- whole tree death

In many cases, water deficit injury is not noticed until more severe symptoms appear, such as leaf drop and branch dieback. Although well-established or mature trees can tolerate moderate to severe deficits, young trees may be seriously injured. Species vary as well: coast live oak and interior live oak typically hold most of their leaves during periods of water deficit but may partially defoliate during extended droughts. Black oak has been reported to partially defoliate during droughts, while blue oak and valley oak may completely defoliate (McCreary 1991b). Symptoms first appear in the top of the crown and outermost foliage, then progress downward and inward (fig. 7.179). This defoliation response has been referred to as “drought deciduous” and appears to be a mechanism to avoid the more severe consequences of water deficit (McCreary 2000b).

Causes

In oaks, water deficits can result from a number of causes, foremost of which are diminished supply, reduction in the capacity of roots to absorb water, and environmental conditions that favor evaporative water loss. Often, it is a combination of these factors that results in water deficit injury.

Diminished supply

Oaks become established in particular locations because water resources are adequate to meet their seasonal needs. When reductions in water supply occur, the potential for injury increases.

Available water in the root zone fluctuates from year to year due to changes in annual rainfall, and below-normal years lead to water deficits. When years of below-normal rainfall occur consecutively, the potential for water deficit injury increases substantially.

A reduction in groundwater level can lead to depletion of the amount of water available for trees that extract water

Figure 7.179. California native oaks can show fall color early and drop leaves prematurely during low-rainfall years. This response to low soil moisture levels has been termed "drought deciduous." In late August 2008, after 2 years of below-normal rainfall, the black oak on the left shows early fall color, while the blue oak on the right has turned brown and dropped a considerable number of leaves. Evergreen oaks in the same area (coast live oak and interior live oak) did not show the same response. L. Costello

from the capillary zone above groundwater supplies. The groundwater level can decline for a number of reasons: diminished recharge resulting from below-average rainfall, depletion due to well pumping, and changes in groundwater flow due to nearby excavation.

Changes in stream flows (e.g., from diversions or pumping) and surface flow patterns (e.g., caused by landscape grading or the foundations of buildings) can affect water supply as well. Oaks growing next to streams or creeks may experience deficits if flows are reduced or diverted. Likewise, oaks located in areas where surface flow is naturally channeled to the root zone (such as at the base of a slope) may incur water supply reductions if surface contours and flow patterns change, channeling water away from the tree.

Similarly, a reduction in water movement into the root zone can diminish supplies. Soil compaction and surface barriers can reduce water infiltration rate, thereby reducing water movement into the root zone. Surface compaction is common in urban areas due to foot traffic and vehicle activity. Surface barriers such as asphalt and concrete pavement effectively block the movement of water into soils, diverting it away from the root zone in some cases. Avoiding surface compaction and the use of barriers around oaks helps reduce the potential for water supply reductions and water deficit injury.

For oaks that have grown in an irrigated setting or that now receive irrigation water during the growing season, changes in irrigation schedule or malfunctions in the delivery system (broken valves, pipes, or heads) can cause a reduction in supply. Trees adjust their root-to-shoot ratios in response to water and mineral availability (Chapin 1980). Thus, root systems of trees that have developed in regularly irrigated sites are generally less extensive than those of similar-sized trees that developed without irrigation. Consequently, trees that are regularly irrigated are more likely to suffer injury if irrigation is curtailed or discontinued. It is difficult to assess the potential impact of such changes because it is hard to determine how much of the tree's supply is being provided by irrigation and how much by rainfall. Nonetheless, the potential for water deficit injury increases when reductions in irrigation water supply occur, particularly for transplanted trees and where soil volume is restricted (fig. 7.180).

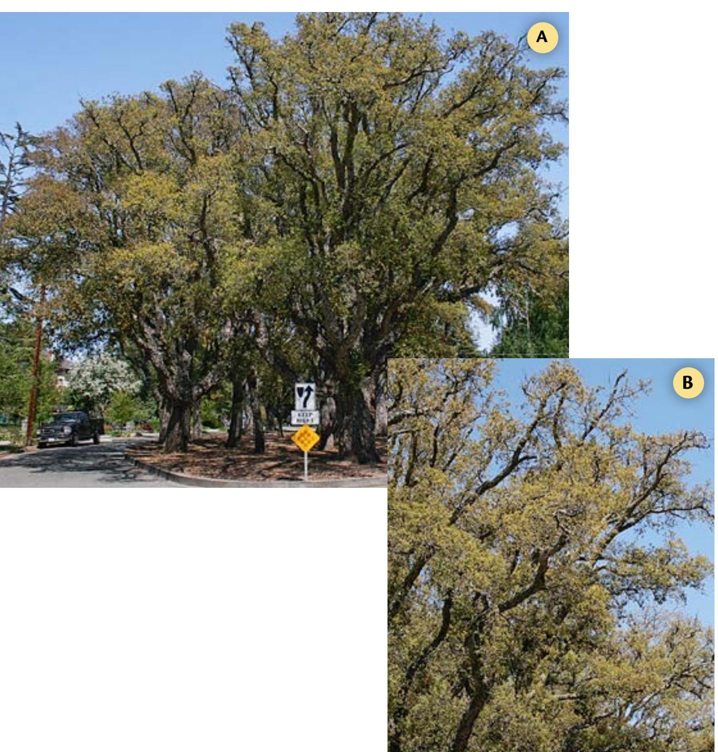

Figure 7.180. Water deficit injury can result from a number of causes. In this stand of cork oak, the trees had been declining for several years, as indicated by thinning canopies, chlorosis, and dieback (A, B). A combination of limited soil volume for water storage (island median), competition for water resources (many trees in a small area), and 2 years of below-normal rainfall were considered to be key factors leading to water deficit. Summer applications of water notably improved the canopy density, color, and growth (C, D). L. Costello

Reduction in root system capacity to absorb water

Water is absorbed by fine roots, which are connected to lateral, sinker, and (to a lesser extent) oblique roots. For oaks, absorption is aided substantially by mycorrhizae (or mycorrhizal roots). If fine roots, with or without mycorrhizae, are cut or otherwise damaged, the capacity of the root system to absorb water declines. Likewise, if the water absorption function of fine roots is diminished by unfavorable soil conditions (such as an aeration deficit) or a biotic agent (such as a root pathogen), water uptake is compromised.

Root loss is not uncommon for urban oaks (fig. 7.181). During the development process, roots can be cut for foundations, utility lines, and roads. Typically, these are lateral roots that occur close to the soil surface. Since a substantial percentage of fine roots are connected to lateral roots, however, there is an increasing potential for reductions in absorptive capacity when root cutting occurs, particularly when the cut roots are large (i.e., greater than 2 inches in diameter). Even when little root cutting occurs, direct mechanical damage to fine roots can occur from surface activities such as shallow grading or the removal of the organic layer in preparation for building.

Water deficits can also result when soil aeration levels are critically low, such as in waterlogged or highly compacted soils. In addition, root disease and high soil salinity can reduce water absorption, leading to water deficits.

Mycorrhizal roots play an important role in the absorptive capacity of oak root systems (see chapter 4). If mycorrhizae are not present at a planting site for new oaks or if soil conditions are unfavorable for mycorrhizal associations (e.g., compaction, high salt content, low organic matter content, high surface temperatures), the contribution of mycorrhizal roots to water absorption will be diminished.

Environmental conditions that favor evaporative water loss

Although many oak species have inherent mechanisms for conserving water (leaves with a thick cuticle, reduced leaf size, modified stomatal response, etc.), transpirational water loss is an inevitable occurrence. Evaporation of water from leaves through stomates drives transpiration, which in turn is driven by air temperature, solar radiation, humidity, and wind. When evaporative potential is high, transpirational water loss increases, such as when trees are in full sun or a windy location, the air temperature is high, and humidity is low. When evaporative conditions favor water loss, yet the tree cannot absorb or transport water to offset the loss, water deficits may occur.

For mature trees, it is highly difficult to modify the environment to reduce evaporative potential: not much can be done to moderate temperature, wind, or humidity in the crown of large trees. Changes can be made that increase evaporative potential, however. For instance, removing trees adjacent to an oak can increase solar radiation and wind exposure while decreasing humidity in the crown. Also, by placing highly reflective surfaces (such as windows) or heat-releasing surfaces (such are asphalt) near oaks, evaporative water loss increases along with the potential for water deficit injury.

Combinations of causes

When more than one cause is active, the potential for water deficit injury increases. For instance, if a very low rainfall season is followed by an abnormally hot and windy summer, the potential for injury is higher than in years with average or normal conditions. Tietje et al. (1993) reported that oaks on ridgetops and south-facing slopes were most severely injured by drought. Ostensibly, a low water supply

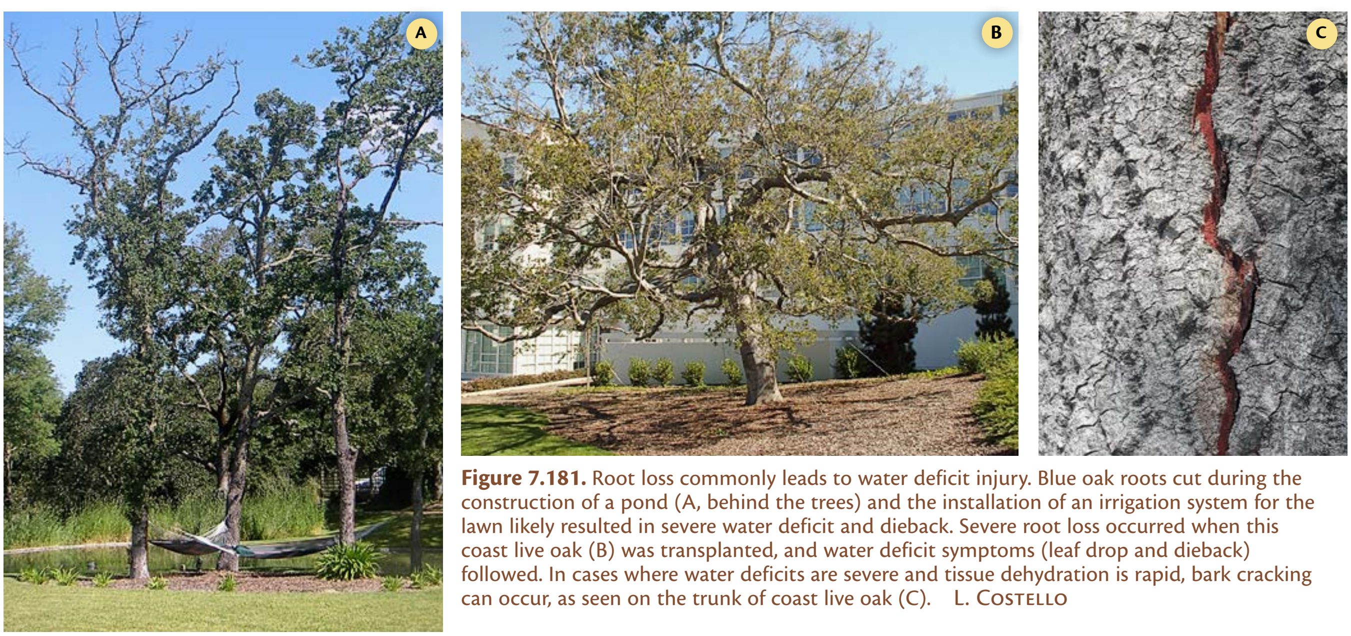

Figure 7.181. Root loss commonly leads to water deficit injury. Blue oak roots cut during the construction of a pond (A, behind the trees) and the installation of an irrigation system for the lawn likely resulted in severe water deficit and dieback. Severe root loss occurred when this coast live oak (B) was transplanted, and water deficit symptoms (leaf drop and dieback) followed. In cases where water deficits are severe and tissue dehydration is rapid, bark cracking can occur, as seen on the trunk of coast live oak (C). L. Costello

(drought) in combination with wind exposure (ridgetops) and high solar radiation loads (south-facing slopes) led to water deficit injury.

Of particular concern is root cutting in combination with a reduction in supply or an increase in evaporation. Reducing the capacity of an oak to absorb water when supplies are relatively low and demand is high is a formula for severe injury. If root cutting is unavoidable, it should be done when other factors that contribute to water deficits are not active, such as in the winter months. For transplant operations that occur during the summer months, trees must be preirrigated before root cutting to lower the potential for water deficit. In addition, transplants not planted immediately after digging should be stored in sites with relatively low evaporative conditions, such as under shade structures.

Remedies

Clearly, prevention of water deficit injury is far better than remediation. Avoiding conditions that lead to a reduction in water supply, a reduction in the capacity of the root system to absorb water, or an increase in evaporative potential is preferable to mitigating soil-moisture deficit. When injury has occurred, however, further impact must be minimized. Points to consider for each of the key causal factors are listed below, with emphasis on what to do rather than how to do it. For more information, see chapter 5.

Diminished supply

- In drought years, irrigate in spring, particularly if multiple years of below-average rainfall have occurred.
- For changes in groundwater levels, supplement the water supply through irrigation.
- For changes in surface flow, attempt to restore natural flow patterns. If this cannot be achieved, augment supply with irrigation.
- For reduced soil infiltration rate, identify the cause and correct the condition. For soil compaction, cultivate and mulch the soil surface. For surface barriers, provide access through the barrier by removing sections and replacing them with permeable materials. Drilling holes through the barrier may be helpful in some cases.
- Before irrigating native oaks using an automated system, check the irrigation schedule and system operation to ensure that the soil within the root zone will be irrigated as needed to meet the objective. Replace malfunctioning components and ensure that the schedule provides enough water to wet the root zone to field capacity to the desired depth, usually 12 to 18 inches. Allow a dry-down period after each irrigation cycle. In general, established oaks should not be irrigated more than once a month during the summer. Trees in fast-draining, sandy soils may need to be irrigated more frequently to meet the objective. Avoid wetting the soil within about 3 times the trees diameter. For more information, see chapter 5.

Root loss and loss in root system capacity to absorb water

- Augment water supply to the remainder of the root system.
- Create conditions favorable for new root development (e.g., add mulch and irrigate the area adjacent to where roots were cut).
- Remediate conditions that limit root function (e.g., soil compaction, pavement, fill soil, excess irrigation, poor drainage, and salt buildup). For more information see chapter 5.
- Avoid further root damage: establish tree protection zones in construction areas.
- If native mycorrhizae are thought to be deficient due to unfavorable soil conditions, it may be beneficial, once soil conditions have been mitigated, to inoculate areas of the root zone with soil obtained from healthy oaks nearby.

If environmental conditions favor evaporative water loss

- Ensure an adequate water supply during periods when evaporative conditions are severe (unusually hot periods).
- Avoid changes in the tree environment that can increase the evaporative potential, such as removing adjacent trees. Excessive crown thinning may lead to an increase in water loss rate from the remaining leaves.
- Preirrigate transplants before digging and protect them from sun and wind if stored before planting. Monitor soil moisture status carefully. Soil moisture sensors should be used to determine whether irrigation is needed; this is a much better approach than waiting for the development of leaf symptoms. For more information, see chapter 5.
- Antitranspirants may be useful to moderate water loss from transplants, but they are not advised for established trees.

For combinations of the key causal factors

- Recognize that combinations of the above factors often contribute to injury. Make sure each is addressed when considering remedies.
- Avoid situations where multiple causal factors may contribute to water deficit injury, such as root pruning during the summer when water supplies are low and air temperatures are high.

Aeration Deficit

Aeration is the movement and availability of oxygen in soils. Plant roots require an adequate supply of oxygen for growth and development, and injury results when supply declines below a critical level. Root respiration is the first process to be restricted, followed by disruptions in metabolism, nutrient uptake, water absorption, and photosynthesis.

In oak woodlands, soil aeration deficits are uncommon, except in areas subject to periodic flooding. Oak species are generally well adapted to their site conditions. Trees become established and grow because site conditions are favorable, and unless significant changes occur that adversely affect aeration status, the potential of aeration deficit injury is minimal. In urban areas, however, changes in soil conditions are comparatively common, and aeration deficit injury is a more likely occurrence. Typical changes include soil compaction from vehicle or pedestrian traffic and saturation of the root zone from irrigation (fig. 7.182). Both of these conditions adversely affect soil aeration status and can result in injury.

Symptoms

Aeration deficit injury can range from slow growth (which may be difficult to detect) to whole tree death. The severity of injury depends on the extent and duration of the aeration deficit, species tolerance, tree age and condition, and the occurrence of secondary agents such as root pathogens. Leaves can be undersized, chlorotic, and prone to abscission (leaf drop), resulting in a general thinning of the crown (fig. 7.183). Branch shoots may be shorter than normal, and dieback may occur in severe cases. Bleeding cankers on the lower trunk are also associated with severe aeration deficits. Similarly, roots can become discolored and water-soaked. These symptoms are also indicative of Phytophthora root disease (see figs. 7.140 and 7.141).

Oaks and Defoliation

Defoliation of oaks can occur as a result of insect activity (e.g., California oak moth), disease activity (e.g., anthracnose), or from unfavorable environmental conditions (e.g., water deficit). Oaks can survive consecutive defoliations, although some dieback may occur. Swiecki and Bernhardt (1990) reported mortality in some oaks following several consecutive years of defoliation due to California oak moth.

Vigor of affected trees prior to defoliation is an important consideration (see Kozlowski 1969). Trees subjected to drought following defoliation may decline or succumb to secondary pest attacks. Drought greatly amplifies the effects of defoliation.

Timing of defoliation is also critical. Heavy defoliation following leaf flush (when stored energy is typically at a low level) usually results in a second flush of leaves that consumes much of the tree's energy reserves (Wargo 1978). A significant reduction of starch content in defoliated oaks has been reported (Wargo et al. 1972). Trees defoliating later in the year are less impacted because they have time to restore carbohydrate levels.

Extensive mortality in blue oak was reported in the hills behind the Stanford University campus in 1986. Trees were stressed by several years of drought and then repeatedly defoliated by several leaf diseases during the extremely wet spring of 1985. Ostensibly, the oaks, impacted by the long-term effects of drought followed by defoliation, had depleted their energy reserves and succumbed to a combination of biotic and abiotic factors. Swiecki (pers. communication, 2009) indicated that he had noted a high incidence of canker rot and some root diseases, which were likely major contributors to decline. Severe anthracnose infections caused widespread defoliation of oaks following an unseasonably wet spring in 1993 in parts of Northern California. The leaves were succulent, the temperature was warm, and there was rainfall—ideal conditions for anthracnose. No increase in mortality was reported (Owen 1994).

Figure 7.182. Oaks planted next to irrigated lawns are subject to aeration deficit injury. This lawn and irrigation system recently had been installed next a number of cork oak trees, and irrigation water was collecting in the root zone. Although symptoms were not yet being expressed, this condition can lead to aeration deficit injury as well as infection by root pathogens. L. Costello

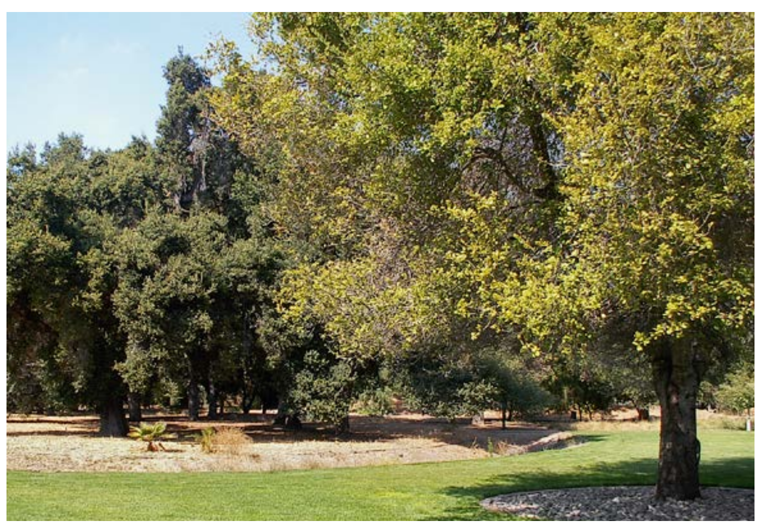

Figure 7.183. Aeration deficit injury can result from excess water in the root zone. Here, chlorosis and canopy thinning in coast live oak in the foreground may have resulted from an aeration deficit caused by frequent irrigation for the lawn. The coast live oak trees not receiving frequent irrigation (background) show typical color and canopy density. L. Costello

Not all symptoms of aeration deficit occur in all cases. Depending on species and conditions, some symptoms may be quite obvious and others not at all. For instance, foliar chlorosis and leaf drop may be readily apparent, while trunk bleeding may not be found. Generally, if aeration deficits are severe and chronic, crown symptoms likely will be extensive.

Although there is little information on the relative tolerance of oak species to aeration deficits, it is possible that species occurring in areas prone to saturated soil conditions (e.g., from flooding, high rainfall amounts, or high water table), such as valley oak, are more tolerant of aeration deficit than species occurring in drier sites, such as blue oak and Engelmann oak (fig. 7.184).

Figure 7.184. Valley oak can tolerate winter flooding without apparent injury. Flooding during the spring or summer months can cause severe injury, however. B. Hagen

Causes

Aeration deficits occur when the oxygen diffusion pathway from the atmosphere to root surfaces is blocked or diminished in size. Oxygen enters the soil through the surface and moves largely through macropores by diffusion from areas of high concentration to areas of low concentration. If the soil surface becomes sealed (e.g., from surface barriers such as asphalt or fill soils), or macropore space is reduced (e.g., from soil compaction), or macropores become filled with water (e.g., from excess irrigation or poor drainage), the oxygen diffusion rate (ODR) declines. Consequently, oxygen that is consumed by roots and soil organisms such as fungi and bacteria is not replenished, and the oxygen concentration declines. As the oxygen concentration declines below a critical point, an aeration deficit occurs and injury follows. The level of injury depends largely on the extent and duration of the deficit.

As noted above, key causes of aeration deficits include soil compaction, soil saturation, and soil surface barriers. When two or more of these causes occur at the same site, conditions become highly favorable for aeration deficit injury. Following are brief descriptions of how each cause leads to an aeration deficit.

Soil compaction

As noted in chapter 4, soil pore space is composed of both micropore and macropore space. At field capacity, micropores are largely filled with water, while macropores contain air (air-filled pore space) and serve as channels for gaseous diffusion. When soils experience a reduction in macropore space, typically from compaction, gas diffusion is diminished and aeration deficits can occur.

Soil compaction commonly results from vehicle and foot traffic, construction-related activities, and livestock. Surface loading from such sources causes soil aggregates to collapse (loss of soil structure), reducing air-filled porosity. In some cases, macropores are compressed to the size of micropores, resulting in an increase in water-holding capacity. With severe compaction, both macropore and micropore space can be severely reduced, increasing soil resistance to root penetration and reducing the oxygen diffusion rate.

Excess soil moisture

Water in soil pores is a barrier to oxygen diffusion: oxygen diffuses through water 10,000 times slower than through air. When the oxygen diffusion pathway (macropore space) is filled with water, the diffusion rate declines substantially. This occurs in flooded soils, poorly drained soils, and soils that are irrigated excessively. It is particularly a problem in soils that have little macropore space to begin with (e.g., clays, compacted soils, and poorly structured soils). In these soils, water occupies the space needed for gas diffusion, and oxygen cannot move to root surfaces rapidly enough to meet respiratory needs.

Flooding and Aeration Deficit

Flooding can occur in low-lying areas, floodplains, along lake shorelines, riverbanks, and in meadows. Flooding reduces the air-filled pore space in soils, reducing oxygen diffusion and, depending on duration in some cases, leading to aeration deficit injury. In addition to reducing soil aeration, flooding creates conditions favorable for infection by root pathogens, particularly when the soil temperature is relatively warm. In some cases, aeration deficit and root disease can result in tree death. Flooding during the growing season is typically more harmful to trees than flooding during the dormant season. The longer trees are exposed to flooding, the greater the potential for injury. Short periods of flooding during the growing season can be tolerated by most trees, but if flooding is recurrent or uninterrupted and the soils remain saturated, serious damage to oaks may occur. Specifically, trees are most susceptible to flooding in late spring just after the first flush of growth.

Most oaks can withstand some flooding. For example, valley oaks in a number of locations are often inundated during the winter for weeks at a time. Healthy, mature trees appear more tolerant of flooding than declining trees and those already under stress. Trees that survive moderate flooding often have a reduced root surface area, as nonwoody roots are more susceptible to injury. Thus, water and mineral absorption may suffer as a result. Once floodwaters recede, it may take weeks for photosynthesis to return to normal. Flooding can also deposit sediments, which can reduce soil aeration later when the soil dries.

Although an assessment of the relative tolerance of California native oaks to flooding has not been made, Harris et al. (1980) documented that mature blue oaks and valley oaks growing on alluvial soils withstood flooding for 50 to 98 days each of 3 years with little or no tree loss.

Surface barriers

Impermeable materials such as asphalt and concrete placed on the soil surface may act as barriers to the movement of oxygen into the soil. Although there is little information regarding the actual effect of such hardscape elements on diffusion, it is likely that some measure of reduction occurs (Costello et al. 2003). Typically, soils beneath hardscape elements are first compacted and a base material is added and compacted. Collectively, the hardscape element, base material, and soil compaction may combine to impede the movement of oxygen into the root zone. Fine roots in the area immediately beneath the compacted soil layer would have the highest potential of being adversely affected. Further research is needed to assess and quantify these effects.

Fill soil

Fill soil has been reported to act as a barrier to oxygen movement into the root zone, similar to that of surface barriers. Yelonsky (1963) reported that fill soil depressed root zone oxygen concentration below a critical level and concurrently increased carbon dioxide levels. This change in gas concentration was considered sufficient to impair root function and cause injury. However, studies with fill soil by MacDonald et al. (2004) and with compacted soils and aeration systems by Day et al. (1995) did not find significant reductions in oxygen concentration or oxygen diffusion rate. Townsend et al. (2003) reported that fill soil reduced the concentrations of oxygen slightly, but not enough to create conditions unfavorable for tree growth. In all three studies, the authors questioned the role of soil aeration deficit as the key factor causing tree injury and indicated that other factors may play an equally important role. Specifically, altered water relations, soil compaction, and mechanical injury to roots were noted as potentially having an equal or greater effect on tree health. The depth, texture, structure, and continuity of the fill soil are factors that may influence the actual impact on soil aeration.

Although it is unclear whether fill soil has a direct impact on soil aeration, oaks that have had fill placed around them often show signs of decline. This may be due to a combination of impacts as noted above that may occur before, during, and after fill installation. When evaluating the potential for an adverse effect from fill soils, it is recommended that all possible contributing factors be considered (Costello and Day 2004).

Remedies

As with other abiotic disorders, prevention is of paramount importance. Avoiding conditions that lead to aeration deficits must be a key component of oak management plans and practices. If conditions arise that may lead to aeration deficit injury, however, remedial measures will be needed. The following factors should be considered when attempting to correct specific aeration limiting conditions.

Soil compaction

- Conduct an assessment of the extent of compaction. Is it limited to the surface 3 inches of soil? Is it deeper? Does it extend across the root zone? Is it limited to one discrete area? Is there a subsurface compact zone? How deep is it? Addressing these and other questions helps provide an evaluation of the scope and severity of the condition.
- Measure soil bulk density in the compacted zones. Take samples at the soil surface or in subsurface compact zones. For critical bulk densities for different textural classes, see Daddow and Warrington (1984).
- Cultivate areas that have been identified as being compacted beyond critical levels. Pneumatic soil excavation tools can be used under and immediately around existing trees to loosen compacted soil without significantly damaging tree roots (see fig. 5.21).
- For fine-textured soils that are prone to compaction, add organic matter to the soil. Use an amendment that has a relatively low water-holding capacity, such as bark or composted wood chips.
- After cultivation, irrigate to settle the soil and then add 3 to 4 inches of organic mulch. Replenish mulch as needed.
- Restrict access around the oak to avoid re-compaction.

Excess water in root zone

- Identify the reason(s) for excess water in the root zone, e.g., irrigation, high water table, changes in drainage patterns, fine-textured soil, etc.
- If irrigation is the cause, inspect the system for leaks and broken heads and repair as needed. Check the water distribution pattern and ensure that water is not being delivered to the oak root zone in excessive amounts. Review the irrigation schedule and ensure that a reasonable "drydown" period occurs between irrigation cycles. The duration of this period will depend on soil texture, structure, and depth, and management objective.
- Avoid disrupting natural patterns of surface drainage. Where natural patterns have been changed and water accumulates over the root zone or at the base of the oak, install drains or swales to direct water away. Be careful not to cause mechanical damage to roots when installing drainage systems. In some cases, vertical drains may be least injurious.

Surface barriers

- When possible, remove pavement (or other surface barrier) within the root zone of oaks, including the base material. In addition, loosen the underlying soil as needed, avoiding mechanical damage to roots.
- If pavement within the root zone cannot be removed, auger holes through it to create channels for gas exchange. Fill the holes with pea gravel and install vent covers. With time, however, finer soil particles are likely to infiltrate the voids in the gravel, diminishing gas exchange.

Fill soils

- Remove fill soil in contact with the trunk. Avoid damage to trunk tissues during the removal process. Construct a tree well and, if possible, provide drainage. This may require trenching to install drain pipes or contouring the soil if the tree is on a slope (see sidebar).
- Check soil moisture at the original grade beneath the fill. If the soil appears dry, irrigate to raise the soil moisture level. To do so, it may be necessary to drill holes through the fill and into the native soil to deliver water to the roots.
- If a fine-textured soil was used as fill (and subsequently compacted), remove it if practical, replace it with a coarse-textured soil, or loosen it and incorporate organic matter.

Salt and Specific Ion Toxicity

Soils contain a number of water-soluble salts that can injure oaks, principally chlorides, sulfates, and nitrates of calcium, magnesium, sodium, and potassium. Although elements of these salts are essential for plant growth and development, their collective concentration in the soil solution can exceed a critical level for a species (salt injury). In addition, if the concentration of an individual constituent of a salt (ion) increases beyond a critical level, specific ion toxicity occurs. In either case, injury ranges from mild to severe depending on the sensitivity of the species (see table 7.1) and the concentration of the salt or specific ion. In some cases, both types of injury can occur.

In addition to soil salts, foliar applications of salts can cause injury as well. Salts deposited on leaves and buds from ocean spray, sprinkler irrigation with poor-quality water, and road deicing applications can injure sensitive species.

In oak woodland areas, salt and specific ion toxicities are not common: species generally do not become established in areas that have growth-limiting concentrations of salt or specific ions. In urban areas, however, input from a number of sources can lead to elevated salt concentrations, and both mature and newly planted oaks can sustain injury. Common sources of salts include recycled water, poor-quality irrigation water, excessive fertilizer applications, and the use of deicing materials (fig. 7.185).

Fill Soil and Trunk Contact

Harris et al. (2004) noted that placing fill soil against the trunks of trees is ill-advised because many trees are subject to infection by disease-causing pathogens. Armillaria root disease (*Armillaria mellea*) and crown rot (*Phytophthora* spp.) are favored by moist soil conditions, especially when soil is in contact with the lower trunk (Jacobs et al. 1997; Baumgartner 2000).

If fill soil has been placed around the base of an oak, expose the tree's root collar to the original soil line using methods that avoid injuring roots. Remove soil within a distance of at least 12 inches of the trunk and to the depth of the trunk flare or root collar, exposing the bark tissue to the air and allowing it to dry. Soil removal can be accomplished using hand tools (shovel, pick), a pneumatic excavation tool (high pressure air jet), or a hydraulic excavation tool (high-pressure water jet used in conjunction with a vacuum unit). Avoid bark damage in the process of removing fill soil. If practical, provide drainage to prevent water from collecting around the root collar during the winter. For safety purposes, cover the excavated area with a grate or decking if it is deep. If it can be done without disturbing a large number of roots, it may be more practical to recontour a wider area to avoid having a deep pit with an abrupt edge.

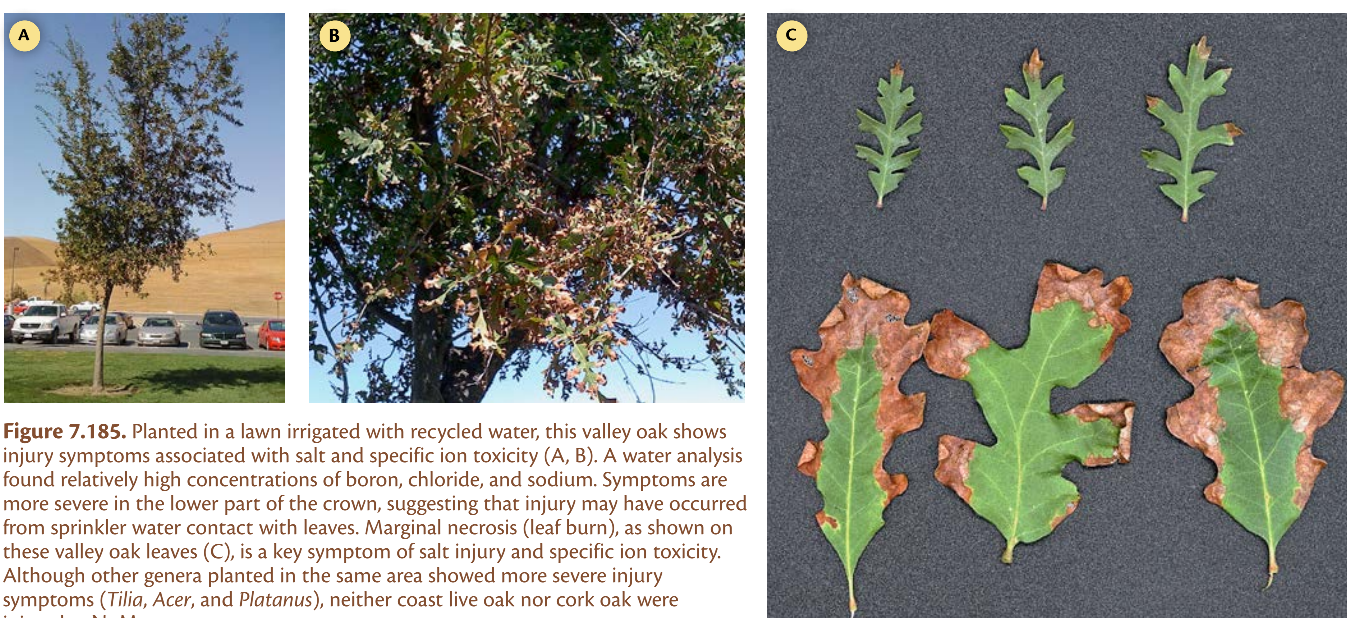

Figure 7.185. Planted in a lawn irrigated with recycled water, this valley oak shows injury symptoms associated with salt and specific ion toxicity (A, B). A water analysis found relatively high concentrations of boron, chloride, and sodium. Symptoms are more severe in the lower part of the crown, suggesting that injury may have occurred from sprinkler water contact with leaves. Marginal necrosis (leaf burn), as shown on these valley oak leaves (C), is a key symptom of salt injury and specific ion toxicity. Although other genera planted in the same area showed more severe injury symptoms (*Tilia*, *Acer*, and *Platanus*), neither coast live oak nor cork oak were injured. N. Matheny

Table 7.1. Salt and boron tolerance of oaks

Scientific name	Common name	Salinity tolerance	Boron tolerance	Reference*
Q. acutissima	sawtooth oak	moderate	—	Wichman et al. 2006
Q. agrifolia	coast live oak	high	high	Wu and Dodge 2005
Q. alba	white oak	high	—	Dirr 1976; Kujawski 2005; Swift 1997; Wichman et al. 2006
Q. alba	white oak	medium-high	—	University of Tennessee Extension 2002
Q. austrina	bluff oak	low to none	—	Wichman et al. 2006
Q. bicolor	swamp white oak	low	—	Cornell Coop. Ext. 1999; Dirr 1976
Q. chapmanii	Chapman's oak	high	—	Wichman et al. 2006
Q. coccinea	scarlet oak	high	—	University of Tennessee Extension 2002
Q. falcata	southern red oak	moderate	—	Wichman et al. 2006
Q. geminata	sand live oak	high	—	Wichman et al. 2006
Q. hemisphaerica	laurel oak	moderate	—	Wichman et al. 2006
Q. ilex	holly oak	moderate	moderate	Miyamoto et al. 2004; Questa 1987
Q. laurifolia	laurel oak	low	—	Meerow and Black 1993; Wu and Dodge 2005
Q. laurifolia	laurel oak	moderate	—	Wichman et al. 2006
Q. lobata	valley oak	—	high	Questa 1987
Q. lyrata	overcup oak	low to none	—	Wichman et al. 2006
Q. macrocarpa	bur oak	low	—	Miyamoto et al. 2004
Q. macrocarpa	bur oak	high-moderate-low	—	Dirr 1976
Q. marilandica	black jack oak	high	—	Dirr 1976
Q. marilandica	black jack oak	moderate	—	Van Arsdel 1980
Q. michauxii	swamp chestnut	low to none	—	Wichman et al. 2006
Q. muhlenbergii	chinquapin oak	low	—	Dirr 1976
Q. myrtifolia	mytrle oak	moderate	—	Wichman et al. 2006
Q. nutalii	Nuttal oak	low to none	—	Wichman et al. 2006
Q. palustris	pin oak	medium-high	—	University of Tennessee Extension 2002
Q. palustris	pin oak	moderate	—	Van Arsdel 1980
Q. palustris	pin oak	low	—	Cornell Coop. Ext. 1999; Dirr 1976; Miyamoto et al. 2004; Swift 1997
Q. robur	English oak	high	—	Cornell Coop. Ext. 1999; Dirr 1976; Ryan 2005; Swift 1997
Q. robur	English oak	moderate	—	Kujawski 2005
Q. robur	English oak	some	—	Bassuk et al. 2009
Q. rubra	northern red oak	high	—	Cornell Coop. Ext. 1999; Swift 1997; University of Tennessee Extension 2002
Q. rubra	northern red oak	some	—	Bassuk et al. 2009
Q. shumardii	Shumard oak	moderate	—	Wichman et al. 2006
Q. shumardii	Shumard oak	low	—	Miyamoto et al. 2004
Q. suber	cork oak	moderate	high	Questa 1987; Wu and Dodge 2005
Q. virginiana	southern live oak	high	—	Black 2006; Meerow and Black 1993; Van Arsdel 1980; Wichman et al. 2006
Q. virginiana	heritage oak	—	—	Jordan et al. 2001
Q. virginiana	southern live oak	high	—	Wu and Dodge 2005

Source: N. Matheny, HortScience, Inc.
Note: *Various rating systems were used to evaluate sensitivity; consult the references at the end of the book for more information.

Symptoms

Salt and specific ion toxicity symptoms have not been well described for oak species. The following are general symptoms for broadleaf woody plants, in order of increasing severity.

Soil salt injury

- Stunting of growth, slow growth.
- Yellowing of foliage.
- Leaf necrosis, particularly along margins and at tips.
- Defoliation.
- Crown dieback (severe cases).

Foliar salt injury

- Yellowing of foliage and reduced leaf size.
- Leaf necrosis, particularly along margins and at tips (see fig. 7.185c).
- Delayed bud break.
- Defoliation.
- Crown dieback (severe cases).
- Note the location of symptoms:
    - for saltwater spray exposure, symptoms are more severe on windward side.
    - for deicing salt exposure, symptoms are more severe on road side.
    - for sprinkler irrigation salt exposure, symptoms are limited to the section of crown wetted by irrigation water.

Specific ion toxicity

- Chloride:
    - leaves smaller than normal and slow growth.
    - necrosis on leaf margins and tips.
- Sodium:
    - foliar mottling and interveinal chlorosis.
    - necrotic leaf tips, margins, and interveinal areas.
- Boron:
    - yellowing of leaf tip.
    - progressive chlorosis and necrosis of leaf margin and between lateral veins. Necrosis is often black and may appear as small spots along the leaf margin.

Causes

Soil salt injury

Plant injury occurs when the soil salt concentration exceeds a critical level for the species. For mature oaks in urban areas, this often results when salts accumulate from irrigation water or fertilizer applications. Recycled water can contain high levels of salts and specific ions as well (see sidebar).

In addition, certain organic amendments such as manures (chicken, cow, horse, etc.) have been found to contain high levels of salt (Hesketh and Hickman 1984) and contribute to injury when applied to the root zone. For young trees, the existing soil salt concentration prior to planting may be sufficiently high to cause injury. Additional inputs from irrigation and fertilizer can further increase the potential for more severe injury.

Foliar salt injury

Deicing salt applications, poor-quality irrigation water, and ocean spray can cause foliar injury on sensitive species. Although sodium and chloride are the principal ions that cause injury from deicing salts (Hofstra and Lumis 1979; Dobson 1991) and sprinkler irrigation (Maas 1985), calcium and magnesium as well as sodium and chloride can contribute to injury from sprinkler irrigation (particularly with recycled water) and saltwater spray. The level of injury varies largely with plant species and salt accumulation levels. In addition to foliar injury, Zimmerman and Jull (2006) reported that deicing salts (sodium and chloride) caused electrolyte leakage and tissue discoloration in dormant buds of deciduous species.

Specific ion toxicity

Sodium, chloride, and boron are the principal elements causing specific ion toxicities. Ammonium can cause injury when high rates of fertilizers containing ammonium are applied. For many species, boron toxicity results when boron concentration in irrigation water exceeds 1.0 mg/L. Other sources include sewage effluent wastes and borate-containing herbicides. Both sodium and chloride can be supplied from irrigation water, deicing salts, and organic amendments (particularly manures). In addition, chloride inputs can occur from chloride-containing fertilizers and sodium from chemically softened water. Factors that can contribute to the severity of specific ion toxicity include soil moisture content, high water table, poor drainage, and irrigation practices.

Remedies

For all three types of injury (soil salt, foliar salt, and specific ion toxicity), a laboratory analysis of soil and water will be needed to determine salt or specific ion concentrations. Total salts, specific ion concentrations (sodium, chloride, and boron), and pH should be measured for soil and irrigation water samples. This will provide baseline data for determining the extent of the problem and developing a strategy for correction. For information on collecting samples and interpreting analyses, refer to Costello et al. (2003).

Soil salt injury

- Determine the source of salts (irrigation water, fertilizer applications, deicing salt applications, saltwater spray, organic amendments, etc.) and restrict further inputs as much as possible.
- For irrigation water with high salt content, use salt-tolerant species and appropriate water management practices. If possible, leach the soil with good-quality water. Correct drainage problems prior to leaching, if needed.
- For cases where high salt levels result from fertilizer applications, discontinue fertilization and leach the soil with

Irrigating Oaks with Recycled Water

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Recycled water, also called effluent or reclaimed water, has been used for municipal purposes, industry, and agriculture. Although treated for reuse, recycled water typically has higher concentrations of salts than potable (drinking) water. Under some conditions the salt concentration may be high enough to damage plants.

Water quality refers to the chemical, biological, and physical characteristics of water. National and state environmental protection agencies dictate minimum water quality standards. The concentration limits for a variety of water constituents are based on what is considered safe for humans and wildlife. Oaks and other plants, however, are more sensitive than humans to normal water components such as salts. Therefore, water that is considered suitable for humans and meets water quality standards may actually damage sensitive oak species.

Irrigation with some recycled, desalinated, and well waters may cause salt toxicity symptoms in sensitive plants. Salt toxicity is first expressed as stunted growth and yellow foliage. Burning of leaf edges and defoliation usually follows. In severe cases, plants are killed. Toxicity symptoms can also occur when water is sprayed directly onto foliage (see fig. 7.185). In fact, most plants have lower tolerance to salts applied to foliage than salts absorbed by the roots.

The degree to which recycled water is likely to damage oaks depends on the following factors.

- **Water quality.** The primary salts of concern are sodium (Na), chloride (Cl), and boron (B). The salt concentration of recycled waters varies depending on the amount of salt in the original water source, what components are added during municipal, industrial, and/or agricultural use, and what treatments are applied to reclaiming the water for reuse. Water agencies must monitor the quality of the water. Contact the agency to request reports.
- **Salt sensitivity of species.** Oaks vary widely in their tolerance to salts (see table 7.1). In general, California native oaks such as coast live oak *(Q. agrifolia)* and valley oak *(Q. lobata)* show good tolerance of recycled water. Oaks native to the high-rainfall areas in the eastern United States, such as laurel oak *(Q. laurifolia)* and pin oak *(Q. palustris)* tend to be less salt tolerant. Unfortunately, specific thresholds have not been established for most oaks.
- **Soil salinity and pH.** Irrigation with recycled water adds salts to the soil over time. The threshold for salt tolerance will be reached sooner if the soil is saline than if the soil is low in salts.
- **Soil texture**. Sandy soils can be irrigated with lower quality water than water used on clay soils. As sodium accumulates in the soil it can cause dispersion of aggregated soils and reduce soil permeability. This restricts the ability to leach salts from the oak's root zone and maintain tolerable salt concentrations.
- **Soil drainage**. Soils that do not drain well accumulate salts and cannot be leached. Examples of soils that may have poor drainage are those with restricting layers in the soil profile, compacted surface, or high water table. The poorer the drainage, the better the quality of the water needed to avoid plant damage.
- **Irrigation method**. Oaks irrigated by sprinklers require better-quality water than oaks irrigated with drip or bubblers. As an example, the only situation in which we have observed salt injury to valley oak and coast live oak irrigated with recycled water was when the foliage was wetted by sprinklers.
- **Irrigation frequency**. Drought stress occurs at a higher soil moisture content as water quality declines because the salts increase the osmotic pressure. When using poor-quality water, irrigation frequency should be increased to maintain a moist soil. As the soil dries, the salts in the soil solution become more concentrated, and plant damage is more likely to occur. The need to maintain moist soil must be balanced with the soil moisture tolerance of the species. California native oaks, for instance, are not adapted to constantly moist soils during the summer.

The potential problems for irrigating oaks with recycled water can be minimized in a variety of ways that involve both design and management.

- Where new recycled water distribution systems are being installed, protect existing oaks from root damage due to trenching, grading, and excavation.
- When introducing recycled water into a landscape, investigate site conditions and perform soil and water analyses so that the potential impacts to the oaks can be evaluated.
- When planning new landscapes, select tolerant species, ensure adequate drainage, and design irrigation systems to accommodate recycled water.
- Monitor soil chemical and moisture characteristics, as well as oak health and appearance. Plan to test the soil in the spring and fall to monitor changes in salt concentration and pH.
- Schedule irrigations to provide adequate leaching to maintain soil salts within a tolerable level. When using recycled water, more water is needed than when applying potable water to avoid salt accumulation in the root zone.
- Adjust fertilization programs to account for nitrogen and phosphorus supplied in recycled water. For most oaks, supplemental fertilization may not be needed.

good-quality water. If further applications of fertilizer are deemed necessary, select low-salt formulations and apply at low rates. Consider the use of slow-release and organic fertilizers.

- For deicing salt injury, use physical barriers to prevent salts from accumulating in the root zone. Leach the soil with good-quality water. Use salt-tolerant species if possible.
- For saltwater spray, select species adapted to the coastal environment, such as island oak.
- For salt injury caused by organic amendments, leach the soil with good-quality water. Discontinue the use of amendments with high salt content, or thoroughly leach salts from the amendment prior to application.

Foliar salt injury

- For injury caused by sprinkler irrigation applications, avoid wetting foliage by redirecting sprinklers away from the tree crown. In some cases, removing sprinklers or capping them may be the best solution. Using sprinklers with low trajectory, decreasing irrigation frequency, and reducing water pressure may be beneficial (Miyamoto and White 2002).
- For injury from deicing salts, wash off foliage, if possible, after a salt application. Since foliar injury is more likely on younger and smaller trees where the crown is close to the ground, consider installing a physical barrier to shield the tree from salt applications. If possible, use less-toxic deicing salts.
- For injury from saltwater spray, wash leaves with good-quality water.

Specific ion toxicity

- Boron: leach with good-quality water. If boron source is irrigation water, consider switching to another water source (such as from well to municipal water). If drainage is poor, correct the cause and then leach. Select tolerant species for locations with high-boron water.
- Chloride: leach with good-quality water. Identify the source of chloride and limit inputs. Correct drainage problems if needed. Manage irrigation water to reduce soil chloride concentrations.
- Sodium: incorporate gypsum (calcium sulfate) and leach with good-quality water. In calcareous soils, use sulfur to reduce sodium content. Identify the source of sodium and limit inputs.

Mineral Deficiencies

As is the case with many other woody plants, mineral deficiencies are not common in California native oaks, whether growing in woodland areas or in urban landscapes (fig. 7.186). This is particularly the case for nitrogen, phosphorus, and potassium (macronutrients), and to a lesser extent for iron, manganese, and zinc (micronutrients). Ostensibly, nutrient cycling and mycorrhizal associations are sufficient to maintain adequate levels of essential elements. Typically, it is when soil pH increases above 7.0 that micronutrient deficiencies occur, particularly for temperate zone species such as pin oak. In some cases, oaks with damaged or diseased root systems will exhibit deficiency symptoms. Considering the infrequent occurrence of macronutrient deficiency in oaks, this section focuses on micronutrient deficiencies. Symptoms, causes, and remedies are addressed for iron, manganese, and zinc deficiency.

Symptoms

Iron

- Interveinal chlorosis on youngest leaves.
- Chlorosis progressing to older leaves in severe cases.
- Leaves small and may develop necrotic margins.
- Leaf drop and shoot dieback in severe cases.

Manganese

- Interveinal chlorosis on youngest leaves. Green bands on veins generally wider than those found for iron deficiency.
- Leaf margins may become waxy, crinkled, or curled.

Zinc

- Leaves are small, narrow, and pointed. Zinc deficiency is also known as "little-leaf" deficiency.
- Leaves may become chlorotic with necrotic spots.
- Internodes are shorter than normal, causing tufts of leaves at the ends of shoots.
- Older leaves may drop.

Causes

Typically, levels of iron, manganese, and zinc are adequate for plant growth in most soils. Most deficiencies are associated with increases in soil pH above 7.0. As the pH rises, these elements become bound in forms that make them unavailable for root absorption. Consequently, uptake is

Figure 7.186. Few cases of nitrogen, phosphorus, or potassium deficiency have been observed by the authors in California native oaks. Iron and manganese deficiencies have been noted, but they are typically found on non-native species. Here, interveinal chlorosis is shown on water oak, ostensibly resulting from iron and/or manganese deficiency. K. Jones

reduced and deficiencies occur in species not adapted to alkaline pH.

In addition to pH changes, deficiencies of these elements can occur when restrictions in soil aeration occur, particularly from flooding, poor drainage, and cold temperatures. Similar to pH-related deficiencies, adequate amounts of these elements usually occur in the soil, but root absorption is diminished due to unfavorable conditions in the root zone.

Remedies

- Check the soil pH. In cases where the pH is above 7.0, reduce it by adding acidifying materials such as sulfur or organic matter. Plant response to this treatment may not occur for some time (weeks or months). Foliar and soil applications of chelated iron, manganese, and zinc can produce a faster response than correcting the soil pH. This effect may be short-lived, however, and repeat applications likely will be needed. Applications of fertilizers containing iron, manganese, and zinc may provide short-term benefit, but the nutrients can become bound in an insoluble form until soil pH declines. For both short- and long-term results, consider applications of chelates in concert with soil pH correction measures.
- Ensure that adequate levels of mulch occur under the tree crown. In addition to helping lower the soil pH, organic mulch contributes to natural nutrient cycling.
- For deficiencies caused by unfavorable soil conditions, identify the limiting soil condition and take measures to correct it. For instance, improve drainage and decrease water inputs for waterlogged soils. For more information, see chapter 4.

Figure 7.187. Although not common on California native oaks, sunburn injury can occur on some oak species. Extensive bark injury noted on the southwest side of this young southern live oak was diagnosed as being caused by sun exposure (A). Note that no damage was found on the northeast side of the tree (B). L. Costello

Figure 7.188. Sunburn canker on the lower trunk of a young coast live oak. Likely, water deficit contributed to this injury. Although the tree survived the injury and drought stress, it will take years to close the wound. B. Hagen

Sunburn Injury

The bark of young oaks is subject to sunburn damage, particularly when water deficits occur. Damage is often most severe on the south or southwest sides of tree trunks and branches, where the heat from direct sunlight is most intense (fig. 7.187). The affected tissue appears discolored, cracked, and somewhat sunken, and with time the bark may slough off (fig. 7.188).

Proper planting and irrigation practices help prevent sunburn injury to newly planted trees. Leaving branches along the lower trunk of young oaks, especially those in a hot, sunny location, helps prevent damage while the tree becomes established and the bark thickens. The foliage on these temporary branches shades the bark and improves trunk taper.

Older trees are subject to sunburn damage following excessive thinning, crown reduction, and crown-raising. Sudden exposure of previously shaded bark can result in extensive bark injury. Removing taller trees that provide shade or adding pavement or buildings that reflect light onto trees can lead to sunburn damage. The injured tissue is often invaded by canker-causing pathogens, sap rot pathogens such as common split gill fungus *(Schizophyllum commune)*, *Stereum* spp., and *Annulohypoxylon thouarsianum*, as well as wood-boring insects such as the pacific flatheaded borer *(Chrysobothris mali)*.

Other Abiotic Disorders

In addition to the disorders described above, a number of other abiotic agents can afflict oaks, such as shading, wind (fig. 7.189), cold temperatures (fig. 7.190), mechanical injury (fig. 7.191), herbicide toxicity, air pollution, hail, gas injury, and lightning. Symptoms and causes for these disorders are similar to those for other woody plants. For detailed information regarding these and other abiotic factors, see *Abiotic Disorders of Landscape Plants: A Diagnostic Guide*, UC ANR Publication 3420 (Costello et al. 2003).

Figure 7.189. Wind can cause dieback of leaves and branches, particularly on young oaks. This temperate-zone oak showed considerable crown thinning and distortion after being planted in a windy location in San Francisco (A). Leaves exhibited marginal necrosis, glazing of the upper surface, and tattering (B). L. Costello

Oak Pest Biology, Ecology, and Management

Oaks and Susceptibility to Insect and Disease Injury

Oak species vary in their susceptibility to pest injury and disease: some are tolerant of pests and pathogens that may cause severe dieback or death in other species. Individuals within a species vary as well: certain trees may be severely injured while others of the same species growing nearby are unaffected. This variability in susceptibility is largely a function of the host (health and inherent factors), the environment, and the pest or pathogen. For pest damage or disease to occur, a destructive pest or an aggressive or virulent pathogen must be present, environmental conditions must favor the agent's development, and the host plant must be susceptible, in a susceptible condition (sufficiently stressed), or in a susceptible stage of development. Plant pathologists refer to these factors as being the three components of the "disease triangle." All three—host, environment, and pest or pathogen—are needed for disease to occur, and the severity of injury is a function of their presence and interactions. This relationship applies to insect pests as well. Understanding the role of these factors in pest damage aids in the development of effective management plans. This section discusses certain elements of each factor that contribute to the resistance or susceptibility of oaks.

Figure 7.190. Cold temperature injury can occur on California native oaks. When temperatures declined below a critical level, the youngest shoots and leaves of interior live oak (A) and Oregon white oak (B) were injured. Fully expanded leaves were not injured on either species. L. Costello

Host Nutritional Suitability and Allelochemicals

The growth and reproduction of leaf- and sap-feeding insects is greatly influenced by the nutritional status of the host. Leaf nitrogen concentration, moisture content, lignin content, cellulose thickening, and sugar content all affect pest abundance and survival (Herms and Mattson 1992). Leaf- and sap-feeding insects typically lay fewer eggs on plants with high carbohydrate reserves, and fewer larvae reach maturity (Herms 1989). Levels of these materials are influenced primarily by environmental factors.

Most damage from leaf-feeding insects is done early in the season when the leaves are young and succulent. Young leaves are more palatable and nutritious than mature leaves

Figure 7.191. Mechanical injury to oaks can occur in many ways. Here, considerable damage to the bark of coast live oak resulted from golf balls striking the trunk. This outcome is not surprising, since the tree is located in the middle of a fairway. L. Costello

because they contain higher concentrations of water, nitrogen (amino acids and proteins), and other essential elements. In addition, leaf tissue becomes less palatable and digestible to chewing insects as concentrations of cellulose, lignin, and tannins increase with age (Herms and Mattson 1997). The leaf cuticle that thickens with maturity is another important deterrent to insect feeding.

Herms (1989) reported that the reproductive success of pests is influenced by the level of natural defensive compounds (allelochemicals) occurring in host tissue. Insect pests on trees with lower concentrations of allelochemicals generally produce more offspring (Herms and Mattson 1997). Except during active growth, developing shoots and leaves normally contain low levels of available nitrogen and high levels of allelochemicals, so they are relatively pest resistant. Moderate to high levels of nitrogen have been found to depress allelochemical levels.

Generally, moderate stress increases resistance to leaf-feeding and sap-feeding pests (Herms and Mattson 1992). Although stress does not increase nutritional content, it generally results in increasing levels of allelochemicals (Larsson 1989) to the point that stress becomes severe. Yet any positive effect of drought stress on host resistance to leaf- and sap-feeding insects may be outweighed by the risk of increased susceptibility to secondary pests. Drought stress and defoliation have been shown to increase susceptibility to bark beetles, borers, as well as canker-causing pathogens and root rots (Herms 2001).

Leaf cuticle thickness, nutritional status, and content of allelochemicals also influence most foliar pathogens. For example, mature foliage is seldom affected by leaf diseases. With the exception of powdery mildews, development of most foliar pathogens coincides with cool, wet springs, which favor disease development by allowing the pathogen to sporulate, germinate, and penetrate host tissue. These conditions also slow shoot elongation and leaf development, extending the period that the leaves are succulent and susceptible to infection.

Tree age and condition

In general, biotic agents have the greatest impact on severely stressed and aging (declining) trees. Many injurious pests are opportunistic, flourishing when a tree's defensive mechanisms are diminished. Mature trees, because of their size, have greater energy (respiratory) demands than younger, smaller trees. Energy demand to maintain living cells increases with increasing size (mass), yet energy production remains relatively constant or begins to decline as trees reach maturity. In other words, net energy production decreases, while energy demand increases. Thus, at some point, energy availability is inadequate to meet all demands. When this happens, tradeoffs occur among growth, energy storage, reproduction, and defense (Bazzaz et al. 1987). Growth (new leaves, shoots, and sapwood) and cellular maintenance take priority over defense (production and maintenance of defensive compounds) when energy is severely restricted. Consequently, as trees age, health and vigor decline, and resistance to serious pests decreases (Loehle 1988). Declining trees are also less resilient to defoliation and other injuries than are younger or more vigorous trees.

Environmental stress is the result of external conditions that limit the ability of trees to acquire essential resources—water, minerals, and sunlight. The most common environmental factors predisposing oaks to secondary pathogens include multiple-year defoliation, water deficits (chronic or acute drought), soil aeration deficits (extended periods of flooding, poor drainage, excess irrigation), fire, and shade. Moreover, many urban oaks have sustained significant root injury and changes to their root zones. When development occurs near mature trees, their short-term survival depends on their ability to tolerate drought stress resulting from root loss until balance between the roots and crown can be reestablished. Their long-term survival, however, depends on the environmental conditions within the root zone and management (cultural) practices that may ensure favorable growing conditions or predispose them to certain biotic agents.

In time, mature trees decline and die. This transition depends largely on the interaction of environmental factors, biotic agents, and structural stability (Clark and Matheny 1991). Oak mortality can result from root or trunk failure (wood decay), environmental degradation (acute or chronic), severe mechanical damage (major root loss), fire damage, energy depletion, predisposition to secondary pests, pathogen invasion, or a combination of these.

Environmental Factors and Insect Pests

Abundance of insects and other invertebrates is greatly influenced by environmental factors. Biotic factors, including natural control agents (e.g., parasites, predators, and pathogenic microorganisms), host availability, nutrition, and resistance, play a critical role in regulating pest populations. Abiotic factors, particularly temperature, are also important because they influence pest development and cause mortality.

The developmental rate of insects and other invertebrates is controlled primarily by temperature. Insects and mites, and the plants they feed on, require a certain amount of heat to develop from one stage of their life cycle to the next. Insect development occurs within a specific temperature range for each species. There is a lower threshold where development begins and an upper threshold beyond which development ceases or mortality occurs. In general, insects and mites develop rapidly when the weather is warm and more slowly when it is cold. Extreme temperatures, however, can be lethal. For example, mortality among second-instar oakworm larvae overwintering on the lower leaf surface of coast live oak is high if the temperature remains low for an extended period (Milstead et al. 1987). Consequently, distribution of oak insects is clearly determined by the range of its host species and temperature extremes within the range.

On the whole, the growth rate of plant-feeding insects is closely correlated with the development of their hosts. This ensures that the host's developmental stage is favorable (for the pest) when the pest reaches a particular stage of its development. In their natural environment, insects are generally well-adapted to the normal prevailing temperature patterns. Unseasonable cold weather, such as early or late frosts, and wide fluctuations in the winter or early spring, however, can result in significant pest mortality. For example, early warm spells followed by freezing temperature can cause high mortality as insects begin to break dormancy and lose their cold tolerance. Extremely high summer temperatures can also harm both the host and its pests.

Other environmental factors such as the physical impact of rain droplets or hail can easily dislodge tiny developing insects such as aphids, scale crawlers, and spider mites. High relative humidity when temperatures are warm can encourage parasitic fungal attack on soft-bodied insects. Wind can desiccate soft-bodied insects, dislodge them from plant foliage, or affect dispersal by blowing them off course, causing significant mortality.

Insect populations fluctuate from year to year and throughout their distribution range. Most pest problems are perennial, and some are sporadic and relatively short-lived, yet a few like the California oak moth are more cyclic. Oak moths *(Phryganidia californica)* characteristically occur at low population densities, and periodically increase to outbreak levels, resulting in severe defoliation to host trees (Furniss and Carolin 1977). In northern California, outbreaks occur about every 8 to 10 years, generally lasting for about 2 years. Typically, during outbreaks, all of the coast live oak trees in an area are completely defoliated in the late spring and early summer by larvae overwintering on the lower leaf surfaces. These larvae are the offspring of the second (summer) generation. Deciduous oaks are defoliated later in the year by the offspring of the first (spring) generation because any overwintering eggs and larvae are shed along with the leaves in the fall. Oakworm outbreaks usually collapse after 2 years when virtually all of the larvae are killed, primarily by a viral pathogen.

Another consideration is that high population density increases competition within the species for food and results in the production of smaller adults with a reduced reproductive capacity. Mass starvation of pests that periodically reach outbreak levels can also occur. Harville (1955) regarded mass starvation to be more important in causing population collapse of oak moth populations than viral infection.

Host nutrition (suitability) is also a factor influencing insect population dynamics. Milstead et al. (1987) concluded that foliage quality (younger vs. older foliage, or new foliage produced by defoliated trees) had profound consequences on the population dynamics of the oakworm.

Environmental Factors and Pathogens

The presence of an infectious agent on a susceptible plant does not necessarily lead to disease. Certain environmental conditions must exist; otherwise, disease will not develop. The incidence and severity of plant diseases are influenced by changes in environmental conditions. For example, Anthracnose infections are highest when rainfall continues into the spring when new leaves are emerging. Late-spring rainfall has also been shown to increase the incidence and spread of sudden oak death *(Phytophthora ramorum)* because it favors spore production and spread of the pathogen. Similarly, Phytophthora root rot infections are favored by high soil moisture level during the active growing season.

Host resistance and nutritional suitability, as well as the activity and development of plant pathogens, are also influenced by environmental conditions. For instance, plants receiving ample irrigation and nitrogen fertilization are usually more susceptible to foliar diseases than plants that have not been irrigated and fertilized, because together these practices promote succulent growth and improved plant nutrition. Higher levels of nitrogen have also been shown to increase susceptibility to root and canker diseases. Severe stress, on the other hand, increases susceptibility to secondary pathogens such as *Armillaria mellea* and those that cause cankers and sap rots. The most common environmental factors predisposing oaks to secondary pathogens include multiple-year defoliation, water deficits (chronic or acute drought), soil aeration deficits (extended periods of flooding, poor drainage, and excess irrigation), fire, and shade.

Disease initiation and development is enhanced or retarded by environment factors, such as temperature, moisture, humidity, soil conditions, light, etc. Most pathogens are able to infect plants and cause disease only when environmental conditions are favorable and when their hosts are susceptible or in a susceptible stage or condition. Plant pathogens, as well as their hosts, require minimal temperatures to grow and function. Most plant diseases develop during the warmer months of the year the development of diseases already initiated is usually retarded by cold weather. Foliar diseases appear to develop best during warm, wet periods, particularly after rain.

Moisture is important for the release of spores from the fruiting bodies of most foliage diseases. Moisture is also critical for spore germination and penetration of the host. Generally a film of water must be present for an extended period for spores to germinate and invade their host. Splashing rain and flowing water influence the distribution and spread of disease. For example, sporangia and zoospores of *P. ramorum*, the pathogen causing sudden oak death, are disseminated by wind-driven rain splash and fog drip. Furthermore, moisture increases succulent growth, increasing susceptibility to foliar pathogens. The spread and severity of Phytophthora root rot is greatest when the soil is near the saturation point. This facilitates the production of sporangia and movement of zoospores. Low soil aeration levels also reduce the capacity of the plant to resist the pathogen. In addition, the development of Armillaria root disease is favored by moist conditions, perhaps due to soil aeration deficits or because the pathogen develops more slowly in dry soil.

Full sunlight effectively reduces germination, growth, and sporulation of most fungal pathogens. Shade and moderate temperatures are known to favor the development of most powdery mildews. Thinning the foliage of plants affected by powdery mildew is often recommended to increase exposure of the foliage to sunlight and air circulation. This, however, may exacerbate the problem in oaks, because it typically stimulates susceptible new growth.

Woodland versus Urban Settings

Oaks in woodland ecosystems are well adapted to local conditions and generally respond to pests differently than do oaks in urban settings. Many native oak pests are capable of feeding and reproducing on healthy oaks, but only a handful cause serious injury or mortality in woodland areas (Swiecki, Bernhardt, and Arnold 1990).

In urban areas, changes in an oak's environment caused by development, such as root zone excavation, pavement over the root zone, soil compaction, landscaping, and excessive irrigation, can cause stress levels ranging from mild to severe. Severe stress increases susceptibility to secondary pests, which can kill or seriously injure oaks. Such pests include bark beetles, borers (flatheaded, roundheaded, clearwing, and carpenterworms), root rots, and canker-causing pathogens.

Pests and Natural Enemies

Pest outbreaks typically occur when natural enemies (insect predators and parasites) are scarce and pathogenic microorganisms are inactive or at low levels. Adverse environmental conditions may suppress populations of natural enemies more than they suppress populations of the pest. When favorable conditions return, pest populations often rebound quickly because their natural enemies usually take longer to recover, giving the pest a short-term advantage.

Occasionally, pest populations become widespread and conspicuous for one or more seasons. The population then declines due to multiple factors such as natural enemies, epizootics (epidemics of pathogenic microorganisms) or environmental constraints, and then remains at a low level for a number of years. An understanding of this natural cycling of pest populations plays an important role in the development of effective pest management plans.

Managing Insect Pests and Diseases

Only a handful of insect pests and diseases can seriously injure or kill oaks. Generally, most pests do not need to be actively managed unless they are creating a nuisance, causing unacceptable damage, contributing to decline, or likely to kill the tree. Environmental conditions or site disturbances that cause stress, leading to the incidence of secondary (stress-triggered) biotic agents such as bark beetles and borers, canker-causing pathogens, and root rots should, however, be managed. Such pests are indicators of soil water and aeration deficits or advancing decline. Management in such cases should involve assessing and mitigating unfavorable soil conditions contributing to the problem. Because chemical means to manage these biotic agents are largely ineffective, the management goal should be to create or restore favorable growing conditions to improve plant health and increase pest resistance.

Consider managing high populations of defoliating insects such as oakworm, fruittree leafroller, and tussock moth that are likely to cause defoliation. This usually involves spraying the foliage of affected trees with a suitable pesticide. Pesticides such as carbaryl, acephate, chlorpyrifos, diazinon, and pyrethroids, which kill both pests and beneficials, should be avoided because they may induce outbreaks of spider mites, aphids, whiteflies, or scale insects. *Bacillus thuringiensis* (Bt), a bacterial pesticide, and Spinosad, a product derived from bacteria, are relatively harmless to beneficial insects, people, and pets, and they are effective against leaf-feeding insects. Proper timing and application rates are important considerations; follow all label instructions when applying these and any other pesticides.

Sap-feeding insects such as aphids and whiteflies can, at times, become a nuisance, warranting treatment. Materials like insecticidal soaps, horticultural oils, and neem oil products should be considered to minimize impact to beneficial insects. Oak pit scale, which can build up to destructive levels on oaks, should be managed whenever damage becomes noticeable. The best management approach is to spray affected trees with a narrow-range insecticidal oil in the spring just before bud break.

In general, management of leaf diseases is difficult and largely unwarranted. Powdery mildew problems on coast live oak can be minimized by avoiding cultural practices that stimulate shoot growth in the late spring and early summer, such as fertilization and irrigation, and late-spring and summer pruning. Wood decay pathogens have no cure or treatment, so the most effective approach is prevention—using proper pruning techniques and avoiding unnecessary wounding, removal of large branches, and cutting roots near the trunk. Another effective tactic involves minimizing stress through mulching and judicious irrigation to promote defensive responses (allelochemical production and compartmentalization).

Natural control agents generally keep indigenous pest populations relatively low or limit infection and pathogen development for certain disease-causing agents. Pathogens that colonize wounds, foliage, and the roots are subject to antibiosis, the production of substances by microorganisms that inhibit the growth and development of other organisms, and to competitive pressure from other microorganisms.

Native oaks have also developed resistance mechanisms that generally minimize damage or susceptibility to native insect pests and disease-causing pathogens. Serious damage, however, can occur when a new pest or pathogen is accidentally introduced, because natural control agents or host resistance mechanisms are lacking. Examples of serious non-native pests include the oak pit scale (*Asterolecanium* spp.) goldenspotted oak borer (*Agrilus coxalis*) and *Phytophthora ramorum* (the pathogen that causes sudden oak death), *Phytophthora cinnamomi* and other *Phytophthora* species.

Because many diseases, such as sudden oak death, cannot be cured once the plant is infected, control strategies, whether cultural, chemical, or biological, generally focus on excluding, eradicating, inhibiting spore germination and penetration by the pathogen or increasing the ability of the plant to resist infection. The use of phosphonate for the control of *Phytophthora ramorum* is purportedly to increase the host's defensive responses.

Integrated Pest Management

Integrated pest management (IPM) is a comprehensive and effective strategy for managing insect pests and disease-causing pathogens. It is a decision-making process that anticipates problems and prevents or minimizes damage by combining a number of different strategies to achieve long-term solutions to pest problems. The most effective, long-term, and least toxic methods are emphasized. The following controls can be used.

- Biological: Encouraging natural control agents, reducing vegetative competition when planting seedlings or acorns; protecting seedlings from grazing or herbivory.
- Cultural: Proper planting techniques, mulching, judicious irrigation and pruning, use of resistant species, careful species selection and appropriate seed source.
- Mechanical: Eradicative pruning.
- Physical: Mitigating unfavorable environmental conditions, such as by loosening compacted soil, exposing the root collar and large lateral roots affected by oak root disease to drying, improving soil structure, providing drainage, removing fill soil, and mulching to moderate soil temperature.
- Chemical: Applying conventional pesticides as well as oils, soaps, growth regulators, and biologicals, including competitive and antagonistic microorganisms for disease pathogens.

The objective of IPM is to maintain pest populations or disease damage below an unacceptable injury level. IPM relies on

- regular monitoring to determine when pest populations or damage threaten to cause unacceptable injury
- early detection of symptoms
- identifying the pest(s) involved and/or environmental factors that may be contributing to the problem
- understanding pest biology
- modifying horticultural practices to promote plant health
- avoiding site disturbance and managing for environmental stability
- selecting and applying chemicals in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment
- proper timing and rate of chemical applications when required