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A Field Guide to Insects and Diseases of California Oaks

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Contents

Insects and Mites

Acorn feeders

General foliar feeders

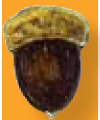
Gall formers

Sap feeders

Twig borers

Bark and wood boring insects

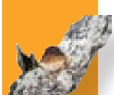
Diseases



Acorn diseases

Diseases affecting leaves and twigs

Branch diseases



Diseases affecting branches and trunks

Root diseases

Introduction

California has more than twenty-five native species, natural hybrids, and varieties of oaks (*Quercus* species). The form of these oaks ranges from large trees, up to about 25 m tall, to shrubs no taller than about 1.5 m. California's native oaks include representatives of three oak subgroups or subgenera (*Table 1*). Hybridization only occurs between oaks in the same subgroup. In addition, some insects, pathogens, and other agents may selectively colonize or damage oaks in certain subgroups.

Table 1—*Scientific and common names of California native oaks by subgroup.*

Subgroup (subgenus)	Species	Common name	Common form[1]
White oaks	*Q. douglasii*	blue oak	tree
(*Quercus* or	*Q. engelmannii*	Engelmann oak	tree
Lepidobalanus)	*Q. garryana*	Oregon white oak	tree
	Q. lobata	valley oak	tree
	Q. berberidifolia	scrub oak	shrub
	Q. cornelius-mulleri	Muller oak	shrub
	Q. dumosa	Nuttall's scrub oak	shrub
	Q. durata	leather oak	shrub
	Q. john-tuckeri	Tucker's oak	shrub
	Q. sadleriana	deer oak	shrub
	Q. turbinella	desert scrub oak	shrub
Red/black oaks	*Q. agrifolia*	coast live oak	tree
(*Lobatae* or	*Q. kelloggii*	California black oak	tree
Erythrobalanus)	*Q. parvula* var. *shrevei*	Shreve oak	tree
	Q. wislizeni[2]	interior live oak	tree
Intermediate oaks	*Q. chrysolepis*	canyon live oak	tree
(*Protobalanus*)	*Q. tomentella*	island oak	tree
	Q. vacciniifolia	huckleberry oak	shrub

[1] ***Some of the species have both tree and shrub forms.***
[2] ***This species was formerly spelled*** *Q. wislizenii.*

As of the early 1990's, oak woodlands and forest types dominated by oak trees covered about 3.6 million hectares in California, or roughly 8.9 percent of the state's land area (Waddell and Barrett 2005). Oak savanna (grasslands with less than 10 percent tree cover) was estimated to occur on an additional 0.73 million hectares (Bolsinger 1988). California native oaks also occur as components in riparian and desert plant communities, chaparral, and conifer-dominated forest ecosystems (*fig. 1*).

Figure 1. Approximate composite range of all native oak species in California.

Remnant native oaks have also become incorporated into developed areas within many California communities. The importance of oaks in the California landscape is reflected in the large number of California cities, localities, and geographic features that include references to oaks in either English or

Spanish (encina, roble). In many urbanized landscapes, as in wildlands throughout much of California, individual oaks and oak woodlands are critical elements of the ecosystem.

Oak woodlands provide extremely important wildlife habitat and have higher levels of biodiversity than virtually any other terrestrial ecosystem in California. At least 300 terrestrial vertebrate species (Guisti and others 1996), 1,100 native vascular plant species (CalFlora 1998), 370 fungal species, and an estimated 5,000 arthropod species (Swiecki and others 1997) are associated with California oak woodlands.

This publication focuses on the relatively small number of microorganisms (primarily fungi) and arthropods (primarily insects) that are capable of causing noticeable damage to oaks in California. We have included agents that cause serious damage to oaks, as well as some common agents that produce conspicuous impacts even if they are not especially detrimental to oak health. Conspicuous but relatively inconsequential agents, such as cynipid gall wasps, often attract more attention than more cryptic agents that can severely impact oak health and structural integrity, such as canker rot fungi. However, some agents that have little or no impact on oak health may still create a nuisance in urban settings as the result of materials that are shed (e.g., sap) or because they adversely affect the appearance of oaks in the landscape.

Sudden oak death, caused by the pathogen *Phytophthora ramorum*, has emerged as a major disease of several California oaks. This new disease, which was first recognized as a problem in 1995, has highlighted the need for information about agents that damage oaks in California. This publication is primarily intended to help arborists, land managers, pest management specialists, and other professionals identify and assess the likely impacts of common agents that attack oaks in California. While we have incorporated enough technical information to make this document useful for professionals, property owners and other members of the general public can also use this publication to better understand common oak diseases and pests. A much more comprehensive compilation of agents that feed on, colonize, and/or damage oaks can be found in the California Oak Disease and Arthropod (CODA) database (currently available at http://Phytosphere.com/coda).

Due to a lack of detailed range data for most agents on California oaks, the included range maps are approximate. For most agents, range maps are based on multicounty regions (*fig. 2*). On the range maps for individual agents in the following pages, the agent's documented range is shown in maroon. The likely but unconfirmed range, based on both the likely distribution of the agents and the range of the known oak hosts, is shown in gold. More detailed range data was available for a few agents, and for these species, we have generally used specific county boundaries to show the reported range. Agents may also occur beyond the illustrated ranges and are not necessarily found in all portions of the illustrated ranges.

Figure 2. Multicounty regions used in agent range maps.

Information on agent biology, host range, and importance provided in this publication will be helpful for determining whether management actions are likely to be necessary or practical. However, this publication does not provide specific recommendations for the management of the described pests and diseases. Readers interested in current management recommendations should consult the University of California Integrated Pest Management website (http://www.ipm.ucdavis.edu/), their local University of California Cooperation Extension office, or their local County Agricultural Commissioner's Office.

Filbert weevils

Curculio aurivestis, C. occidentis,
C. pardus (Curculionidae)

Distribution/Hosts

Curculio aurivestis occurs from Victoria, British Columbia, to southern California. It is reported on canyon live, Oregon white, and other oaks. *C. occidentis* is widely distributed throughout the western U.S. and California. It is reported on a wide variety of oaks as well as tanoak and California hazelnut. *C. pardus* occurs from Washington to Los Angeles County, California. It is reported on coast live, interior live, canyon live, blue, valley, and other oak species.

Symptoms

Pinhead-sized oviposition wounds on acorns are commonly surrounded by a discolored and/or raised area and may exude small amounts of sap. Round, open holes (about 1–2 mm diameter) are left in the acorn seed coat when larvae exit. When infested acorns are cut open, dark brown granular frass caused by larvae tunneling throughout the interior of the acorn is visible. One or more (up to at least eight) filbert weevil larvae may be found in a single acorn. Filbert weevil and filbertworm larvae may occur in the same acorn (*fig. 3*).

Agent Description

Larvae are white to cream-colored and about 6–8 mm long; the head is small and brown. They are legless, plump, and relatively sluggish, and assume a curved C-shape when removed from an acorn (*fig. 4*).

Figure 3. This valley oak acorn contained five filbert weevil larvae and one filbertworm larva (second from left). The exit hole (right) indicates that at least one additional larva has already exited the acorn.

Adult weevils are about 5.5–6.5 mm long, yellowish-brown, and have long slender snouts (*fig. 5*).

Biology

Adult weevils emerge from pupae in debris or soil beneath trees in summer. Oviposition occurs in summer and fall. The female weevil chews a small hole in the shell of a developing acorn and lays eggs in these holes. Larvae tunnel throughout the acorn. Heavily damaged acorns drop early, beginning in August or earlier. Larval feeding and development continues after the acorns have fallen. When the larva matures in the fall and winter, it bores an exit hole through the acorn seed coat and enters the ground, where it spends the winter. Larvae pupate in spring or summer. Only one generation occurs per year.

Importance

Severely damaged acorns are unable to sprout. Acorns without damage near the embryo axis at the pointed end of the acorn may still germinate, but seedling survivability may be reduced. Infestation levels can vary substantially with locality, year, oak species, and between individual trees at a particular locality. Infestation levels among acorns from a single tree can range up to at least 75 percent.

Figure 4. Filbert weevil larvae and associated damage to a blue oak acorn.

Figure 5. Adult filbert weevil.

Filbertworm

Cydia latiferreana (Tortricidae)

Distribution/Hosts

Filbertworm is widely distributed throughout the U.S. and California. It attacks the acorns of most oak species as well as hazelnuts or filberts.

Symptoms

Larvae tunnel throughout the interior of acorns (*fig. 6*), leaving brown granular frass and sometimes silken webbing. Round open holes (about 1–2 mm diameter) are left in acorn seed coats when larvae exit.

Agent Description

Larvae are beige to light gray, about 18–20 mm long at maturity, with three pairs of true legs; the head is dark brown. Usually only a single filbertworm larva colonizes an infested acorn, but filbert weevil larvae may occur in the same acorn (*fig. 3*). Compared to the slow-moving larvae of the filbert weevil, filbertworm larvae are typically active when removed from an acorn and may drop down on a strand of silk when disturbed. Adults are small, stout-bodied moths with wingspans of 12–15 mm (*fig. 7*). They have rust-brown forewings with several irregular dark or metallic bands and dark hindwings.

Figure 6. Filbertworm larva & damage to valley oak acorn.

Biology

Moths emerge from pupal cases in litter beneath trees in late spring and early summer, up to about two months before oviposition occurs. Female moths lay eggs throughout the summer on acorns that are still attached to the tree. Eggs are laid singly on the acorn surface. Larvae bore into acorns and feed internally. Heavily damaged acorns drop early, beginning in August or earlier. Insect development continues after the acorns have fallen. When the larva matures, in the fall or winter, it bores an exit hole through the acorn seed coat and pupates in plant debris on the ground. There is typically one generation per year, but two generations may be possible in some areas.

Importance

Heavily damaged acorns are unable to sprout. Acorns without damage near the embryo axis at the pointed end of the acorn may still germinate, but survivability may be reduced. Infestation levels can vary substantially with locality, year, oak species, and between individual trees at a particular locality. Infestation levels among acorns from a single tree can range up to at least 80 percent.

Figure 7. Filbertworm adult and pupal case.

Photo: Don Owen, CDF.

California oakworm, California oakmoth

Phryganidia californica (Dioptidae)

Distribution/Hosts

The California oakworm is generally found in coastal areas from Del Norte to San Diego County, and inland to near Riverside in the south and Davis in the north. It occurs on most oak species present within its range, as well as on tanoak.

Symptoms

Young larvae feed between veins on the lower leaf surface. Although the upper leaf surface is left intact, it dries out and turns brown. Larvae in later instars chew completely through the leaf blade, often leaving only major leaf veins. Small frass pellets drop from the canopy as larvae feed. In outbreak years, individual trees or groups of trees may be almost entirely defoliated, typically by late summer or early fall.

Agent Description

Eggs are round and clustered in groups of 20 or more. Eggs are initially white, but develop red centers that become pinkish to brownish before hatching occurs. Larvae (*fig. 8*) are black with lengthwise yellow stripes, and are about 3 cm long at maturity; the head is large, globose, and brown. Pupae are white or yellow with black markings. Adults are tan to gray moths with

Figure 8. California oakworm larva feeding on coast live oak leaf.

prominent wing veins. Moths are about 15 mm long with wingspans of about 25 mm (*fig. 9*).

Biology

Young larvae overwinter on the lower leaf surfaces of evergreen oaks. In northern California, overwintering larvae mature in May to June. First generation adults are present in June and July and lay eggs for the second generation of larvae. The second larval generation defoliates trees from July through September. Second generation adults are present in October and November and lay eggs that give rise to overwintering larvae. Evergreen or live oaks are attacked by both spring (first) and summer (second) generations; deciduous oaks normally avoid attack by the spring (first) generation. Development is more variable in southern California where three generations can occur per year and moths may be present at various times between March and November. Oakworm population levels cycle over a period of years, so that numbers may range from very high to nearly absent in any given year.

Importance

Within its range, this is probably the most serious defoliator of oaks in California. When defoliation is severe, tree appearance is degraded and frass production may be a nuisance. In years with high oakworm populations, all trees in affected areas may be infested. However, defoliation seldom, if ever, kills affected trees.

Figure 9. California oakworm adult moth.

Photo: Bruce Hagen, CDF.

Fruit tree leafroller

Archips argyrospila (Torticidae)

Distribution/Hosts

Fruit tree leafroller is found throughout the U.S. In California, it is found from Siskiyou County southward to San Diego County and occurs on almost all oak species as well as pome fruits, shade, and ornamental plants. The obliquebanded leafroller (*Choristoneura rosaceana*), which has similar larvae, has been reported on coast live oak in California. It occurs on many hosts throughout the U.S. Other larvae that cause similar damage on oaks in California include the European leafroller (*A. rosana*), the oak leaftier (*Croesia semipurpurana*), the stenomid oak leaftier (*Setiostoma fernaldella*), and the phycitid oak leaftier (*Trachycera caliginella*).

Symptoms

Larvae feed only in the spring on new leaves. Feeding occurs in young leaves that are rolled and tied with silk. Larvae chew through the entire leaf blade. Damaged leaves become distorted and ragged in appearance as the uneaten portions of the leaf continue to grow (*fig. 10*). During a heavy infestation, most or all trees in a local area may be severely defoliated. In most instances, trees outgrow the damage by producing new leaves.

Figure 10. Damage to newly expanding valley oak leaves from feeding of fruit tree leafroller larvae.

Agent Description

Eggs are cemented together into flat, grayish to whitish masses that become riddled with small holes when larvae emerge. Larvae are green and 1.5–2.5 cm long at maturity; the head is shiny and black (*fig. 11*). Larvae have a dark band behind the head on the prothorax; this band may be absent in the last larval instar. If disturbed, larvae wriggle actively and may drop from the leaf on a strand of silk. Obliquebanded leafroller larvae resemble late-instar larvae of the fruit tree leafroller, but do not react vigorously when disturbed. Adult fruit tree leafroller moths are bullet-shaped when viewed from above with variegated dark brown or yellowish tan wings; the wingspan is 20–25 mm.

Figure 11. Fruit tree leafroller caterpillar hanging from silken thread.

Biology

The insect overwinters as masses of eggs on twigs and branches. Eggs hatch in the spring, usually at the same time that new leaves emerge. Larvae construct nests by rolling or tying young leaves together and feed within the nests. At maturity they pupate inside the nests or on bark in thin brown cocoons. Adult moths emerge eight to 12 days after pupation. After adult moths mate, females lay the overwintering egg masses. There is one generation per year.

Importance

This is a common, well-known, and important insect pest of oaks. A severe multiyear outbreak affecting California black oaks in the San Bernardino Mountains of southern California was reported in 1999–2003. Before this, the last serious outbreak in southern California was in 1951–1953. In some trees, repeated defoliation combined with drought and high levels of leafy mistletoe infection has reportedly increased overall mortality rates.

Oak ribbed casemaker

Bucculatrix albertiella (Lyonetiidae)

Distribution/Hosts

The oak ribbed casemaker occurs throughout California. It is reported on coast live, interior live, valley, and California black oak, but probably occurs on other oak species as well.

Symptoms

Young larvae feed within the leaf, creating a linear leaf mine. Older larvae cause necrotic windowing: they feed on the undersides of the oak leaves, sparing the upper epidermis and veins, which become brown and somewhat translucent. Small, flat circles of webbing (molting shelters) and small, white, narrow-cylindrical cocoons with longitudinal ribs may be present on the undersides of affected leaves (*fig. 12*).

Agent Description

Mature larvae are yellowish to olive green with rows of pale spots and are about 6 mm long. Adult moths are mottled white, brown, and black, with a wingspan of 8–9 mm.

Figure 12. Oak ribbed casemaker cocoons and feeding on coast live oak. Note the round first-instar larval molting shelter to the left near the midrib.

Photo: Bruce Hagen, CDF.

Biology

The oak ribbed casemaker overwinters as pupae inside cocoons. Adult moths emerge in early spring, mate, and lay eggs on oak leaves. Eggs hatch and the young larvae mine inside the leaf. After the first molt, larvae feed on the lower epidermis and interior tissues of leaves. Larval instars molt within flat, rounded shelters. Mature third-instar larvae spin the characteristic white ribbed cocoon. Adults emerge from cocoons, mate and lay eggs that hatch into the second (summer) generation. Larvae of the summer generation form overwintering pupae. There are two generations per year.

Importance

The oak ribbed casemaker is one of the more common insects affecting oaks and may cause serious leaf damage over large geographic areas in some years.

Tent caterpillars

Western tent caterpillar -
Malacosoma californicum
Pacific tent caterpillar - *M. constictum*
Forest tent caterpillar - *M. disstria*
(Lasiocampidae)

Distribution/Hosts

The western tent caterpillar occurs west of the Rocky Mountains and in New York. Four subspecies (*Malacosoma californicum* ssp. *ambisimilis*, *californicum*, *fragile*, and *recenseo*) with distinct geographic ranges are reported in California. The species is reported on oak, willow, poplar, birch, alder, madrone, ceanothus, redbud, hazel, ash, toyon, apple, almond, apricot, cherry, prune, plum, coffeeberry, currant, antelope bitterbrush, and apple.

The Pacific tent caterpillar occurs in California, Oregon, and Washington and is reported only on oaks. In California, subspecies *M. constrictum austrinum* is found from Santa Barbara County southward; *M. constrictum constrictum* occurs from Los Angeles County northward.

The forest tent caterpillar is widespread throughout the entire U.S. Its host plants include oak, poplar, birch, alder, willow, cherry, peach, plum, prune, pear, apple, quince, hawthorn, and rose.

Figure 13. Tent (left) and larva (right) of the western tent caterpillar on coast live oak.

Symptoms

Larvae feed on leaves, often defoliating affected branches. Western tent caterpillar larvae spin large tents of silk (*fig. 13*) and the larvae do most of their feeding in the tents. Pacific tent caterpillars spin more rudimentary tents that can be up to 10 cm wide (*fig. 14*). The larvae feed in groups outside the tent, entering it only to molt. Sometimes tents are absent in local populations of both the Pacific and the western tent caterpillar.

Figure 14. Pacific tent caterpillar tent on blue oak.
Photo: Don Owen, CDF.

Forest tent caterpillars do not construct tents; they construct silken mats on branches or the trunk where the larvae congregate when at rest or during molting.

Agent Description

Tent caterpillar larvae are fairly large, 40–50 mm in length at maturity. Adult moths have stout bodies and are tan to brownish, with two oblique lines on each forewing (*fig. 15*).

Western tent caterpillar larvae are blackish, with light blue speckles on the sides, and are covered with orange hairs (*fig. 13*). Egg masses are pale gray to dark brown.

Pacific tent caterpillar larvae are blackish, with light blue speckles on the sides, orange hairs on top and grayish or cream colored hairs on the sides (*fig. 16*). The head is dark blue. Egg masses are golden yellow (*fig. 17*).

Forest tent caterpillar larvae are mostly dark blue, with wavy reddish brown lines and white, keyhole-shaped spots on their backs (*fig. 18*). Egg masses are dark brown.

Figure 15. Pinned specimen of the Pacific tent caterpillar female moth.

Photo: Don, Owen, CDF.

Figure 16. Pacific tent caterpillar larva on blue oak.

Photo: Don Owen, CDF; www.forestryimages.org.

Figure 17. Pacific tent caterpillar egg mass cut away to show individual eggs.

Photo: Don Owen, CDF.

Figure 18. Forest tent caterpillar larvae.

Photo: Robert S. Kelley, Vermont Department of Forests, Parks and Recreation; www.forestryimages.org.

Biology

Overwintering eggs are laid during the summer in masses that encircle twigs. Eggs are coated with a varnish-like substance called spumaline. The young larvae are active from early to late spring. Young larvae congregate and spin communal tents. Mature larvae may spin cocoons (*fig. 19*) in folded leaves, or under bark or litter. Adult moths emerge in mid-summer, mate, and lay eggs. There is one generation a year.

Importance

Other than obvious aesthetic impacts, tent caterpillars typically do not cause major damage on California oaks. When present in high numbers, caterpillars may be a nuisance.

Figure 19. Pacific tent caterpillar cocoons.

Photo: Don Owen, CDF.

Western tussock moth

Orgyia vetusta (Lymantriidae)

Distribution/Hosts

Western tussock moth occurs from southern California to British Columbia. It is reported on virtually all California oak species as well as various fruit and nut trees, ceanothus, hawthorn, manzanita, pyracantha, toyon, walnut, and willow.

Symptoms

Larvae feed on leaves, especially young growth, sometimes causing substantial defoliation. Masses of cocoons may be present on branches in late spring.

Agent Description

Eggs are white, nearly spherical, 1.2 mm in diameter, and depressed on top. Egg masses may contain over 100 eggs. Egg masses are gray and felt-like, and include hairs and scales from the adult female's body. Mature larvae are 13–22 mm long, hairy, and have red spots on their sides and four prominent white tufts of hair (tussocks) on their backs (*fig. 20*). The adult male moth is about 2.5 cm across when at rest. Its wings are brown and have two evenly spaced irregular dark

Figure 20. Western tussock moth larva on blue oak.

brown lines which run perpendicular to the body. The female is covered with wavy light gray hair, has greatly reduced wings, and cannot fly.

Biology

Western tussock moth overwinters as eggs laid in masses on twigs, on bark of larger stems, or on old cocoons. Eggs hatch from March through early June. Larvae are present for six to eight weeks. Mature larvae spin loosely woven grayish-white cocoons that may contain larval hairs (*fig. 21*). Pupae mature in two to three weeks. Adult moths are active from May to July. There is usually one generation a year, but two generations can occur in southern California. Where the second generation occurs, larvae are present late August through October, and adults lay overwintering eggs in September and October.

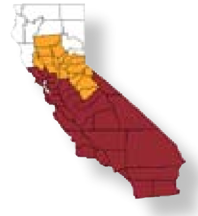
Importance

Oaks may occasionally be seriously defoliated. Damage on other hosts can sometimes cause branch dieback. Hairs from western tussock moth larvae can be very irritating to humans. Frass may be a nuisance when larval populations are high.

Figure 21. Western tussock moth cocoons on coast live oak.

Erineum mite

Eriophyes mackiei (Eriophyidae)



Distribution/Hosts

Eriophyes mackiei is distributed through much of California. It is reported on evergreen oaks in the red/black oak subgroup (coast live and interior live oak) and intermediate oak subgroup (canyon live and huckleberry oak).

Symptoms

The mites cause blisterlike swellings, 1–12 mm long, that protrude from the upper leaf surface (*fig. 22*). On the lower leaf surface, the blisters appear as depressions filled with mats of rusty brown hairs (erinea). The blisters are initially green but later become brown. Leaves may become distorted if large populations of mites are present.

Agent Description

Mites are 0.2 mm long and difficult to see without magnification. They are whitish or yellowish, slender and wormlike, and have two pairs of legs.

Figure 22. Symptoms of erineum mite on coast live oak.

Biology

Erineum mites overwinter in leaf blisters or in leaf buds. They establish new colonies on the underside of spring foliage. The mites induce the host leaf to produce the characteristic erinea in the blisterlike depressions that form on the underside of leaves. Mites feed and reproduce within the blisters.

Importance

The damage caused by erineum mites is generally limited and of little or no consequence to affected trees.

Gall wasps

Over 100 species in about 20 genera including *Andricus* spp., *Antron* spp., *Callirhytis* spp., *Disholcaspis* spp., *Dros* spp., *Neuroterus* spp. (Cynipidae)

Distribution/Hosts

Many gall wasp species are found throughout the range of their hosts, whereas others are more limited in distribution. Virtually all native California oak species are hosts to one or more gall wasp species. Most gall wasp species can colonize several to many oak species within a given subgroup such as the white oaks, red/black oaks, or intermediate oaks. *Andricus californicus*, the California gallfly, produces galls known as oak apples on at least eight species in the white oak subgroup (*fig. 23*). Others, such as *Andricus chrysobalani*, which causes galls on canyon live oak acorns, are reported only from a single host species.

Symptoms

Galls may be produced on catkins, acorns, leaves, petioles, or twigs (*fig. 24–27*). They appear as simple swellings, amorphous growths, or unique, highly organized structures, often with strange shapes and bright coloration. Galls may be detachable (distinct structures that are readily removable from underlying tissues) or integral (swellings or distortions of the plant part itself that cannot be removed without cutting or breaking the affected part). Galls range from 1 mm to more than 50 mm across. Some galls are

Figure 23. Oak apple galls on valley oak produced by *Andricus californicus*.

associated with localized chlorosis or necrosis of underlying host tissue. Galls affecting branches or major leaf veins may interfere with water and food transport within the branch or leaf, causing tissues beyond the gall to decline or die.

Agent Description

Adults are small wasps, typically no more than about 4 mm long (*fig. 28*). Larvae are small, whitish, and legless and develop completely inside larval chambers that form within the galls. Depending on the wasp species, each gall may have either one (monothalamous galls) or many (polythalamous galls) larval chambers.

Biology

Gall wasp larvae can apparently only induce galls in undifferentiated meristematic or cambial cells, so female wasps must lay eggs in specific host tissues (buds, leaves, etc.) when the tissues are at the correct growth stage. Developing larvae produce substances that induce the plant to form a larval chamber of a structure that is unique to the wasp species and generation. The gall wasp larvae typically remain small while they induce the gall to grow rapidly. As the gall nears its mature size, larvae feed on nutritive tissue produced in the center of the gall and begin to grow rapidly. As the larvae mature, they induce lignification of the gall. In detachable galls, lignification may induce the gall to fall off the plant.

Figure 24. *Andricus crystallinus* galls on blue oak leaves.

Larvae pupate within the gall and adult wasps emerge from the galls to initiate the next generation.

Many oak gall wasp species have two alternating generations; a sexual generation with females and males followed by an asexual generation with only females, which can lay fertile eggs without mating. Each of these generations produces a unique gall, often on different parts of an oak. Galls produced by the sexual generation are usually found during winter

Figure 25. *Andricus fullawayi* galls on leaves of valley oak.

Figure 26. Stem galls produced by *Andricus chrysolepidicola* on blue oak.

on permanent parts of the tree, such as twigs. The asexual generation typically is produced during spring and summer, and galls are often on leaves and catkins. Some oak gall wasps are known to produce only a single generation, which is typically asexual.

Importance

Most wasp galls, especially foliar galls, cause little or no lasting damage to oaks. However, a few galls cause limited leaf or twig dieback by blocking the vascular tissue.

Figure 27. *Disholcaspis plumbella* gall on scrub oak.

Figure 28. Adult gall wasps.

Photo: Don Owen, CDF.

Kuwana oak scale

Kuwania quercus (Margarodidae)

Distribution/Hosts

In California, *Kuwania quercus* has been found in Amador, Napa, San Joaquin, San Mateo, Santa Clara, Solano, Sonoma, and Yolo Counties, but may be more widespread. It has been observed on blue oak and unidentified live oaks (probably coast live and/or interior live oak) and in an American chestnut orchard. It was originally described on oaks in Japan, but also occurs on oaks in China and Formosa. Gill (1993) indicates that California specimens may actually be a different species from the Asian species.

Symptoms

In blue oak, infestations are associated with obvious roughening and exfoliation of bark (*fig. 29*). The ground close to the trunk of infected trees may be covered with pieces of bark that have flaked off the tree. Hard grayish or whitish waxen capsules that surround the pre-adult females can be seen under loose bark in spring.

Figure 29. Exfoliating bark of blue oak infested with Kuwana oak scale.

Agent Description

Bright red ovate-shaped adults are about 1.75–2.25 mm long. Adult females produce a dorsal mass of white, waxy threads. They are secretive and often hide under rough, loosened bark. The pre-adult female is bright red, legless and covered with a hard grayish or whitish waxy capsule. Only waxy residue may be visible on the bark of affected trees through much of the summer and fall (*fig. 30, 31*).

Figure 30. Reddish Kuwana oak scale females and associated waxy filaments under blue oak bark.

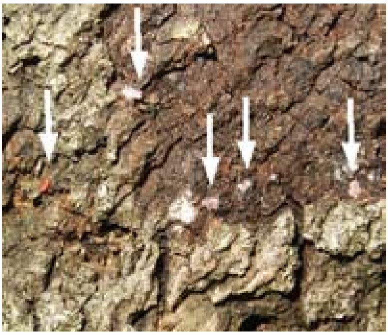


Figure 31. Reddish Kuwana oak scale females and associated waxy filaments (arrows).

Biology

The life cycle of this insect in California is unknown. In Solano County, pre-adult females have been observed in mid-March; mature females laid eggs by mid- to late April.

Importance

Infestations tend to be highly localized in distribution. Other than obvious visual impacts due to bark flaking, long-term impacts on tree health are unknown.

Oak leaf phylloxera

Phylloxera spp. (Phylloxeridae)

Distribution/Hosts

One or more *Phylloxera* spp. are found through much of California west of the Sierra Nevada, as well as in the southeastern U.S. and the Pacific Northwest to British Columbia. Oaks in the white oak subgroup are attacked, including valley, Oregon white, Engelmann, and blue oak.

Symptoms

Small (about 1 mm diameter) yellow and brown spots are visible on the upper and lower surfaces of affected leaves (*fig. 32)*; spots are most noticeable in mid summer to early fall. Spots form where the small, yellow to brownish, wingless insects feed. Spots may be located primarily along veins or spread over the entire leaf surface. Different species may have different distribution patterns on leaves. If population levels are high enough, part or all of an affected leaf may turn brown and die (*fig. 33*). Symptoms are commonly most severe on oak seedlings and saplings.

Agent Description

Eggs are oval, about 0.3 mm long. Nymphs and adults are oval, with fine ridges and short spine-like projections (tubercles), and very short legs (*fig. 34*). The taxonomic status of some species reported in California is not completely resolved. At least five species are described on oaks in California. *P. davidsoni* wingless adults (apterae) are light orange to

Figure 32. Oak leaf phylloxera symptoms on valley oak; this unidentified species tends to congregate along veins.

Figure 33. Damage associated with high oak leaf phylloxera populations, here on valley oak, may include leaf scorch (right). Lady beetles (note adult at left and pupal case at right) prey upon phylloxera.

yellowish-brown and about 0.7 mm long. Winged adults (alatae) are orange with a black thorax. Immatures are pale yellow. *P. querceti* apterae are yellow to orange and 0.6–1 mm long. *P. reticulata* apterae are bright orange-yellow, about 0.8 mm long, and have reddish eyes. *P. rileyi* apterae are dark brown with almost black dorsal tubercles and are about 0.6 mm long. Paler forms also occur. *P. stanfordiana* apterae are pale yellow and about 0.75 mm long.

Biology

Life cycles of these species have not been studied in California. Data from other locations indicate that overwintering occurs as eggs or first-instar nymphs in sheltered locations on the branches. Multiple generations occur over the spring and summer, some of which involve asexual reproduction. Winged adults develop in at least some species. Populations build up over the summer and are highest in September and October.

Importance

The species of oak leaf phylloxera known from California are apparently of minor importance, although damage to seedlings may be significant in some situations. The oak leaf phylloxera (*P. glabra*) is reported to be a severe pest of Oregon white oak in British Columbia, causing significant scorching and defoliation of mature trees. *P. glabra* has not been reported in California to date.

Figure 34. Close-up of several phylloxera nymphs on the underside of a valley oak leaf.

Oak lecanium scale

Parthenolecanium quercifex (Coccidae)

Distribution/Hosts

Oak lecanium scale is found on oaks in many parts of the eastern U.S. In California, it is reported on coast live and valley oak from the Sacramento Valley and the San Francisco Bay Area to southern California. Other reported hosts include other oak species, sycamore, pecan, chestnut, birch, persimmon, and pricklyash.

The very similar and related European fruit lecanium, *P. corni*, is reported on California black oak in the northern Sierra Nevada. *P. corni* is common throughout California and the U.S. on many hosts.

Symptoms

Globose brown scale insects occur on twigs and produce honeydew. Black sooty mold grows on the honeydew that drips on leaves and twigs. Very heavy infestations can cause twig dieback and stunted leaves.

Figure 35. Close-up of oak lecanium scale.

Photo: Bruce Hagen, CDF.

Agent Description

Mobile nymphs (crawlers) are flat and orangish and occur on leaves or twigs. Adult scales are immobile and occur on twigs. Adults are hemispherical, 4–6 mm long, brown, and have a smooth, shiny surface that may include some white powdery material (*fig. 35, 36*). Females have a pair of lateral bumps.

Biology

Nymphs overwinter and mature into adults in the spring. Winged adult males mate with wingless females. Eggs are laid beneath the female in late spring. First-instar nymphs emerge from beneath the female and crawl to the leaves where they feed. After settling they retain their tiny legs and antennae and are able to move very slowly. The second-instar nymphs migrate back to twigs in late summer, where they overwinter. This insect has one generation per year.

Importance

Honeydew dripping and subsequent sooty mold growth may become a nuisance. Greatest impacts of this insect reportedly occur on coast live oak in southern California.

Figure 36. Oak lecanium scale.

Photo: Don Owen, CDF.

Obscure scale

Melanaspis obscura (Diaspididae)

Distribution/Hosts

Obscure scale is widely distributed in the eastern and southeastern U.S., particularly in warmer areas. It has been established in Sacramento, CA, for an extended period, but is now controlled by an introduced parasitoid. Infestations in San Diego and Los Angeles Counties occurring before 1940 were eradicated. In California, obscure scale has been reported on native coast live, interior live, and oracle oak (natural hybrid between interior live and California black oak), and the introduced pin, willow, and northern red oaks. It prefers oak and pecan, but is found on many other woody species including hickory and walnut.

Symptoms

These scale insects are inconspicuous due to gray covers and may be found on twigs, branches, trunks, and exposed roots, sometimes under loose bark. They often settle close together, resulting in masses of overlapping scale insects. Heavy infestations may cause twig and branch dieback, which can weaken trees, increasing their susceptibility to other opportunistic agents. Obscure scale does not produce honeydew.

Agent Description

Adult scale covers are gray, circular to oval, 2–3 mm in diameter, flat to slightly convex, and may have an off-center dark spot, which is the first-instar cast skin. Scales are often in overlapping clusters (*fig. 37*). A noticeable white spot is left on the host stem if the scale is removed.

Biology

Eggs hatch beneath females in mid summer. Crawlers (mobile nymphs) are very tiny, about the size of a period, and flat. They settle close together on the bark of the host, often under existing adult shells. Once the crawler begins to feed it produces a clear wax shell. Nymphs continue to grow to adulthood beneath the protective wax shell. Winged adult males crawl out from under their armored shells in the spring to mate with immobile females, which lay eggs beneath their bodies. Egg laying can last for an extended period. There is one generation per year.

Importance

This scale was introduced to California from the eastern U.S., where it is a significant pest of oaks in landscapes, but is not a forest pest. It was originally discovered in 1933 in southern California infesting pecans, although the Sacramento infestation may date to 1897, when trees from Civil War battlefields were transplanted into Capitol Park. In Sacramento, a tiny wasp parasitoid (*Encarsia aurantii*) introduced from Texas has provided complete biological control (Ehler 2005).

Figure 37. Overlapping clusters of obscure scale on an infested twig.

Photo: John A. Weidhass, Virginia Tech; www.forestryimages.org

Pit scales

Oak pit scale -
Asterolecanium minus, *A. quercicola*
Golden oak scale - *A. variolosum*
(Asterolecaniidae)

Distribution/Hosts

Asterolecanium minus and *A. quercicola* are widely distributed in California but *A. variolosum* is reportedly rare (Gill 1993). All three species are common in other parts of the U.S. on oaks. In California, *A. minus* and *A. quercicola* prefer white oaks including valley, blue, and Engelmann oak, and some non-native white oaks, but are also found on coast live and California black oak. *A. variolosum* is reportedly restricted to English oak and California black oak in California. Reports of this species on other oaks may be due to confusion between the three species of *Asterolecanium*. Additional oaks in the white and red/black oak subgroups are hosts of these pit scales in the eastern U.S.

Symptoms

Pinhead-sized scales are found on twigs and small branches (*fig. 38-40*). Each scale is in a depression that develops in the center of a ring of swollen bark. Heavy infestations cause the normally smooth bark of young twigs to become rough. Poor twig growth

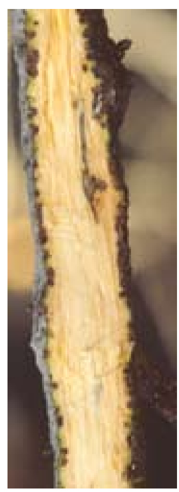


Figure 39. Small coast live oak branch with tangential slice of bark and wood removed showing necrosis associated with oak pit scales.

Figure 38. Oak pit scale. Swellings that give rise to pitted appearance have not yet formed around some of the younger scales.

Photo: Bruce Hagen, CDF.

and dieback are common results of pit scale infestation. Deciduous oaks retain dead leaves on killed twigs throughout the winter. Damage to oaks is caused by the removal of plant fluids and perhaps the injection of toxins into twigs. Pit scales do not produce honeydew.

Agent Description

Diameters of adults vary somewhat by species: 1–1.5 mm for *A. minus*, 1.25–1.75 mm for *A. quercicola*, 1.75–2.25 mm for *A. variolosum*. All three species are otherwise similar in appearance. Scales are rounded and green, gold, or brown, depending on age.

Biology

Only females are known. There is only one generation a year, but an individual female may produce young for up to five months. Females overwinter in pits on twigs. Eggs are laid beneath the female's protective cover. Most mobile nymphs (crawlers) emerge from beneath the females from April to June, but some may emerge as late as October. The crawlers settle near the parent on twigs not more than a year old. Once settled, the scale remains immobile for the rest of its life.

Importance

Pit scales are serious pests of oaks in California, especially in southern California. Pit scales tend to be more common on deciduous oaks than on live oaks, and more common on oaks in landscapes than in wildlands.

Figure 40. Golden oak scale. Pits have not yet formed around these scales.

Photo: Jack Kelly Clark, courtesy UC Statewide IPM Program

Treehoppers

Platycotis vittata, *P. vittata quadrivittata*
(Membracidae)

Distribution/Hosts

Platycotis vittata is widely distributed in California and is found throughout the U.S. It is reported on various oaks in California, including coast live and valley oak. In other parts of the U.S., *P. vittata* is reported on oaks, birch, chestnut, and other hardwoods. *P. minax* occurs on coast live oak and possibly other oaks in southern California.

Symptoms

Slit-like egg-laying (oviposition) wounds on fine branches can cause leaves to wilt and die and may cause twig dieback. Callus developing around these longitudinal oviposition slits may leave scars on affected twigs. Honeydew produced by treehoppers drips on foliage and branches and can support growth of black sooty mold on these surfaces.

Agent Description

P. vittata nymphs are black with yellow and red markings (*fig. 41*). Adults are 9–12 mm long, and have an enlarged hardened plate (pronotum) on the back of the thorax. The pronotum covers the insect's head, much of its abdomen, and part of the

Figure 41. *Platycotis vittata* adults and nymphs.

Photo: Bruce Hagen. CDF.

prominently-veined wings (*fig. 42*). In *P. vittata*, two lateral horns project from the pronotum; between these two horns there may be a central forward facing horn. *P. vittata* adults vary in color (dull olive, bronzy, or sea green) and have small red pits on the pronotum. *P. vittata quadrivittata* adults are a pale blue color with four red longitudinal stripes and usually have well-developed central and lateral pronotal horns. Both immatures and adults jump.

Biology

P. vittata adult females overwinter and oviposit in slits or crescent-like punctures they cut in the bark of twigs in spring. Females remain with eggs and nymphs as they mature. In the spring generation, nymphs are gregarious and aggregate along twigs. Spring-generation adults give rise to a second generation later in the summer.

Importance

Although damage may sometimes be conspicuous, damage to mature trees is generally minor. Large amounts of twig dieback may stunt affected seedlings or saplings.

Figure 42. *P. vittata* adults.

Photo: Bruce Hagen, CDF.

Whiteflies

Crown whitefly - *Aleuroplatus coronatus;* Gelatinous whitefly - *A. gelatinosus;* Stanford's whitefly - *Tetraleurodes stanfordi* (Aleyrodidae)

Distribution/Hosts

Crown whitefly is found throughout California. It prefers coast live oak, but is also reported on canyon live, interior live, valley, and scrub oak, as well as chinquapin, tanoak, coffeeberry, toyon, madrone, and *Rhus*.

Gelatinous whitefly is reported from the San Francisco Bay Area southward through the San Joaquin Valley and southern California on coast live and interior live oak.

Stanford's whitefly is found mainly throughout coastal California. It is reported on coast live, California black, and interior live oak as well as chinquapin, tanoak, and coffeeberry.

Symptoms

Non-mobile nymphs and pupae on leaves are the most conspicuous and identifiable sign of an infestation. They appear as small (less than 1 mm) black or black and white spots on leaves which can be wiped off. Crown and gelatinous whiteflies occur only on lower leaf surfaces, whereas Stanford's whitefly mostly feeds on the upper leaf surface. At certain times of the year, the adult whiteflies may fly around infested plants, sometimes in great numbers. The honeydew secreted by nymphs accumulates on leaves and supports the growth of black sooty mold. Very heavy infestations may cause some leaf distortion, yellowing, and premature leaf drop.

Figure 43. Close-up of crown whitefly pupae on underside of a coast live oak leaf.

Agent Description

Adult whiteflies look like tiny (about 1 mm) white moths. Eggs are white to pink and are attached to the leaf surface by a short stalk. Nymphs are initially translucent but become black as they mature. Pupae are tiny, black, oval, and flat. Species differ in the amount and color (clear or white) of wax associated with the pupae. Crown whitefly pupae are covered with somewhat rectangular plates of white wax that project outward in all directions (*fig. 43, 44*). Gelatinous whitefly pupae are surrounded by a matrix of clear, gelatinous wax. Stanford's whitefly pupae are surrounded by a flat fringe of white waxy plates (*fig. 45*). Nymphs of crown whitefly resemble Stanford's whitefly pupae.

Figure 44. Close-up of a crown whitefly pupa on a coast live oak leaf.

Biology

Adults emerge from overwintering pupae in spring and lay eggs on the lower leaf surface. Eggs hatch to give rise to tiny mobile nymphs called crawlers. Within hours, crawlers settle down and insert their mouthparts into the leaf to suck plant sap from phloem cells. Whitefly nymphs remain immobile as they go through successive molts. The last molt gives rise to pupae which overwinter. Crown whitefly has a single generation per year.

Importance

Whiteflies do not cause significant damage to oaks and are typically of little or no importance. Crown whitefly populations can sometimes reach high enough populations to pose a nuisance, mainly due to honeydew production and related sooty mold growth. The gelatinous and Standford's whitefly generally occur in lower numbers than the crown whitefly.

Figure 45. Stanford's whitefly pupae on coast live oak.

Photo: Bruce Hagen, CDF.

Woolly oak aphids

Stegophylla querci, *S. quercifoliae*, *S. essigi*
(Aphididae)

Distribution/Hosts

Stegophylla querci (=*S. quercicola*) is widely distributed in North America and much of California. In California, it occurs on blue, valley, coast live, interior live, California black, and scrub oak and probably other oaks.

S. quercifoliae is found in the San Francisco Bay Area on at least blue oak and coast live oak. It occurs on other oak species in other portions of the U.S.

S. essigi is known only from the West Coast, and is reported from many California oaks, including blue, valley, Oregon white, coast live, interior live, California black, and scrub oak. However, there is only limited information on its distribution.

Symptoms

Masses of white wax filaments produced by *S. querci* and *S. quercifoliae* nymphs and adults are visible on infested leaves (*fig. 46*). *S. querci* forms small, scattered colonies on upper or lower leaf surfaces. *S. quercifoliae* infests the undersides of leaves. Large colonies may cause leaves to curl. Feeding by first generation *S. essigi* in spring causes the edges of young leaves to fold over to the upper side of the leaf, forming a protective shelter in which the aphids feed and where wax accumulates (*fig. 47*). The folded leaf area may show a reddish discoloration initially and eventually may die.

Figure 46. Woolly oak aphid (*Stegophylla querci*) colonies on valley oak.

Agent Description

Wingless adults (apterae) of all species are covered in white wax wool. *S. querci* apterae are oval, pale greenish- or brownish-yellow, 1–1.5 mm long, and have dense wax wool (*fig. 48*). *S. quercifoliae* apterae are yellowish to yellowish green with a brown head, 1.1–1.5 mm long, and have loose wax wool. *S. essigi* apterae are broadly oval, pale gray-green to olive and 1.2–1.8 mm long.

Biology

Woolly oak aphids overwinter as eggs. Several generations develop each year. In the spring, females reproduce parthenogenically (without mating). In the fall, male and female aphids are produced. Adult males may be either winged or wingless. *S. querci* has sexual females (oviparae) and both wingless and winged males in September and October. For *S. essigi*, oviparae and both wingless and winged males are produced in November. Populations of *S. essigi* may continue to reproduce parthenogenically on evergreen oaks such as coast live oak, especially in leaves tied together by caterpillar silk.

Importance

Woolly wax deposits may become conspicuous and possibly unsightly, especially late in the season. Damage to trees is normally minimal.

Figure 47. Symptoms of *S. essigi* on coast live oak; affected leaf margins are folded upward and become reddish.

Figure 48. Close-up of *S. querci* nymph.

Oak twig borer

Styloxus fulleri californicus
(Cerambycidae)

The California subspecies of oak twig borer (*Styloxus fulleri californicus*) is widespread in California and has been reported on coast live, interior live, and California black oak. *S. fulleri californicus* makes a large, oval, frass-filled tunnel in the heartwood of twigs, particularly those that are 0.5–1.25 cm in diameter. Larvae are yellowish roundheaded borers, 12.5–19 mm long. Adult beetles (*fig. 49*) are slender and greenish brown.

Figure 49. Pinned specimen of adult oak twig borer.
Photo: Larry G. Bezark, CDFA.

Other twig borers

Aneflomorpha lineare (Cerambycidae)

Figure 50. Pinned specimen of adult *Aneflomorpha lineare*.

Photo: Larry G. Bezark, CDFA.

Aneflomorpha lineare is a twig borer reported on coast live and scrub oak in southern California; it is also found in Oregon. Other hosts of *A. lineare* include bitterbrush and chamise. Larvae of *A. lineare* bore through small branches, making holes at frequent intervals through which frass is expelled. Upon reaching the point where the branch diameter is about 2–4 cm in diameter, larvae construct tunnels that spiral outward from the center of the branch. Adults are slender and brown (*fig. 50*). Adults are present from July to September and are attracted to light.

Scobicia suturalis (Bostrichidae)

Scobicia suturalis, a false powder post beetle, is reported from the San Francisco Bay Area. It mines the small branches and twigs of coast live oak, California black oak, and acacia, as well as grape canes. Adults of *S. suturalis* are cylindrical and 5 mm long. The head and abdomen are black, the prothorax and posterior half of the elytra are dark reddish brown, and the antennae, legs, and front half of the elytra are pale amber in color.

Oak twig girdler

Agrilus angelicus (Buprestidae)

Distribution/Hosts

The oak twig girdler is widespread in California and is reported from other states including Oregon and Nebraska. In California, coast live oak may be the most commonly affected species, but oak twig girdler is also reported on canyon live, interior live, California black, Engelmann, leather, and valley oak.

Symptoms

Mining by the oak twig girdler beneath the bark girdles small diameter twigs, causing the portion of the twig beyond the mine to die. Heavy infestations of oak twig girdler, which are relatively common on coast live oak in southern California, give rise to numerous patches of dry, dead leaves scattered in the canopy (*fig. 51*). Because other twig borers and agents such as twig blight fungi can cause similar symptoms, it is necessary to remove the bark from affected twigs at the junction between live and dead tissues to determine the cause of the damage. Oak twig girdler larvae form flattened tunnels under the bark that spiral around the twig from the younger (typically dead) portion of the twig toward the point of branch origin (*fig. 52*). Dark brown granular frass and whitish larvae may be found in the tunnels.

Figure 51. Twig dieback due to oak twig girdler damage on coast live oak.

Figure 52. Oak twig girdler boring on coast live oak; bark has been removed to show the spiraling larval tunnel.

Agent Description

Oak twig girdler adults are 7 mm long and dark metallic brownish bronze. The larvae are up to 19 mm long, white, legless, somewhat flattened, and constricted at each body segment (*fig. 53*). The flattened head is large relative to the body.

Biology

Adults emerge from pupae between May and September. Adults mate and the female lays eggs singly on the youngest twigs. Eggs hatch after two weeks and larvae bore directly into twigs. The young larva makes a slender linear tunnel for up to three to six months as it moves toward the older portion of the twig. The tunnel then begins to spiral around the twig. The larva feeds for two years in spiral tunnels, which can extend 30 cm or more down the twig. The larva then bores to the center of the twig and tunnels up to 15 cm back toward the killed portion, where it pupates near the twig surface. After several weeks it emerges as an adult. A single generation thus requires about two years.

Figure 53. Oak twig girdler larva.

Photo: Bruce Hagen, CDF.

Importance

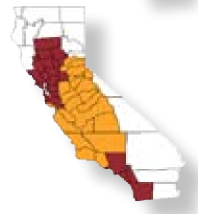
Oak twig girdler is believed to be attracted to trees weakened by drought. High levels of damage can be unsightly, but overall impacts to tree health are minor to insignificant.

Ambrosia beetles

Monarthrum dentiger, *M. scutellare* (Scolytidae)

Distribution/Hosts

Monarthrum scutellare is widespread throughout California and Oregon on various oak species, including coast live, California black, and valley oak. It also occurs on tanoak.



M. dentiger is less common than *M. scutellare* and is reported in Arizona and California. It occurs on coast live and valley oak, and probably on other oak species. It has also been reported on avocado and walnut.

Symptoms

The most obvious symptom of infestation is fine, light-colored boring dust that accumulates on the bark surface and/or around the tree's base (*fig. 54*). Small, cone-shaped piles of boring dust, which are pushed out of small (about 1–1.5 mm diameter) holes in the bark, may be visible on the surface of infested trunks and branches. In cross-sections through affected areas, thin, black-stained tunnels can be seen extending 2–15 cm into the wood (*fig. 55, 56*). Tunnels often branch from a single point near the cambium or at the end of a short length of tunnel that extends into the outer sapwood.

Figure 54. White boring dust produced by ambrosia beetles on the surface of a tanoak infected with *Phytophthora ramorum*.

Agent Description

Adults are small dark brown to blackish cylindrical beetles (*fig. 57*). From above, the head is completely hidden beneath a bullet-shaped plate (pronotum) over the thorax. *M. scutellare* adults are 3.5–4.1 mm long. The smaller *M. dentiger* adults are 1.9–2.4 mm long.

Biology

Both species tunnel into the wood of trunks or branches that are severely stressed, diseased, dying, or recently dead. Ambrosia beetles commonly invade trees with *Phytophthora ramorum* cankers (sudden oak death), initially in the vicinity of cankers. As diseased trees decline, parts of the tree well away from cankers may be colonized. Ambrosia beetles bore galleries in wood, but feed on ambrosia fungus (*Ambrosiella brunnea*) that grows on the inner surfaces of the galleries after it is introduced by the adult female. Galleries are maintained free of frass, resulting in accumulations seen outside the bark.

In *M. scutellare*, the adult male initiates colonization by tunneling up to about 6 cm into the wood and excavating

Figure 55. Broken trunk of a failed coast live oak that was killed by *Phytophora ramorum* (sudden oak death) shows a very high density of ambrosia beetle galleries. Although ambrosia beetle galleries are common in trees with this disease, only some trees show such high gallery densities.

Figure 56. Detail showing ambrosia beetle larval tunnels branching from the end of the main entrance tunnel excavated by the adult male.

Figure 57. *Monarthrum scutellare* adult beetle.

Photo: Jack Kelly Clark, courtesy UC Statewide IPM Program

a chamber. The male is joined by a female, who carries the inoculum of the ambrosia fungus in specialized leg cavities. After mating, eggs are laid in niches along the sides of the chamber where the fungus also becomes established. Gallery extension and oviposition may last two to four months. Larvae extend the niches into "larval cradles" that branch off of the chamber. Larval development lasts six to eight weeks and pupation takes two to three weeks. Two generations occur per year in California. Most egg laying takes place in March and October, but adults may be found much of the year. The biology of *M. dentiger* is presumed to be similar to that of *M. scutellare*.

Importance

Ambrosia beetles only attack trees or branches that are already dead, diseased, or declining. Heavy attacks commonly occur on oaks and tanoak with trunk cankers caused by the sudden oak death pathogen, *Phytophthora ramorum*. In some situations, heavy attacks appear to hasten the decline of dying trees or branches, but the effects of beetle attacks are difficult to separate from those of wood decay fungi that are also common in declining trees. Extensive ambrosia beetle tunneling may increase the risk of branch or trunk failure, especially in branches and trunks less than about 30 cm in diameter.

Bark beetles

Western oak bark beetle -
Pseudopityophthorus pubipennis
Oak bark beetles - *P. agrifoliae, P. pruinosus*
(Scolytidae)

Distribution/Hosts

Pseudopityophthorus pubipennis is reported throughout California from the coast to the western slopes of the Sierra Nevada and Cascade Range. It occurs north to southern British Columbia, at least in the coastal zone. It is common on various oaks, including coast live, California black, and Oregon white oak, but has also been reported on tanoak, chestnut, and California buckeye.

P. agrifoliae is reported from at least Marin to Los Angeles County on coast live, California black, and canyon live oak. Both *P. agrifoliae* and *P. pubipennis* are often very abundant in oak firewood.

P. pruinosus (=*P. pulvereus*) is reported as uncommon in southern California, and occurs on various oaks. *P. pruinosus* also occurs in Arizona, Texas, Mexico, and some states in the eastern U.S.

Figure 58. *Pseudopityophthorus* engraving in outer sapwood of an oak branch; bark has been removed to expose the bark beetle galleries.

Photo: Don Owen, CDF.

Symptoms

Oak bark beetles colonize the bark of branches and trunks. The outermost sapwood just under the bark may be extensively engraved due to tunneling by the adult beetles. The engravings score the wood surface across the grain but do not enter deeply into wood (*fig. 58*). Tunnels produced by *P. pubipennis* adults are limited to the inner bark and do not score the sapwood (Bright and Stark 1973). In dry, dead stems, deposits of sawdust-like frass and/or pinhead sized emergence holes are typical symptoms. Oak bark beetle boring dust is typically dark or reddish due to the feeding of the beetles in the phloem (*fig. 59*).

Ambrosia beetles, *Monarthrum* spp., which bore deeply into the wood, produce light-colored boring dust. On live stems, bleeding sap or foam may be associated with oak bark beetle attack (*fig. 60*).

Figure 59 (left). Boring dust on bark of coast live oak resulting from infestation by bark beetles (darker brown dust) and ambrosia beetles (lighter boring dust).

Figure 60 (right). White ooze associated with oak bark beetle attack.
Photo: Don Owen, CDF.

Agent Description

Larvae are whitish, legless grubs, 1–2.5 mm long. Adult beetles are very small (1.7–2.3 mm long), cylindrical, dark brown to black, and shiny (*fig. 61*). The pronotum and elytra are finely and densely punctate and covered with fine hairs.

Biology

Adults bore through the bark to the interface with the sapwood. From the entrance hole, two tunnels, about 5 cm long combined, are excavated in the inner bark perpendicular to the wood grain. Eggs are laid in niches along these tunnels. As larvae hatch they begin tunneling in the inner bark (phloem) at right angles to the adult gallery, i.e., with the wood grain. Larval tunnels are up to 2.5 cm long for *P. pubipennis* and 1–2 cm long for *P. agrifoliae*. At maturity, the larvae tunnel to just below the bark surface and pupate at the end of the tunnel. Adults emerge and chew through the bark, leaving behind small exit holes ("shotholes"). Depending on the location, there may be two or more generations per year. Generations overlap, so adult beetles are always present during the growing season. Larvae and adults overwinter under bark.

Figure 61. *Pseudopityophthorus pubipennis* adult beetle.

Photo: Jack Kelly Clark, courtesy UC Statewide IPM Program

Importance

Oak bark beetles colonize trees or parts of trees that are severely weakened, dying, or dead. Beetles may also colonize freshly cut oak firewood. When adult beetles emerge from cut logs, they may attack nearby healthy oaks. *P. pubipennis* is commonly found in association with trunk cankers caused by the sudden oak death pathogen, *Phytophthora ramorum*, in coast live oak, California black oak, and tanoak. Attacks by oak bark beetles may hasten the decline of dying branches and trees. Healthy, non-stressed trees are not likely to be substantially harmed by oak bark beetle attack.

Carpenterworm

Prionoxystus robiniae (Cossidae)

Distribution/Hosts

The carpenterworm feeds on decidous trees throughout the U. S., including ash, aspen, cottonwood, poplar, elm, locust, oak, and willow. In California, coast live and California black oak are the most common oak hosts.

Symptoms

The larvae feed by tunneling through the inner bark and into the wood of trees. Larvae keep the tunnels open to the outside of the tree. Tunnel ends appear as 13–18 mm diameter holes in the bark. Bleeding often occurs from the infested area and sawdust-like frass accumulates below the open-ended tunnels. The bark over tunneled areas is sometimes roughened or missing in patches (*fig. 62*). After adults emerge, empty pupal cases may be found protruding from tunnel openings.

Agent Description

Larvae are off-white, pinkish, or greenish-white, and up to 64 mm long at maturity; the head is dark (*fig. 63*). Unlike larvae of wood-boring beetles, carpenterworm larvae have abdominal prolegs, each of which has a band of hooks (crochets) at the bottom. Pupae are shiny, dark brown, and have a double row of spines (*fig. 64*). Adults are large, heavy-bodied moths with mottled grayish

Figure 62. Areas of roughened and missing bark on this valley oak are symptoms of carpenterworm damage.

Photo: Bruce Hagen, CDF.

forewings (*fig. 65*). Female moths are large, with a wingspan of about 75 mm and grayish hindwings. Male moths are about two-thirds the size of females, generally darker, and have an orange to red area on their hindwings. The male's antennae are more comb-like (pectinate) than the female's.

Figure 63. Carpenterworm larva.

Photo: Bruce Hagen, CDF.

Figure 64. Carpenterworm pupal case.

Photo: Bruce Hagen, CDF.

Figure 65. Carpenterworm adult female moth.

Photo: Bruce Hagen, CDF.

Biology

Adult moths emerge from pupal cases from May through July, or as early as April in southern California. Females are poor fliers and frequently lay eggs on the same tree from which they have emerged. Eggs are laid in sticky clumps of two to six on the bark, often in cracks or crevices or in areas of rough bark from previous infestations. After hatching, the larva immediately bores through the bark. Larval feeding initially occurs mostly in the sapwood, but later instars tunnel into the heartwood, returning to the tunnel entrance to expel frass. The gallery is mostly vertical and about 15–25 cm long. After the mature larva pupates, the pupa wiggles toward the bark surface, where the adult emerges. The larval stage takes up most of the two to four year life cycle.

Importance

Bleeding and scarring of the affected area may be unsightly. Girdling associated with tunneling may induce branch dieback. Wounds may also serve as an entry point for wood decay fungi or canker pathogens. Extensive boring and associated wood decay can make trees more susceptible to breakage.

Flatheaded borers/ Metallic wood boring beetles

Flatheaded appletree borer - *Chrysobothris femorata*
Pacific flatheaded borer - *Chrysobothris mali*
(Buprestidae)

Chrysobothris femorata occurs throughout the U.S. and southern Canada. *C. mali* occurs in western North America from the Rocky Mountains and southern Canada to the Pacific Coast. Both species attack a wide variety of woody plants, including both young and mature shrubs and trees. They primarily attack plants that are stressed, diseased, or injured.

Eggs are laid singly in bark crevices or near injuries. The larva emerges from the egg by boring through the bottom of the shell directly into the bark. Larvae are whitish to yellowish, legless, and have a wide, flattened segment near the head (*fig. 66*). They mine the inner bark, sapwood

Figure 66 (top). Flat-headed borer larva and frass-packed tunnels in the outer sapwood of a recently-cut coast live oak log. The enlarged thoracic segments give the larva a "flat-headed" appearance.

Figure 67 (bottom). Flat-headed borer tunnels in coast live oak wood.

and heartwood of trees, forming tunnels that are wide and flattened in cross section (*fig. 67*). The tunnels are partially filled with powderlike frass. Sap may ooze from the affected area. In vigorous trees, heavy sap flow can kill invading borers. Tunneling may girdle and kill trees, especially young trees. Larvae construct a chamber for pupation in the outer wood or heartwood and overwinter as larvae in the chamber. They pupate in the spring or early summer. Adults chew oval holes through the bark as they emerge. One generation is produced per year, although in cooler areas more than a year may be required to complete a generation (Solomon 1995).

C. femorata adults emerge from March through September and feed at the bases of twigs. Adult beetles, 7–16 mm long, are dark metallic brown to dull gray, with greenish blue mottled areas (*fig. 68*). Mature larvae reach 25 mm in length. Larvae feed in the inner bark and surface of the sapwood, migrating into the sapwood when they reach maturity.

C. mali adults, found from April to August, are about 6–11 mm long and dark bronze, gray, or a mottled copper color (*fig. 69*). Mature larvae reach 15–18 mm long. Larvae feed in both the phloem and the sapwood.

Figure 68. Pinned specimen of adult flatheaded appletree borer.

Photo: Larry G. Bezark, CDFA.

Figure 69. Pinned specimen of adult Pacific flatheaded borer.

Photo: Larry G. Bezark, CDFA.

Lead cable borer

Scobicia declivis (Bostrichidae)

The lead cable borer is common throughout California and southern Oregon. Larvae mine and completely destroy dead and seasoned wood, but also attack living hardwoods including oak. The larvae are heavy bodied, 10 mm long at maturity, white to pale yellow, C-shaped, and enlarged at the front end. They have three pairs of true legs. Frass-filled tunnels produced by larvae are mostly aligned along the wood grain. Adult beetles are 5–6 mm long, cylindrical, and dark brown to black (*fig. 70*). Antennae and portions of the legs and mouthparts are reddish in color. The head is bent downward and completely hidden by the prothorax when viewed from above. Adults emerge from April through September, and are most common in July and August. Adults sometimes bore through non-wood materials, including the sheathing of aerial telephone cables.

Figure 70. Adult lead cable borer.

Illustration: John Muir Laws, California Academy of Sciences.

Pigeon tremex

Tremex columba (Siricidae)

This wood-boring wasp is found in the northern part of the U.S. from coast to coast and throughout California. Larvae bore almost perfectly round tunnels, 6–7 mm in diameter, through the heartwood of declining and dead hardwoods including oak, pear, apple, beech, sycamore, hickory, elm, and maple. Tunnels are not open to the outside of the tree. Larvae are up to about 50 mm long. Adults are 25–38 mm long and have golden-yellow wings and a yellow abdomen with black bands (*fig. 71*). The adult female pigeon tremex inserts her ovipositor into solid wood to a depth of 13 mm and deposits a single egg at each site. Often, the ovipositor cannot be extracted and the female dies on the tree.

Figure 71. Adult pigeon tremex.

Illustration: John Muir Laws, California Academy of Sciences.

Roundheaded borers/ Long-horned beetles
(Cerambycidae)

California prionus - *Prionus californicus*

The California prionus is found along the Pacific Coast from Alaska to Sonora, Baja California, and the Rocky Mountains south to New Mexico. Larvae feed in the lower trunk and roots of oaks and many other hardwood trees, conifers, and woody shrubs. Eggs are laid in the soil near host roots. Larvae are large white grubs up to 60–75 mm long that tunnel in the wood and sometimes in the bark of roots. Larvae attack living roots, but also feed in dead and decaying roots. The mature larva leaves the root and constructs a pupation tunnel up to 1 m long in the soil. Adult beetles are 40–60 mm long, shining, dark reddish brown, with three sharp teeth on each lateral margin of the prothorax (*fig. 72*). Adults are active in twilight hours and at night, and are attracted to light. The adult flight period is from June to September. The life cycle takes three to five years. Extensive feeding by larvae can completely girdle the trunk of the host tree just below the ground. Injury is greater among trees growing in light, well-drained soil.

Prionus lecontei larvae also tunnel within living oak roots. This species is found from British Columbia to Baja California. *P. lecontei* adults fly from June to August and are sometimes captured with *P. californicus* adults.

Figure 72. Adult California prionus.

Illustration: John Muir Laws, California Academy of Sciences.

Banded alder borer, California laurel borer - *Rosalia funebris*

The banded alder borer is found along the Pacific Coast from southern Alaska to southern California and the Rocky Mountains south to New Mexico. The larvae bore in dead or declining hardwoods including oak, alder, willow, ash, and California bay. Adults are 25–38 mm long, with alternating bands of black and light blue, gray, or white on their wing covers (elytra) and long antennae (*fig. 73*). Adults are attracted to fresh paint and are also occasionally found in large numbers on alder or California bay.

Figure 73. Adult banded alder borer.

Nautical borer - *Xylotrechus nauticus*

The nautical borer is common throughout California on oaks and other hardwoods. This beetle colonizes dead or declining trunks and limbs but normally does not attack healthy trees. Larvae, which grow to a length of about 18 mm, bore into the inner bark, producing an engraved pattern on the surface of the sapwood. Tunnels differ from those of bark beetles in that no central egg gallery is formed, and the larval tunnels are longer, larger in diameter, and oval in cross-section. Larvae also tunnel into heartwood and pack the tunnels with dry, powder-like frass. Adult beetles may emerge in large numbers from infested wood. Adults are about 8–15 mm long and dark gray (*fig. 74*). The elytra (hard outer forewings) are crossed with three light-colored zigzag-shaped markings. Antennae are relatively short. Adult beetles are found in homes when they emerge from firewood stored indoors.

Figure 74. Adult nautical borer.

Photo: T.W. Davis © California Academy of Sciences.

Neoclytus conjunctus

This beetle is found along the Pacific Coast from British Columbia to southern California. Hosts of this borer include oak, eucalyptus, ash, pear, manzanita, and madrone. The larvae are common in freshly-cut deciduous trees and adults may emerge from firewood. The larvae initially tunnel under the bark before progressing to the sapwood and outer heartwood, which are extensively tunneled. The adult flight period is March to June. Adults have light-colored markings on the black elytra (*fig. 75*). The pronotum is broadly rounded with many elevated ridges. Antennae are long and clubbed.

Figure 75. Pinned specimen of adult *Neoclytus conjunctus*.
Photo: Larry G. Bezark, CDFA.

Western sycamore borer

Synanthedon resplendens (Sesiidae)

Distribution/Hosts

The western sycamore borer occurs from Washington to California and east to New Mexico. It is reported on sycamore, ceanothus, coast live oak, and other oaks. It is reported to be more common on oaks in southern than in northern California. A related species, *Synanthedon mellinipennis*, has been reported on coast live oak and possibly other oaks in California along the Central Coast and San Francisco Bay Area.

Symptoms

Larvae mine the bark below the surface, producing numerous meandering feeding tunnels (*fig. 76*). Reddish sawdust-like frass, which larvae expel from tunnels, accumulates in branch crotches or on the ground below the infested area. The outer bark surface over the tunnels becomes roughened after repeated infestations and may produce wet ooze (*fig. 77*). Pupal skins may be visible in emergence holes, which are 3 mm in diameter.

Figure 76. Western sycamore borer damage on coast live oak. The outer surface of bark has been cut away to show tunneling in inner bark.

Figure 77. Symptoms of western sycamore borer damage on coast live oak.

Photo: Bruce Hagen, CDF.

Agent Description

Adult moths resemble yellowjacket wasps and have a wingspan of about 18 mm (*fig. 78*). Adults are mostly yellow with black markings on the thorax and abdomen; the head is brownish black. Wings are mostly clear with yellow to orange edges. Larvae are pinkish to whitish and reach 18 mm in length; the head is brown (*fig. 79*).

Figure 78. Western sycamore borer adult.
Illustration: John Muir Laws, California Academy of Sciences.

Biology

One generation occurs per year. Adults emerge from May through early August, with greatest emergence in June and July. The ovoid, gold-colored eggs are laid singly on the bark in small cracks or depressions. Old or slow-growing trees and injured tissues are favored sites for egg laying and feeding. The larva tunnels into the inner bark after hatching, creating winding tunnels that extend over about 100 cm^2. Larvae rarely damage the cambium or feed in the wood. Pupae are formed just below the bark surface, and protrude through the bark when the adult is ready to emerge. Overwintering occurs as larvae or pupae within the bark tunnels. In southern California, larvae feed through most of the winter months and pupate in early spring.

Importance

Bark of infested trees may become unsightly, but the amount of damage caused by this insect is generally considered to be of minor importance. Repeated infestations may retard tree growth.

Figure 79. Western sycamore borer larva.
Photo: Bruce Hagen, CDF.

Drippy nut

Brenneria quercina (=*Erwinia quercina*)

Distribution/Hosts

Drippy nut is reported on both coast live and interior live oak. The disease may occur throughout the ranges of these species but is especially common in the San Francisco Bay Area counties. It has also been reported on holly oak and *Quercus pyrenaica* in Spain.

Symptoms

The most obvious symptom is copious oozing of frothy, sticky sap from affected acorns (*fig. 80*). Sap may continue to drip from acorn caps attached to the tree after acorns have dropped. The ooze is more watery under humid conditions. In affected trees, the total amount of dripping sap tends to increase with the size of the acorn crop. Affected acorns may show discoloration at insect oviposition wounds and evidence of internal decay. In Spain, the bacterium is reportedly associated with bark cankers and oozing buds in addition to oozing acorns.

Agent Description

The agent is visible only with a high-magnification microscope. The causal bacterium, originally described under the name *Erwinia quercina*, is a non-spore forming, gram negative rod with flagella distributed over the entire cell surface (i.e., peritrichous flagella).

Biology

Bacteria apparently enter the acorn through insect oviposition wounds, including those caused by acorn weevils, filbertworms, and some cynipid wasps. The disease is typically more severe during warm weather. Drippy nut disease severity varies from year to year, but the disease is more likely to recur in trees that have shown symptoms in previous years.

Importance

In California, this disease has not been associated with any obvious damage to trees, although the seed crop is reduced. The sticky sap can be abundant and can pose a substantial nuisance, especially around dwellings.

Figure 80. Frothy sap oozing from coast live oak acorns affected by drippy nut.

Early defoliation/ leaf browning/ drought stress

Distribution/Hosts

Early defoliation related to prolonged drought stress is most commonly seen in blue oak and can occur throughout its range. It is most common on drought-prone sites, such as areas with shallow or rocky soils.

Symptoms

In low rainfall years, leaves of mature trees turn brown prematurely and begin to drop well in advance of the normal time for leaf fall (*fig. 81*). This drought–deciduous characteristic is seen in a more extreme form in California buckeye and is also common in chaparral and desert plants. Drought-induced defoliation can be differentiated from branch dieback by the fact that buds and twigs of drought-defoliated branches remain alive and normally leaf out the following spring. In 1987, following extreme drought conditions in the preceding rainy season, foliar browning and leaf drop in blue oak occurred by mid-August in affected areas. During droughts lasting multiple years, symptoms may be widespread. In less extreme drought years, only blue oaks growing in drought-prone areas may be affected, and defoliation may occur later in the season, but still earlier than the usual November-December leaf drop.

Seedling advance regeneration in the understory (seedlings less than about 10–15 cm tall that are typically several to many years old) commonly

Figure 81. Early leaf browning and defoliation associated with drought in a stand of blue oak.

defoliates much earlier than overstory trees, sometimes losing leaves in response to drought stress by June or July (*fig. 82*). In seedling advance regeneration, the shoots may also partly or completely die back to the ground by midsummer in response to severe drought stress.

Figure 82. Early browning in blue oak seedling at right compared to green seedling at left.

Biology

Blue oak is the most drought-tolerant of California's tree-sized oaks. Early defoliation in response to extreme drought reduces water loss to a minimum and presumably favors tree survival under these conditions. One year of early defoliation had no discernable effect on tree health in one study (McCreary 1991). Trees in this study that defoliated early were among the earliest to leaf out the following spring. However, some trees that defoliated early in response to the extreme 1976–1977 drought (the most severe drought in California during the 20th century), were subsequently leafless for an entire growing season before leafing out in the following year. Well-established seedling advance regeneration can resprout from the base to produce new shoots if the previous season's shoot has been drought-killed. However, successive years of early defoliation and shoot death are associated with reduced seedling survival.

Importance

Mature blue oaks periodically endure drought-induced early defoliation without obvious ill effect. If repeated in successive years, or if coupled with root damage due to construction-related activity, such defoliation could contribute to tree decline. Drought-induced defoliation and shoot dieback reduce the survival of blue oak seedlings and are commonly a contributing factor to poor regeneration in blue oak stands.

Oak anthracnose, twig blight, and leaf spots

Apiognomonia errabunda (=*Discula umbrinella*), *Cryptocline cinerescens*, *Septoria quercicola*, and other fungi

Distribution/Hosts

A number of fungi cause necrotic spotting of leaves and/or twig dieback symptoms on oaks. The fruiting bodies of these fungi are minute, making them difficult to distinguish from each other.

Apiognomonia errabunda (asexual stage = *Discula umbrinella*, synonyms include *Discula quercina*, *Gnomonia errabunda*, *G. quercina*, *G. veneta*, *Gleosporium nervisequum*, *G. quercinum*, *G. quercuum*, and many others) is widely distributed across temperate North America and Europe and occurs on oaks, beech, and sycamore. In California, it attacks both white oaks, including valley, Oregon white, and blue oak, and red/black oaks, including California black, coast live, and interior live oak.

Cryptocline cinerescens occurs on oaks in North America and Europe, and in California is reported on valley, coast live, and interior live oak. Susceptibility varies across species and among individual plants. In general, coast live oak appears to be the most susceptible host in California.

Septoria quercicola is distributed throughout temperate regions on oaks and is reported on California black, coast live, interior live, and canyon live oak.

Other leaf spotting fungi reported on native oaks in California include *Cercospora polytricha* on canyon live oak; *Colletotrichum gloeosporioides* on California black oak; *Cylindrosporium kelloggii* on coast live, California black, and Oregon white oak; *Dicarpella bina* on coast live oak; *Marssonina martinii* on blue and coast live oak; *Pseudomassaria agrifolia* on coast live oak; *Septoria dryina* on California black and possibly other oaks; and several other described fungi that may or may not be distinct from other species reported above.

Figure 83. Anthracnose symptoms on California black oak.

Photo: Bruce Hagen, CDF.

Symptoms

Oak anthracnose is a term used to describe diseases caused by fungi that produce dark, pinpoint-sized asexual fruiting bodies and cause localized necrotic spots or lesions on leaves and young shoots (*fig. 83, 84*). Some of these fungi may completely kill young leaves and twigs under certain conditions. Dead leaves may remain attached to killed twigs. *C. cinerescens* has been associated primarily with twig dieback (*fig. 85*). Symptoms are usually scattered throughout the canopy, and can resemble those caused by twig boring insects. *C. cinerescens* symptoms are reported to be more severe in twigs colonized by oak pit scale. *S. quercicola* produces small, circular to angular necrotic leaf spots visible on both leaf surfaces. It may cause defoliation if disease levels are severe.

Agent Description

The sexual stages of these anthracnose and leafspot fungi are in the Ascomycotina, which contains fungi that produce spores in microscopic saclike structures (asci). For some anthracnose fungi (e.g., *C. cinerescens*) the sexual stage has not been observed. Most anthracnose fungi produce asexual spores in acervuli (spore-bearing structures without distinct walls that arise beneath the epidermis) or in pycnidia (minute globose or flask-shaped fruiting bodies). Active lesions usually show only asexual fruiting bodies.

A. errabunda is the sexual stage of *D. umbrinella*. Asci are formed in long-necked black perithecia (nearly globose or flask-shaped fruiting bodies) that are 130–440 µm in diameter. Ascospores are colorless and have two unequal sized cells.

Figure 84. Anthracnose symptoms on coast live oak.

D. umbrinella forms acervuli in lesions on leaves, most commonly near major veins, or on dead twigs. Acervuli on leaves appear as small (about 250 µm diameter) raised brown flecks. On twigs they are orange-brown, turning dark with age. Conidia (asexual spores) produced in acervuli are single celled, colorless, and elliptical (9–14 by 3.5–5 µm). Microconidia half the size of these conidia are also produced.

C. cinerescens acervuli occur within discolored areas of leaves and twigs. They are round in outline, approximately 100–180 µm in diameter and rupture through the epidermis and cuticle. Acervuli appear black on twigs (*fig. 86*) and yellowish to light brown on leaves. Conidia are elliptical to clavate with a truncate base, 10–25 by 3.5–5 µm, single-celled, clear, smooth-walled, and have internal oil droplets.

S. quercicola produces small, black pycnidia that are embedded in host tissue within lesions. Conidia have several cells, and are colorless and narrowly elongate to filiform (thread-like).

Biology

Symptom severity and appearance can vary with host, time of season, and weather. Spores of anthracnose and leaf spot fungi are primarily dispersed by splashing and wind-blown rain. Wet conditions are required for infection to occur. Immature

Figure 85. Branch dieback of coast live oak caused by *Cryptocline cinerescens*.

Photo: Bruce Hagen, CDF.

Figure 86. Dark spots are *C. cinerescens* acervuli erupting through bark of an oak twig.

Photo: Bruce Hagen, CDF.

host tissue is most susceptible, so disease severity is greatest if rains occur during spring growth flushes. Prolonged periods of rain throughout the spring provide the optimum conditions for disease development. Because such weather patterns are uncommon in California, severe disease levels rarely develop.

Perithecia of the sexual stage of *A. errabunda* form in fallen leaves. In cold winter areas, perithecia mature in spring and release ascospores during spring rains. The fungus can also overwinter within lesions in infected twigs. New infections occur when leaves and twigs remain wet for several hours. Temperatures suitable for infection range from 15–27 ˚C. Wet conditions at 15–20 ˚C are most favorable for infection and disease development. Spores produced in acervuli initiate new infections and multiple disease cycles continue as long as moisture conditions are favorable. Some acervuli produced on newly-infected tissue in spring do not produce mature spores until the following fall.

C. cinerescens and *S. quercicola* have similar disease cycles but do not produce the sexual perithecial stage. In *S. quercicola*, asexual spores are produced in pycnidia rather than acervuli.

Importance

Anthracnose and leafspot diseases are generally of minor importance to California native oaks, but can cause substantial amounts of defoliation and dieback in years with frequent and abundant rainfall that continues through late spring. Unless several wet years occur in succession, long-term impacts of a severe disease year are minimal.

Oak leaf blister

Taphrina caerulescens

Distribution/Hosts

Although *Taphrina caerulescens* is reported to affect more than 50 species of oaks in the U.S., specialists believe that this taxon may actually include multiple similar species. In California, this pathogen is reported on native blue, valley, Engelmann, California black, and coast live oak and on some non-native oaks. Oaks in the red/black oak subgroup are generally more susceptible than those in the white oak subgroup.

Symptoms

Rounded, wrinkled blisters develop on the upper surface of young leaves. These blisters appear as depressions when the lower leaf surface is viewed (*fig. 87*). Blisters range in size from 3 to 30 mm and sometimes coalesce, affecting large areas of the leaf. Severe leaf distortion may result, and young leaves may drop if heavily infected. Blisters are initially light green,

Figure 87. Oak leaf blister symptoms on the upper and lower surfaces of California black oak leaves.

Photo: Jack Kelly Clark, courtesy UC Statewide IPM Program.

yellowish, or whitish on the upper leaf surface and yellow-brown to gray on the underside of the leaf. As blisters age, their upper surfaces may turn reddish or purplish and then brown. On coast live oak, symptoms caused by erineum mites may appear similar to oak leaf blister. Inspection of symptomatic tissues under a microscope may be necessary to confirm whether symptoms are associated with erineum mites or *T. caerulescens*.

Agent Description

All life stages of this fungus are microscopic. Fungal mycelium develops just below the leaf cuticle and between epidermal cells. No distinct fruiting body is formed. Sexual spores (ascospores) are produced in club-shaped, sac-like structures (asci) that form in a layer beneath the upper or lower leaf cuticle and eventually break through the leaf surface. Eight ascospores are formed in each ascus, but ascospores can produce additional asexual spores (conidia) by budding, which may occur within the ascus. All fungal tissue is initially colorless, but the layer of asci darkens after spores are released.

Biology

The fungus overwinters as spores (ascospores and conidia) in bark cracks and under bud scales. In the spring, young, germinating spores infect expanding leaves primarily through stomata. After ascospores are released, they may continue to grow saprophytically on plant surfaces in a yeast-like form, reproducing asexually by budding. Initial infection and subsequent saprophytic growth are favored by mild, wet conditions. Usually only one disease cycle occurs per year.

Importance

In California, oak leaf blister is generally uncommon and typically does not cause substantial damage when present. In the southeastern U.S. and Gulf Coast states, disease is commonly more severe, leading to a high amount of early defoliation in some years.

Powdery mildews

Brasiliomyces trina, *Cystotheca lanestris*, *Microsphaera extensa curta*, *Microsphaera penicillata* (wide sense), *Phyllactinia angulata*

Distribution/Hosts

Powdery mildews are widespread and occur on most oaks throughout California. The taxonomy of the powdery mildews has undergone a number of revisions, with some genera and species being renamed.

Brasiliomyces trina (= *Erisyphe trina*) is relatively uncommon and has been reported from coast live oak, canyon live oak, and tanoak.

Cystotheca lanestris (= *Sphaerotheca lanestris*) is widespread and has been reported from most oaks in California.

Microsphaera penicillata (= *M. alni*) has been split into four species (*M. alphitoides*, *M. abbreviata*, *M. calocladophora*, and *M. extensa*). As noted below, at least some of the records previously reported as *M. penicillata* have been reassigned to *M. extensa* var. *curta*. However, most of the host/distribution reports based on the older name cannot be reassigned to the new species without microscopic examination of the original specimens. *M. penicillata* was reported on a wide variety of native oaks in California, including coast live, interior live, blue, valley, leather, Engelmann, Oregon white, California black, and various scrub oaks. It was also reported on several cultivated non-native oaks in California, including English oak. *Microsphaera extensa* var. *curta*, previously included within *M. penicillata*, occurs on a wide variety of oak species in North America. In California, *M. extensa* var. *curta* has been confirmed on blue, valley, Oregon white, and California black oak, but may occur on other species.

Phyllactinia angulata (= *Phyllactinia corylea*, *P. guttata*) is distributed throughout North America on trees in the families Fagaceae (includes oak, chestnut, beech) and Ulmaceae (includes elm, hackberry) and is reported in California on coast live, California black, and valley oak. According to Braun

(1987), the species of *Phyllactinia* previously identified as *P. corylea* on oaks in California should be assigned to this species.

Symptoms

All of the powdery mildews on California oaks produce dry, whitish fungal growth (mycelium) on leaf surfaces. Young leaves are often affected more than mature leaves. High infection levels may cause leaf distortion and discoloration. Symptom location and appearance varies somewhat among the powdery mildew species:

Figure 88. *Brasiliomyces trina* on coast live oak.

Figure 89. *Brasiliomyces trina* on coast live oak. Masses of brown cleistothecia give a mottled brown or grayish appearance to the lesions.

B. trina produces well defined, grayish to brownish-white, rounded to irregular colonies on the upper leaf surface (*fig. 88*, *89*).

C. lanestris mycelium primarily grows on the lower leaf surface (*fig. 90, 91*). The white mycelium turns tan to brown with age. The fungus can cause systemic infections that induce the formation of witches' brooms (abnormal clusters of shoots that are thickened, elongated, and highly branched). Leaves on witches' brooms are small and senesce early (*fig. 92*). The entire broom becomes white when the fungus sporulates, and may either die out over the winter or produce either more brooms or normal shoots the following season.

M. extensa var. *curta* mycelium is normally present on the upper leaf surface. It commonly forms a persistent thin whitish film over the entire leaf (*fig. 93, 94*).

P. angulata mycelium primarily occurs on the lower leaf surface but is also found on the upper surface.

Figure 90. *Cystotheca lanestris* on lower surfaces of valley oak leaves.

Agent Description

Powdery mildew fungi on California oaks are differentiated primarily on the basis of their sexual fruiting bodies (cleistothecia), which are just large enough to see without magnification, and to a lesser degree on their microscopic asexual spores (conidia).

Figure 91. *Cystotheca lanestris* symptoms on upper surfaces of valley oak leaves; note leaf chlorosis and distortion.

B. trina cleistothecia are abundant, yellow-brown, somewhat transparent, small (60 µm diameter) and lack appendages. Each cleistothecium contains two to three saclike structures (asci), each of which contains two spores (ascospores). *B. trina* produces almost no conidia.

C. lanestris cleistothecia are of intermediate size (95 µm diameter) with unbranched, flexuous appendages. Each cleistothecium has a single ascus with eight ascospores. Conidia are abundant, barrel-shaped, and stick together end to end in chains.

M. extensa var. *curta* cleistothecia are intermediate to fairly large (80–170 µm diameter). Each has five to 20 somewhat stiff appendages which are one to 2.5 times as long as the cleistothecium. Ends of mature appendages have many

Figure 92. *Cystotheca lanestris* witches' broom symptom on coast live oak.

Figure 93. *Microsphaera extensa var. curta* on valley oak.

Figure 94. *Microsphaera extensa var. curta* on blue oak.

short dichotomous branches (*fig. 95*). Each ascus has four to six (rarely three to eight) ascospores. Conidia are roughly cylindrical to somewhat barrel shaped.

P. angulata cleistothecia are large (about 270 µm diameter) and have needle-like appendages that are inflated at the base. Cleistotheica contain about 10 asci, each with two ascospores. Conidia are roughly cylindrical or somewhat constricted in the middle.

Figure 95. Micrograph of *M. extensa var. curta* cleistothecia showing unbranched developing appendages and characteristic dichotomously branched appendages.

Biology

Powdery mildew fungi derive nutrition from living host cells, so infected host tissues are generally not directly killed by these parasitic fungi. Most powdery mildew leaf infections affect only the outermost layer of leaf cells (epidermis), but the systemic infections caused by *C. lanestris* affect multiple cell layers.

Powdery mildew fungi overwinter as cleistothecia or, in the case of *C. lanestris*, as mycelium in infected buds. Cleistothecia may be less likely to form on evergreen oaks than on deciduous oaks. In spring, ascospores are released from the cleistothecia and are blown or splashed onto host leaves. After ascospores germinate, they form swollen structures (appressoria) on the leaf surface. Hyphal pegs formed under the appressoria penetrate host epidermal cells. Fungal structures (haustoria) are formed within living host cells and absorb nutrients that the fungus uses for growth and reproduction. Most of the fungal mycelium grows on the outer surface of infected leaves. Dry conidia are formed on this superficial mycelium and are blown to young succulent shoots where they initiate new infections throughout the growing season. Infections by powdery mildew conidia are favored by warm days and cool nights and inhibited by wet conditions. Vigorous new growth produced late in the growing season, such as stump sprouts and epicormic shoots produced after heavy pruning, may develop severe powdery mildew infections. Unlike the other powdery mildew infections, which are most noticeable in late summer and fall, infections by *B. trina* can be found in the spring.

Importance

Levels of infection are not normally severe enough to substantially affect plant health, except possibly in small seedlings. Symptoms, including mycelium, witches' brooms, and leaf distortion, may be unsightly.

Branch canker

Diplodia quercina

Distribution/Hosts

This pathogen has been reported only from oaks in California and Europe. In California, it has been reported to occur on coast live, valley, and California black oak.

Symptoms

Infections are normally found on branches up to 10 cm in diameter. The fungus can girdle infected branches causing leaves beyond the point of infection to wilt and die. Affected trees show discrete dead branches in the crown (*fig. 96*) as opposed to the widely scattered twig dieback caused by anthracnose/twig blight fungi. Infections cause extensive dark brown discoloration of the wood. The border between discolored and healthy tissue is generally well-defined (*fig. 97*). Fruiting bodies emerge from the bark, causing a roughened appearance.

Agent Description

Diplodia quercina produces tiny flask-shaped asexual fruiting bodies (pycnidia). On branches with bark, pycnidia are in black masses of fungal tissue (stromata). Pycnidia also occur singly on the surface of wood that has lost its bark. Asexual spores (conidia) are about 30 by 15 µm or larger.

Figure 96. Dead branches on California black oak (top) and coast live oak (left) due to Diplodia canker.

Photo: Larry Costello, UC Cooperative Extension.

Figure 97. Diplodia canker on an artificially inoculated, greenhouse-grown coast live oak seedling.

Photo: Steve Koike, UC Cooperative Extension.

Conidia are initially one-celled and colorless but become dark with one or more cross walls (septae). The sexual stage of *D. quercina* is reported to be *Botryosphaeria stevensii*, but this stage has not been reported on oaks in California.

Biology

The fungus may enter branches through wounds and possibly natural openings such as leaf scars. The fungus can only be recovered from within a few centimeters of the infection point even though discoloration may extend 0.6–1 m further (Hecht-Poinar and others 1987, Costello and others 1989). In artificial inoculations, asexual fruiting bodies are produced within 24 weeks and continue to produce spores for about two years. Spore production and germination are favored by moisture. Drought stress may predispose trees to infection. The disease became widespread following the extreme drought of 1976–1977.

Importance

Historically, this disease has been commonly reported only after severe drought conditions and is not a widespread problem in most years. Drought-stressed trees with wounded branches are most likely to be affected.

Orange hobnail canker

Cryphonectria gyrosa
(=*Endothia gyrosa*)

Distribution/Hosts

Cryphonectria (=*Endothia*) *gyrosa* has been reported on coast live oak in the San Francisco Bay Area but may also occur on other oaks and in other areas. It has also been observed on tanoaks in coastal Sonoma County. This pathogen is widespread in the eastern U.S. and the southeast from Virginia to Texas, where it occurs on many hardwood trees, including oaks, beech, sweetgum, American elm, and American chestnut. Oak hosts are primarily in the red/black oak subgroup and include eastern black, cork, English, southern live, pin, post, northern red, southern red, scarlet, water, and willow oak. The fungus is also reported from Europe, Asia, and New Zealand.

Symptoms

The fungus causes somewhat sunken, slowly expanding cankers which may girdle and kill branches and trunks of trees under stress. Cankers sometimes extend from smaller branches to the larger parent branch. Small (1–2 mm diameter), cushion-shaped masses of fungal tissue containing fruiting structures (stromata) erupt from the bark of killed stems (*fig. 98*). Stromata are initially bright orange but become cinnamon brown with age. Stromata

Figure 98. *Cryphonectria gyrosa* stromata on coast live oak.

Figure 99. Close-up of *C. gyrosa* stromata. At right is a slide mount of stromata in a solution of potassium hydroxide, showing the characteristic release of red pigment.

remain bright orange internally and release a beet-red pigment when wetted with a solution of potassium hydroxide (*fig. 99*). The common name, hobnail canker, refers to the masses of rounded, bumpy stromata that appear on affected stems.

Agent Description

Stromata that emerge from killed bark initially produce asexual spores (conidia) in irregular chambers. Conidia of the asexual stage (*Endothiella gyrosa*) are colorless, straight to somewhat curved rods that are 3–4 by 0.75–1.5 µm. Flask-shaped sexual fruiting structures (perithecia) are produced in the stromata late in the season. Perithecia are 150–300 µm in diameter, with elongate necks that protrude slightly above the surface of the stroma. Sexual spores (ascospores) are produced in saclike structures (asci) within the perithecia. The one-celled, curved ascospores are 7–11 by 1–3 µm.

Biology

The biology of this fungus in California has not been studied. The fungus is reported to infect through wounds, such as those which form naturally through branch breakage, or through pruning cuts or other mechanical wounds. Moisture favors dispersal of spores, so presumably most infections occur during the rainy season. Asexual spores are most likely spread by rain splash, and possibly by insects or pruning tools. Ascospores are probably wind-dispersed. On many hosts, canker expansion occurs most rapidly on drought stressed trees during summer months.

Importance

On coast live oak, *C. gyrosa* is typically a branch pathogen, often affecting suppressed or wounded branches.

Oak mistletoe

Phoradendron villosum

Distribution/Hosts

Oak mistletoe occurs from northwestern Oregon, throughout California, and into Mexico. Reported oak hosts in California include valley, blue, Oregon white, coast live, interior live, canyon live, and California black oak. *Phoradendron villosum* prefers oaks as a host but is also found on some other hardwoods, including California bay, manzanita, *Adenostoma*, and *Rhus*. The related *P. macrophyllum* (big-leaf mistletoe) attacks other hardwoods such as alder, ash, walnut, sycamore, cottonwood, mesquite, locust, and willow, but not oaks.

Symptoms

Oak mistletoe forms spherical to ellipsoidal clumps of light green leafy shoots that emerge from oak branches. The oak branch is slightly to significantly swollen at the point where clusters of mistletoe shoots emerge. Over time, the portion

Figure 100. Oak mistletoe clumps in the upper canopy of a dormant blue oak. Mistletoe infestations are most obvious in deciduous oaks during the winter.

of the oak branch beyond the mistletoe clump may decline and die. Clumps of oak mistletoe are often located in the upper portion of oak canopies (*fig. 100*). Mistletoe infections tend to be clustered and multiple clumps commonly occur in individual trees or in groups of adjacent trees.

Figure 101. Shoots and leaves of oak mistletoe, showing inflorescences in leaf axils. A few of the white berries are visible in the lower half of the photo.

Agent Description

P. villosum plants are evergreen with thick obovate-elliptic leaves that are 1.5–4.7 cm long by 1–2.5 cm wide (*fig. 101*). The leaves and young stems are covered with whitish or yellowish hairs, but older stems are hairless (glabrous). Branches are generally erect, although longer stems, which can be up to 1 m long, may become pendulous under the weight of the foliage. Flowers are present between July and September with male and female flowers occurring on separate plants. Fruit are globose, 3–4 mm in diameter, pinkish white, and have short hairs near the tip.

Figure 102. Clump of oak mistletoe seeds deposited via bird droppings on an oak branch.

Biology

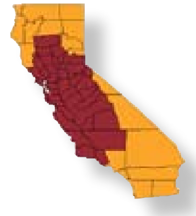
Oak mistletoe fruit mature in early winter. The fruit are eaten by various birds, including robins, bluebirds, thrushes, and cedar waxwings. Seeds in consumed fruit pass quickly through birds' digestive systems and are defecated onto the source tree or nearby trees (*fig. 102*). Seeds are coated with a sticky fluid which helps them adhere to bark surfaces. Wet conditions favor seed germination. Germinating seeds produce a root-like structure that grows along the bark surface to a point where it produces a specialized structure (haustorium) that penetrates into the bark. Within the host branch, the mistletoe plant forms connections between its own phloem and xylem cells and those of the host. The connections allow the mistletoe plant to absorb water and nutrients from its host. One or more years may elapse between infection of the host stem and the emergence of green mistletoe shoots. Although dependent on the host oak for water and mineral nutrients, leafy mistletoe plants meet all of their carbon-based energy and nutritional needs through their own photosynthesis. Mistletoe plants are perennial and generally live until the branch of the host on which they are situated dies.

Importance

Leafy mistletoe usually has little impact on healthy oaks, although it may be unsightly in urban settings. Swellings on stems may serve as points of entry for wood decay fungi. *P. villosum* uses water at a higher rate than its host oaks. Oaks with heavy mistletoe infestations may therefore deplete available soil moisture reserves earlier in the season. Earlier and/or more severe water stress levels related to heavy mistletoe infestations can lead to early defoliation in deciduous oaks and may contribute to decline in some trees.

Canker rots

Inonotus andersonii, *I. dryophilus*



Distribution/Hosts

These canker rot fungi are distributed throughout oak woodlands in California, the Pacific Coast and the southwestern U.S. as well as in the oak-hardwood forests of the eastern U.S.

Inonotus andersonii is reported from coast live, California black, blue, and valley oak in California, but probably infects other oak species as well. In addition to oaks, it reportedly occurs on *Carya*, *Populus*, and willow.

I. dryophilus is reported on coast live, interior live, canyon live, California black, Oregon white, blue, and valley oak in California. It is primarily found on living oaks, but is also reported on maple, *Populus*, *Prunus*, *Schinus*, and willow.

Symptoms

These fungi cause a white rot of the heartwood of living oaks but also decay strips or sections of sapwood. For *I. andersonii* especially, wood with advanced decay appears bleached, is very light weight, and crumbles easily. Where sapwood decay reaches the cambium, the cambium may be killed, giving rise to an externally visible canker. Cankers are commonly elongate and may become callused at the edges (*fig. 103*). Cankers are sometimes

Figure 103. Blue oak with typical elongate canker rot cankers and fruiting body of *Inonotus dryophilus*.

associated with an elongate, decayed cavity. The bark near expanding or developing cankers may ooze varying amounts of dark sap.

Affected branches or trees may show general symptoms of decline including poor growth, thinning, dieback, epicormic shoots (short twiggy branches arising from dormant buds on large-diameter stems) and branch or trunk failures. Generally, trees with canker rots decline slowly, often appearing to die from the top down as they slowly fall apart over a period of many years.

The fruiting bodies (basidiocarps) may appear on living trees or on recently-failed stems.

Agent Description

I. andersonii produces a sheet-like (resupinate) annual basidiocarp on dead wood under the bark, or occasionally between outer sapwood layers. Basidiocarps are commonly 0.3–1 m long. Fresh basidiocarps are cinnamon brown (*fig. 104*), but become black as they age (*fig. 105*). The basidiocarp consists of two layers: a thin (up to 1 mm thick) layer of sterile tissue (context) that is attached directly to the woody substrate and a layer of downward-pointing tubes (up to 1 to 2 cm long) attached to the context that terminate in an uneven layer of circular to angular pores (1–6 per mm). Bright chrome yellow

Figure 104. Close-up of *I. andersonii* fruiting on coast live oak, showing resupinate pore layer formed under bark on recently killed wood. Bright yellow spores have been deposited on bark, which has been peeled away from the wood for the picture.

Figure 105. Old resupinate pore layer of *I. andersonii* has dark brown to black appearance.

Figure 106. Fallen coast live oak branch with distinctive deposit of chrome yellow *I. andersonii* spores at the bark/wood interface.

Figure 107. Close-up of *I. dryophilus* fruiting on interior live oak.

deposits of basidiospores develop on the inner surface of bark that initially covers new basiodiocarps (*fig. 104, 106*). Spore deposits become brown over time.

I. dryophilus basidiocarps are annual, hoof-shaped, up to 11 by 19 by 9 cm, usually solitary, and firm and corky when fresh (*fig. 107*). The upper surface of the basiodiocarp (pileus) is buff to reddish-brown. The lower surface is covered with a layer of tubes up to 3 cm thick that terminate in a smooth layer of small angular pores (1–3 per mm). The pore surface is white to buff at first, but becomes dark reddish-brown with age. Basidiospores are brownish. The context (sterile tissue between the tube layer and the pileus) mostly consists of a hard, granular core of intermixed brown and whitish mycelium.

Biology

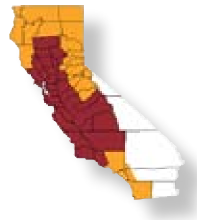
Basidiocarps mature mainly between fall and spring. *I. dryophilus* typically fruits on living stems. *I. andersonii* only fruits on dead wood, including dead portions of living stems, dead branches, or on stems that have failed due to decay. Basidiospores are produced along the inner walls of the tubes in the basidiocarp. They are discharged though the pores on the lower surface of the basidiocarp and are disseminated by air currents. Basidiospores initiate new infections, most likely by invading wounds such as broken branch stubs or pruning cuts.

Importance

I. andersonii and *I. dryophilus* are among the most frequently observed wood decay fungi on living oaks in many types of hardwood forests. These fungi are serious pathogens of California oaks and are associated with oak decline, failure, and mortality in many California oak woodlands.

Hedgehog fungus

Hericium erinaceus f. *erinaceus*



Distribution/Hosts

Hericium erinaceus is known by several common names including lion's mane and hedgehog fungus. It is widely distributed throughout temperate North America and is also found in Europe and Asia. It occurs on a variety of oaks and other hardwoods, including maple, ash, and eucalyptus. In California, *H. erinaceus* f. *erinaceus* has been reported on coast live, canyon live, interior live, California black, blue, and valley oak.

Figure 108. Fresh fruiting body of *Hericium erinaceus* f. *erinaceus* at the edge of a decayed wound on coast live oak.

Symptoms

The fungus is usually associated with a wound and causes a white pocket rot of living trees. Decayed tissue becomes spongy and eventually disintegrates to form a cavity. The distinctive fruiting bodies (basidiocarps) generally appear near the edges of old wounds in the fall (*fig. 108*).

Agent Description

The basidiocarps are annual, usually solitary, and 10–20 cm across at maturity. They commonly form on wounds or recently-cut log ends. The spore-bearing surface consists of many closely-packed, slender, icicle-like teeth that are 2–5 (rarely 1–10) cm long. The teeth are white when fresh, and become pale yellow, brownish, or rarely reddish with age. Spores are nearly globose, 5–6 by 4–5.5 μm, and smooth to slightly roughened. The spore print is white. Young basidiocarps are edible but may cause allergic reactions in some individuals.

Biology

Basidiocarps are formed in the fall months, often at the site of a wound. Basidiospores are disseminated by air currents. Infection presumably occurs at wounds such as cracks, fire scars, or branch stubs.

Importance

This fungus has the potential to affect tree health and increase failure in infected trees. It is not observed as commonly as other decay fungi in most stands.

Hypoxylon thouarsianum

Distribution/Hosts

Hypoxylon thouarsianum occurs throughout much of California. Its reported range also includes the southeastern U.S., Central and South America, and parts of Africa, including South Africa and Tanzania. It occurs on California black, blue, coast live, interior live, canyon live, and valley oak, as well as tanoak. It is occasionally found on other species including hackberry and avocado.

Symptoms

Black hemispherical fruiting bodies (stromata) of *H. thouarsianum* develop, sometimes in great numbers, on the surface of dead bark or wood (*fig. 109*). The fungus causes a white rot of the sapwood of living trees and dead wood. Sapwood decay caused by *H. thouarsianum* in trees affected by *Phytophthora ramorum* canker may be quite extensive and may lead to branch or trunk failure.

Agent Description

Figure 109. Mature *H. thouarsianum* fruiting bodies on coast live oak.

Immature stromata that emerge through the bark over wood colonized by *H. thouarsianum* are initially rounded, black, smooth, and glossy and covered with a thin, fragile membrane. This short-lived membrane ruptures, revealing a layer of powdery, dark olive green asexual spores (conidia) on the surface of the new stromata (*fig. 110, 111*). Conidia are subglobose, about 6 µm in diameter, and are borne on densely packed specialized spore bearing hyphae (conidiophores). Mature stromata are hard, hemispheric to nearly spherical, 1–4 cm in diameter, and blackish brown to black. Stromata may occur singly or in merged overlapping clusters. Internally, mature stromata are carbonaceous with some faint concentric zonation (*fig. 112*). Sexual spores (ascospores) are formed in flask-shaped structures (perithecia) arranged in a single layer just below the outer surface of the stroma. The rounded openings of the perithecia are visible as fine bumps that cover the outer surface of the stroma. Ascospores are dark brown, smooth, ellipsoidal, and 14–24 by 4–5.5 µm.

Figure 110. Young *Hypoxylon thouarsianum* fruiting body on tanoak covered with powdery asexual spores (conidia).

Figure 111. Maturing *H. thouarsianum* fruiting bodies (center) show remnants of conidia between bumps formed by the openings of the underlying perithecia. Small newly emerging fruiting bodies to the left and below are still covered by a shiny thin membrane.

Biology

Little is known about the biology of this species. Many *Hypoxylon* species initiate latent (dormant or inactive) infections in healthy hosts or grow to a limited degree within host tissues without causing obvious disease symptoms. When the host is severely stressed, some *Hypoxylon* species become opportunistic pathogens, and may cause rapid and extensive decay of the sapwood. *H. thouarsianum* commonly fruits abundantly on or near bark cankers caused by *Phytophthora ramorum*. It is also commonly found on dead or declining branches and on downed wood. It is unclear whether conidia and/or ascospores establish infections, but infections are probably initiated during the wet season.

Importance

This fungus appears to be of little consequence in healthy trees, but can quickly overrun severely stressed trees and trees with extensive *Phytophthora ramorum* cankers. Sapwood decay caused by this pathogen probably plays a role in rapid tree death that occurs in some *Phytophthora ramorum*-infected trees. *H. thouarsianum* contributes to the failure potential of both living and dead *P. ramorum*-infected stems.

Figure 112. Sliced *H. thouarsianum* fruiting body shows slightly zonate interior and outer layer of perithecia which contain sexual spores (ascospores).

Sulfur fungus

Laetiporus gilbertsonii
(=*L. sulphureus* in part)

Distribution/Hosts

The taxonomy of this fungus in North America has recently been revised by Burdsall and Banick (2001). Fungi previously described as *Laetiporus sulphureus* in the Pacific Coast and southwestern states have been renamed *L. gilbertsonii* if they occur on hardwoods and *L. conifericola* if they occur on conifers. In California, *L. gilbertsonii* has been observed on blue, valley, California black, coast live, interior live, and canyon live oak, as well as eucalyptus, *Prunus*, and probably other hardwoods.

Symptoms

This fungus causes a distinctive brown cubical wood decay of living trees, as well as dead trunks and logs (*fig. 113*). Wood decayed by *L. gilbertsonii* is a cinnamon to dark brown color and tends to fracture into flat-sided, somewhat cubical pieces. *Daedalea quercina*, which is uncommon in California, is the only other reported cause of brown rot in living oaks in the state. Brown rot caused by *L. gilbertsonii* commonly leads to failure of large branches or the trunk (*fig. 114*). White to pale yellow felt-like masses of fungal tissue (mycelium) are prominent in shrinkage cracks in the decayed wood. Fruiting bodies (basidiocarps) are initially bright yellow and become orange on top before fading to a pale color.

The distinctive bright yellow basidiocarps may be the first obvious symptoms of infection by *L. gilbertsonii*. The presence of basidiocarps indicates that substantial internal decay is present and often presages failures at the root crown, trunk, or major branches. However, basidiocarps may not form on affected trees until after failure has already occurred.

Figure 113. Brown cubical wood decay of California black oak caused by *Laetiporus gilbertsonii*.

Figure 114. This *L. gilbertsonii* basidiocarp on valley oak developed on the scar left by a large scaffold failure.

Figure 115. Cluster of *L. gilbertsonii* basidiocarps on interior live oak.

Figure 116. Close-up of fresh *L. gilbertsonii* basidiocarps on California black oak.

Agent Description

Basidiocarps are annual and occur singly or in stacked clusters (*fig. 115*). Newly emerging basidiocarps may appear as bright yellow lumpy masses, but mature to form moist, fleshy, shelf-like fruiting bodies. Basidiocarps are edible when young but may cause allergic reactions in some individuals. Mature basidiocarps are yellow with orange to brownish-orange banding on the upper surface; the lower pore surface is a light to intense lemon yellow and covered with fine circular pores (3–4 per mm) (*fig. 116*). Basidiocarps fade to pale brown or white with age and become dry, chalky, and crumbly. Individual basidiocarps are variable in size, ranging up to at least 20 cm in diameter.

Biology

Basidiocarps are formed in the fall months, often before the first fall rains, and may form in the same location for multiple years. These fruiting bodies release basidiospores, which are disseminated by air currents. Infection presumably occurs most commonly through wounds such as broken branch stubs, pruning cuts, or fire scars. Basidiocarps are typically formed only after the amount of internal decay is considerable.

Importance

L. gilbertsonii is the most important brown rot fungus on oaks in California and is a major cause of tree failure and failure-associated tree mortality.

Other wood decay fungi affecting branches and trunk

In addition to the decay fungi described below and elsewhere in this publication, species of *Pleurotus*, *Trametes*, and *Stereum* are commonly found fruiting on dead wood in living trees, such as on dead branches or fire-scarred areas of the trunk. These fungi cause a white rot of dead wood. They generally do not appear to attack live wood, but will decay wood that has been killed by other agents.

Phellinus gilvus

In California, *Phellinus gilvus* occurs on coast live, California black, and blue oak and probably other oaks. It is found on oaks and many other hardwoods throughout much of the U.S. It decays both living and dead trees, causing a uniform white rot. In California oaks, *P. gilvus* usually colonizes dead wood and severely declining stems. It is also often found on coast live and California black oak with advanced symptoms of *Phytophthora ramorum* canker, where it can cause extensive sapwood decay and is associated with an increased likelihood of branch and trunk failures. *P. gilvus* fruiting bodies (basidiocarps) are shelf-like, 5–15 cm wide, 1.5–3 cm thick, corky, annual or perennial, and solitary or in overlapping clusters (*fig. 117, 118*). The upper surface is generally dark yellowish brown but is variable in appearance and may be wrinkled, woolly, and/or zonate. The lower surface is covered with minute round pores (6–8 per mm)

Figure 117. *Phellinus gilvus* and *Hypoxylon thouarsianum* fruiting on failed coast live oak.

Figure 118. Close-up of *P. gilvus* basidiocarp on coast live oak showing light pore surface.

and is initially buff-colored becoming dark purplish brown at maturity. The pores are white within.

Phellinus robustus (=Fomitiporia robusta)

Phellinus robustus is found across the U.S. in forests which contain oaks. In California, it has been observed on coast live and interior live oak, and probably occurs on other species as well. *P. robustus* causes a white rot of the trunk and large woody roots of living oaks. Infections on the trunk or large branches may be associated with canker rot symptoms. *P. robustus* decay is also associated with stem failure and tree decline. Fruiting bodies (basidiocarps) are produced at the base of the tree or higher up the stem (*fig. 119, 120*). They are hoof-like, perennial, very hard, often massive (up to 20 cm wide and 11 cm thick), and usually in clusters. The upper surface is brown to blackish, concentrically zonate, irregularly cracked, and lacks hairs. The lower surface is covered with fine circular pores (7–9 per mm) and is yellowish to grayish brown.

Figure 119. *Phellinus robustus* basidiocarps high on the trunk of this coast live oak are associated with a trunk cavity and canker rot symptoms.

Figure 120. *P. robustus* basidiocarps at the base of a coast live oak.

Sudden oak death, Phytophthora ramorum **canker**

Phytophthora ramorum

Phytophthora stem canker

P. nemorosa, P. pseudosyringae

Distribution/Hosts

Disease and tree mortality due to *Phytophthora ramorum* was first noted in Marin and Santa Cruz counties in the mid 1990s, but the causal agent was not positively identified until 2000. This introduced pathogen is currently known in California forests from the counties bordering the San Francisco Bay and the Coast Ranges from Humboldt to Monterey Counties, and Curry County in southern Oregon. Future expansion of the known range in California is likely due to both spread of the pathogen and intensive efforts to detect infestations. *P. ramorum* causes cankers on the main stems of coast live, California black, and Shreve oak, and tanoak. It also causes lesions on leaves, twigs, and/or small stems in a variety of native species, including tanoak, canyon live oak, California bay, madrone, California huckleberry, manzanita, toyon, poison oak, Douglas-fir, and coast redwood. In California, the disease is found in mixed hardwood forests containing oaks, usually in association with California bay, and in forests containing tanoak. *P. ramorum* also causes foliar and stem diseases in a wide variety of ornamentals and has been found in nurseries in North America and Europe. In Europe, disease caused by *P. ramorum* has also been found in some landscape plantings and in trees near these plantings.

P. nemorosa is currently known only from California coastal forests from Monterey County north to Central Oregon and from one location

in Mariposa County in the Sierra Nevada. It is common in redwood-tanoak forests, causing cankers on tanoak and foliar symptoms on redwood. *P. nemorosa* is uncommon in coast live oak woodlands, where it primarily causes foliar symptoms on California bay. It also causes foliar symptoms on manzanita and rarely causes stem cankers on coast live oak.

P. pseudosyringae is currently known to occur in California from San Luis Obispo County to Humboldt County and has been found at the same location in Mariposa County as noted for *P. nemorosa* above. This species appears to occur in somewhat drier, more inland sites, almost exclusively in coast live oak woodlands, where it causes cankers on coast live oak and leaf lesions on California bay. *P. pseudosyringae* also occurs in Europe where it is known to cause root and collar rot of oak, alder, and beech.

Symptoms

P. ramorum causes small to extensive bark cankers. In tanoak, *P. ramorum* also infects leaves and twigs, causing twig dieback on both mature trees and understory seedlings and saplings. In oaks, cankers are normally confined to the lower trunk and sometimes low scaffold branches, but oak twigs, canopy branches, and main stems less than about 10 cm diameter are not affected. Cankers do not extend more than a few cm below the soil line, but can occur on exposed buttress roots.

Figure 121. Extensive older *P. ramorum* canker on coast live oak showing both recent bleeding and older area of killed bark that has begun to crack.

Cankers generally ooze dark reddish brown to black sap (*fig. 121, 122*), but some cankers, especially on small diameter tanoak stems, do not ooze. Shaving away outer bark in affected areas reveals a brownish discolored lesion in the bark, with a sharp margin generally delimited by a dark line (*fig. 123, 124*). Bark (phloem) tissues are killed and dark discoloration may extend a few mm to several cm into the wood. Cankered areas are commonly attacked by secondary agents, including *Hypoxylon thouarsianum*, *Phellinus gilvus*, ambrosia beetles, and bark beetles.

Figure 122. Bleeding *Phytophthora ramorum* canker on coast live oak; this canker is less than one year old.

Trees with extensive girdling cankers may die one to two years after cankers develop without showing substantial decline of the canopy beforehand. Especially in warm weather, the drying foliage may turn brown over a period of a few weeks; the name "sudden oak death" was based on this pattern of

Figure 123. Same *P. ramorum* canker shown in Figure 122 with outer bark sliced away to show the dark canker margin.

Figure 124. *P. ramorum* canker on coast live oak; outer bark has been sliced away showing the irregular margin of the canker.

symptom development. In trees with less extensive or slower-spreading cankers, a gradual thinning and progressive dieback of the canopy may develop over several years. Trees that have not been completely girdled by cankers may survive for a number of years after infection, but many eventually die once the stem is completely girdled or when the trunk fails due to wood decay associated with cankered areas. Small cankers in some trees apparently become inactive and may not be colonized by secondary agents. Inactive cankers cease bleeding, may become sunken, and are often bounded by host callus tissue (*fig. 125*).

Figure 125. Coast live oak tree with extensive *P. ramorum* cankers at least 4 years old; sunken canker at the base of the tree shows callus development along right side (arrows).

P. nemorosa causes bark cankers similar to those described above on tanoak primarily, but appears to be less virulent than *P. ramorum*.

P. pseudosyringae causes bark canker symptoms similar to those caused by *P. ramorum* on coast live oak (*fig. 126*). Cankers can be quite extensive, occasionally girdling and killing trees. Overall, this species appears to be somewhat less aggressive than *P. ramorum*.

Agent Description

Phytophthora species fill an ecological niche similar to various fungi, but are members of the kingdom Chromista, which also includes diatoms and brown algae. All structures of *Phytophthora* species are microscopic. *Phytophthora* species reproduce asexually through production of swimming spores (zoospores) which are produced in sporangia. Species are

Figure 126. *P. pseudosyringae* canker on coast live oak.
Photo: Allison Wickland, UC Davis.

distinguished based on the sizes and characteristics of sexually produced spores (oospores), sporangia, thick-walled asexual spores (chlamydospores), and swellings in the vegetative filaments (hyphae).

P. ramorum produces abundant deciduous, nonpapillate sporangia singly or in clusters of two to 12 or more arranged sympodially on long stalks. It produces numerous chlamydospores when grown on most synthetic media and on some foliar hosts. Colony morphology on synthetic growth media is distinctive, with a highly branched growth pattern.

P. nemorosa produces abundant deciduous, scarcely semipapillate sporangia in terminal clusters on stalks (sporangiophores) that branch sympodially. No chlamydospores are produced.

P. pseudosyringae produces abundant deciduous, semipapillate, sporangia in loose to dense sympodially branched clusters. It produces hyphal swellings but no chlamydospores.

Biology

Disease caused by *P. ramorum* is favored by moderate temperatures (near 20 °C) and rain or free surface moisture. Sporangia are formed on the surface of leaves and on twigs of some host plants and can be detached and spread by rain splash and possibly air currents. Infected California bay leaves are probably the most important source of sporangia in woodlands where coast live and California black oak are the main stem canker hosts. Sporangia produced on tanoak twigs may be the most important source of inoculum for that host. Sporangia may germinate as a unit and infect directly or, in the presence of free water, each sporangium can release multiple zoospores. Zoospores swim in water and seek out suitable host tissues. Flow of water down stems during rain storms may concentrate sporangia and zoospores in the lower trunks of oaks and tanoaks where most stem cankers are initiated. Sporangia do not form on bleeding oak and tanoak stem cankers, so reproduction and spread of the pathogen depend primarily on spores produced on infected California bay leaves, tanoak twigs, and possibly some other foliar hosts. *P. ramorum* has been detected in streams and rivers and may also reproduce on fallen leaves of foliar hosts or other substrates in standing or flowing water. *P. ramorum* does not appear to cause substantial root disease in oak and tanoak stands, but has been recovered from the roots of some host species. In contrast, many other *Phytophthora* species primarily attack the roots of their hosts. *P. ramorum* can be detected in soil during and after the wet season but becomes difficult to recover from soil after extended dry periods.

Less is currently known about the biology of *P. nemorosa* and *P. pseudosyringae* in California forests. Both are favored by wet conditions, have deciduous sporangia, and produce zoospores that are likely to be dispersed by rainwater. *P. nemorosa* is adapted to cooler temperatures, and grows optimally at 15 ˚C on synthetic media. For *P. pseudosyringae* optimum growth on synthetic media occurs at 20 ˚C. At least in Europe, *P. pseudosyringae* is capable of living in the soil and causing root disease.

Importance

At present, *P. ramorum* is probably the most important agent causing mortality of coast live oak, California black oak, and tanoak in affected forests. Compared with *P. ramorum*, *P. nemorosa* and *P. pseudosyringae* affect far fewer trees and are much less likely to kill trees.

Sunscald

Distribution/Hosts

Sunscald can occur in most parts of California, but is more common in hot, interior valleys than along the coast. Transplanted young oaks of most species can be affected. Among mature trees, species with thin, smooth outer bark, including coast live and interior live oak, are more likely to develop sunscald.

Symptoms

Symptoms appear on areas of bark that are exposed to the highest sunlight intensity, generally on the west or southwest side. Affected bark may become sunken and darkened, and typically shrinks and cracks as it dries out (*fig. 127, 128*). Dark sap commonly bleeds from recently affected bark or the margin of the affected area. In mature trees with thick bark, only the outer layers of bark may be affected (*fig. 129*). Localized beetle boring or opportunistic decay fungi such as *Trametes versicolor* or *Stereum* spp. may colonize the wood in areas where the cambium is completely killed. Over time, callus may develop around the affected area and eventually the dead bark falls off.

Figure 127. Lower trunk of a transplanted coast live oak shows evidence of abundant past oozing associated with sunburn injury.

Biology

Sunscald develops in trees whose bark is suddenly subjected to a greatly increased level of solar radiation. This commonly occurs in newly transplanted young trees. Nursery stock that is grown under relatively shaded conditions and/or lacks low branches

Figure 128. Mature coast live oak stem sunburned due to loss of surrounding tree canopy shows darkening, cracking, and some bleeding.

Figure 129. Bark cut away from bleeding area shows that bark tissue death (necrosis) is limited to the outermost layers of the inner bark.

needed to shade the trunk is most likely to develop sunscald when it is planted in hot, exposed landscape settings. In mature trees, sunburn is most likely to develop where previously shaded bark is exposed to high sun intensity as the result of pruning, tree failure, or other rapid changes in canopy cover. Sunscald is more likely to develop in water-stressed trees and following episodes of unusually high temperatures.

Importance

Sunscald occurs most commonly on transplanted nursery stock and can contribute to poor health, decline, or death, especially in small trees. It may develop in mature stems that have been overpruned or have lost overtopping canopy, especially in species such as coast and interior live oak, which have relatively thin outer bark. Species with relatively thick outer layers of corky or flaky bark seldom develop sunscald. Areas affected by sunscald may be susceptible to invasion by some wood decay fungi.

Wetwood and alcoholic flux

Various microorganisms

Distribution/Hosts

Wetwood is common in California and occurs worldwide on oak and many other tree species, especially ash, birch, elm, maple, poplar, and willow. Wetwood that occurs in conifers appears to differ from that found in hardwoods.

Alcoholic flux, also known as white, frothy, or foamy flux is reported to occur on various hardwoods, including oak, willow, sweetgum, and elm. It occurs throughout California and is common in the midwestern and southwestern U.S.

Symptoms

Wetwood – Cracks or wounds on branches or trunks of affected trees ooze a sour, rancid-smelling liquid, known as slime flux or wetwood slime, that is initially clear but darkens over time (*fig. 130, 131*). Microorganisms growing in the slime flux contribute to the foul odor and slimy texture of the ooze. Slime flux oozing commonly lasts for years. The slime flux stains the bark and other materials it contacts. Affected wood, primarily heartwood, appears water-soaked and discolored (*fig. 131*). Slime flux may kill cambium and bark (phloem) tissues it contacts, but necrosis (tissue death) associated with wetwood is typically

Figure 130. Bleeding (slime flux) due to wetwood on coast live oak. Ooze is initially clear and darkens with exposure to air.

Photo: Steve Tjosvold, UC Cooperative Extension.

Figure 131. Bark of this coast live oak was chipped away at the point where wetwood ooze originated to show a small area of watersoaked, necrotic bark. Foul-smelling, clear liquid streamed from the area for several seconds when the bark was cut open.

discrete and restricted to areas contacted by the ooze. Occasionally branches beyond the infected wood will wilt or die back.

Alcoholic flux – Symptoms most commonly occur in the summer and are generally limited to stressed trees. A clear to white, frothy exudate typically oozes from multiple spots for a relatively short time (*fig. 132*). The exudate has a pleasant, fermented, alcoholic odor. Alcoholic flux is sometimes found in trees in which the cambium and outer sapwood is decayed, white, and mushy.

In contrast with wetwood and alcoholic flux, cankers caused by *Phytophthora* species, including *P. ramorum*, may exude a relatively thick liquid that is initially dark colored, and has only a faint odor. Secondary organisms may invade *P. ramorum* cankers and give rise to alcoholic or fermented odors. Ooze from *Phytophthora* cankers is a by-product of tissue destruction caused by the pathogen, so the ooze is normally associated with relatively extensive discoloration and necrosis of the underlying bark and cambial tissues.

Figure 132. Foamy flux bleeding from the bark of a coast live oak in southern California that was severely stressed due to extensive root damage; detail (lower left) shows moist dead bark beneath oozing area.

Photo: Edward E. Gripp, Landscape Architect.

Agent Description

Wetwood is commonly caused by various species of anaerobic soil bacteria, including *Clostridium* spp. in oaks. The microorganisms responsible for alcoholic flux are not well characterized, but probably include aerobic bacteria, yeasts, and possibly other fungi.

Biology

Wetwood in oaks is a bacterial infection of the heartwood or inner sapwood. Bacteria that normally live in the soil enter the wood through cracks in the bark or wounds. Wood colonized by these bacteria develops a higher water content than normal wood. Metabolic activity of the bacteria releases gases, especially methane, leading to a buildup in pressure within affected wood. The elevated pressure helps force fluid out of affected wood through external openings in the tree. The liquid contains bacteria and their metabolic products including rancid-smelling fatty acids. Once the liquid is exposed to the air it can be colonized by a wide assortment of bacteria and fungi. The fermentation of the ooze by these organisms may cause it to darken and bubble or froth. Wetwood-infected wood is resistant to decay by fungi.

Alcoholic flux is poorly understood and is probably associated with several different causes. In some cases, it appears to result from the fermentation of sap in shallow wounds in the bark and cambium. In other cases, alcoholic flux may develop when areas of the cambium and/or bark killed by heat stress or other factors are colonized opportunistically by various microorganisms. Foamy exudation associated with some bark beetle attacks may be alcoholic flux.

Importance

Wetwood is not generally considered to have much impact on tree health, although the associated ooze may be considered a nuisance. Alcoholic flux appears to generally result from a secondary invasion of tissues that are damaged, severely stressed, or recently dead, and so may be an indicator of a more severe underlying condition.

Armillaria root rot, oak root fungus

Armillaria mellea

Distribution/Hosts

The name *Armillaria mellea* was previously applied to what is now known to be a number of distinct *Armillaria* species that vary in host and geographic range and pathogenicity. As currently understood, the range of *A. mellea* (narrow sense) extends throughout California to central Mexico, in the U.S. east of the Rocky Mountains, and to portions of Europe and Asia. In California forests, *A. mellea* is primarily associated with oaks and other hardwoods but also attacks conifers, especially in mixed conifer-hardwood stands. *A. mellea* also attacks a wide variety of woody cultivated hosts and is common in California's urban landscapes and agricultural areas, many of which were formerly oak woodlands.

The related *A. gallica* is also common in California oak woodlands and some conifer forests, but is rare in developed areas. It is commonly associated with oak roots, but does not appear to cause disease in oaks.

Symptoms

Trees with Armillaria root rot show general symptoms of poor root health, such as overall unthriftiness, canopy thinning, and branch dieback. Under conditions that favor disease, *A. mellea* can kill mature oaks. Trees with severe root rot also have an elevated risk of toppling due to root failure. Both woody

Figure 133. Coast live oak with *Armillaria mellea* mycelial plaques (fans) under bark and associated bleeding.

roots and the lower trunk may be colonized by the fungus, which kills the bark and cambium and causes a white rot of the underlying wood. The bark of diseased root crown areas or exposed buttress roots may ooze a thick, dark fluid. White sheet-like mycelial mats or plaques, often fan-shaped, form beneath the bark of diseased roots and the root crown (*fig. 133*). These mats have a mushroom odor when fresh. Affected wood initially has a water-soaked appearance, then becomes light colored and spongy as decay progresses. Dark, root-like structures (rhizomorphs) are commonly formed by the fungus on the surface of infected roots (*fig. 134*) and may extend into the soil. Rhizomorphs can also form under the bark of infected trees, generally late in the infection process. The combination of root decay coupled with the presence of both mycelial plaques (fans) and rhizomorphs is typically sufficient to diagnose *A. mellea* root rot in California oaks. *A. mellea* mushrooms sometimes form in the autumn or winter at the base of infected trees. *A. gallica* also produces rhizomorphs that may be associated with living oak roots, but is not likely to cause serious root disease in oaks.

Figure 134. *A. mellea* rhizomorphs and mycelial plaque (right side) growing on decayed root.

Agent Description

Rhizomorphs resemble small dark roots. Rhizomorphs are cylindrical to flattened in cross-section, up to about 2 mm in diameter, brown or blackish on the outside and white on the inside when fresh. Rhizomorphs lack any internal fibers and are not firm, whereas roots have a relatively tough, fibrous center of vascular tissue.

The fruiting bodies (basidiocarps) of *A. mellea* are gilled mushrooms (*fig. 135-137*), produced in clusters of eight to 10 but sometimes 30 or more. Clusters of mushrooms arise from a common base, and each stalk in the cluster tapers to a point at the bottom (*fig. 136*). Stalks are 5–20 cm tall, usually with a persistent ring on the upper part (*fig. 137*). The cap (pileus) is honey colored, 3–13 cm in diameter, with a smooth surface; it lacks the small scales seen in some other *Armillaria* spp. The spore print is white and spores are 7–9.5 by 5–7 µm. *A. mellea* is the only *Armillaria* species in North America that lacks a clamp connection (a rounded swelling of the hypha) at the base of the basidium. This is the most definitive characteristic of *A. mellea*, but can only be determined with a microscope.

Figure 135. Close-up *A. mellea* mushroom showing attached, slightly decurrent gills.

Figure 136. Young cluster of *A. mellea* mushrooms.

Biology

A. mellea infections are normally restricted to small root lesions in healthy oaks growing in natural stands, but the fungus thoroughly colonizes dead roots and can cause serious disease in oaks that are severely stressed. Although

Figure 137. Old cluster of *A. mellea* mushrooms fruiting from buried root, showing clustered habit, with ring on central stalk.

mushrooms release airborne basidiospores that can initiate new infections, this mode of spread appears to be very rare in California. Almost all spread of the disease is via spread between infected and noninfected roots that are in direct contact with each other or by growth of rhizomorphs through the soil to noninfected roots. Rhizomorphs can sometimes extend 1 m or more through the soil away from an infected root.

The fungus can survive for decades or longer in the soil on dead, decaying roots. Infections occur when healthy roots contact rhizomorphs or decayed root fragments. If high levels of inoculum are present in the soil, severe disease may develop even in resistant hosts such as oaks. High inoculum levels commonly develop on the dead roots of trees that have been cut or killed by other agents. Consequently, clusters of diseased trees may develop around old stumps or dead trees. Disease is also favored by warm, wet soils. Severe Armillaria root rot commonly develops in native oaks that are exposed to prolonged periods of irrigation in the summer. This typically occurs when irrigated landscaping is installed around existing oaks. Other factors that stress or damage roots, including soil compaction, addition of fill soil, and cutting or crushing of roots by construction equipment, favor the development of severe Armillaria root rot in oaks.

Importance

A. mellea is one of the most important pathogens of mature native oaks that are retained in urban developments and become incorporated into irrigated landscapes. It can also be a major problem in native stands subjected to altered soil moisture regimes, such as in oaks near reservoirs or other water impoundments. In contrast, *A. mellea* is normally a minor pathogen of undisturbed oaks in natural stands, typically only attacking oaks that are in severe decline due to other factors.

Ganoderma root rot

Ganoderma applanatum, *G. brownii*, *G. lucidum*

Distribution/Hosts

Ganoderma applanatum is widely distributed in forests throughout North America and much of the world. It has a wide host range, occurring on many living hardwoods and conifers. It also fruits on dead trees and stumps. In California, *G. applanatum* occurs on coast live, interior live, and California black oak and possibly other oaks, and is common on California bay.

G. brownii is known only from California on living and dead hardwoods including oak, California bay, citrus, *Hakea*, *Prunus*, and *Schinus*. It appears to be less common in California hardwood forests than *G. applanatum* or *G. lucidum*.

G. lucidum is widely distributed throughout the U.S. in hardwood forests and urban areas, except in the Rocky Mountain and Pacific Northwest regions. It occurs on a wide variety of living hardwoods, but also fruits on dead trees and stumps. In California, it has been observed on coast live, interior live, California black, blue, and valley oaks, and probably occurs on oaks throughout the state.

G. annularis and *G. lobatum* also occur in California, but these species reportedly only decay dead hardwoods, including oaks.

Symptoms

The presence of the fruiting body (basidiocarp), usually near the base of the tree, is generally the most obvious sign of Ganoderma root rot. Many trees can tolerate extensive root loss without showing obvious canopy symptoms. Ganoderma root rot may also cause affected trees to fail at the roots or root crown. Other symptoms of root and crown rot may be present, including canopy thinning and dieback, and affected trees may undergo either a slow or rapid decline. *G. applanatum* causes a mottled white rot of the roots and lower trunk. *G.*

brownii causes a white rot of the roots and lower trunk. *G. lucidum* causes a white rot of the heartwood, but can also decay sapwood and kill bark.

Agent Description

Like other polypore fungi (including *Phellinus*, *Inonotus*, and *Laetiporus*), sexual spores (basidiospores) are produced on the inside walls of thin vertical channels that terminate as open pores on the lower surface of the basidiocarp.

G. applanatum produces shelf-like, woody to corky, perennial basidiocarps at or near ground level or on the lower trunk (*fig. 138*). Basidiocarps may be associated with old wounds. Basidiocarps are variable in size, ranging from 6 to 60 cm wide and from 5 to 10 cm thick. The upper surface is hard, gray-brown to brown. Basidiospores (6–9 by 4.5–6 µm) are brown and are commonly deposited on the upper surface of the basidiocarp in great numbers, forming a brown dusty layer. The lower surface is covered with fine circular pores (4–6 per mm) and is white when fresh, quickly bruising brown when handled or inscribed. The basidiocarp is commonly referred to as the “artist’s conk”.

Figure 138. *Ganoderma applanatum* basidiocarp on coast live oak; brown basidiospores released from the fruiting body are visible both beneath it and on its upper surface

G. brownii produces perennial basidiocarps up to 20 cm wide and 5 cm thick. Basidiocarps are similar to those of *G. applanatum* except that the pore surface has a bright yellowish cast, which persists after drying. The growing margin of the basidiocarp is also yellowish. The fresh pore surface bruises dark brown. Basidiospores are 11–12 by 7–8 µm.

G. lucidum basidiocarps are annual, shelf-like or with a short stalk, and leathery to corky when fresh. They develop singly or in overlapping clusters at or near ground level. The upper surface is dark reddish brown and has a thin, shiny, varnish-like crust that becomes coated with a layer of dull brown basidiospores (9–12 by 5.5–8 µm) (*fig. 139*). The pore surface is creamy white, becoming light buff and bruising dark purple brown (*fig. 140*). Pores are circular to angular (4–5 per mm).

Figure 139. *G. lucidum* basidiocarp on California black oak; the coating of brown basidiospores has been rubbed away in one area to show the glossy upper surface.

Figure 140. Lower surface of *G. lucidum* basidiocarp; the white pore surface has turned brown where bruised by handling.

Biology

Fruiting bodies produce great numbers of basidiospores which are disseminated by air currents. New infections appear to be initiated primarily by basidiospores, with wounds being common infection sites. Extensive wood decay develops over the course of many years. Decline and mortality associated with Ganoderma decay may be more pronounced during periods of environmental stress, such as drought. In hardwoods, decay commonly extends 1–2 m above and below the location of the basidiocarp on the host. Although the white rot produced by *Ganoderma* spp. involves the degradation of lignin and cellulose, at least some *Ganoderma* spp., including *G. applanatum* and *G. lucidum*, cause selective delignification of the wood. Selective delignification, which can cause a mottled appearance in the decayed wood, occurs because lignin is degraded at a faster rate than cellulose and other polysaccharide components of the wood cell wall.

Importance

G. applanatum and *G. lucidum* are considered to be important causes of root decay in natural hardwood forests. Though widely distributed in California, basidiocarps of these fungi are found at relatively low frequencies on oaks in most stands. Trees with basidiocarps typically have extensive decay and should be considered to have an elevated risk of failure.

Phytophthora root rot

Phytophthora cinnamomi and other *Phytophthora* species

Distribution/Hosts

Phytophthora cinnamomi is a serious pathogen of many plant species in forest ecosystems and other native plant communities as well as in agricultural and horticultural situations. It affects plants in temperate, subtropical, and tropical regions on all continents except Antarctica. The known host range is in excess of 900 species, most of which are woody plants. It was probably introduced into California in the late 19th or early 20th century and is best known here as a pathogen of agricultural crops, including avocados and various orchard trees, and ornamental plants, including nursery stock and Christmas trees. It commonly affects oaks growing in irrigated landscapes, particularly coast live oak and cork oak, a non-native oak grown horticulturally. *P. cinnamomi* has been found in a native stand of coast live oak in San Diego County and has also become established in native manzanita stands in parts of Amador County where it also affects some native oaks. Other species of *Phytophthora*, including *P. citricola*, *P. cactorum*, and *P. citrophthora* have also been reported to attack coast live, valley, and cork oaks in irrigated landscapes.

Symptoms

Root-rotting *Phytophthora* species decay fine roots and can also invade larger woody roots and cause bleeding cankers on the root crown and lower trunk. In the early stages of infection, trees show little new growth, and develop small, yellowing leaves and a sparse canopy (*fig. 141*). Trees decline and die as cankers girdle the trunk. *Phytophthora* species attack the inner bark and cambium, causing dark brown discoloration of affected tissues (*fig. 142*). Dark brown to black lines are commonly found at the outer margin of the discolored infected tissue in the inner bark. Reddish brown to dark brown to black fluid may bleed from fissures in the bark in the cankered

Figure 141. Early (left) and advanced (right) decline of scrub oak (*Q. berberidifolia*) due to *Phytophthora cinnamomi* root rot. Both trees are along a small creek in an area infested with *P. cinnamomi* in Amador County.

area (*fig. 143*). Trunk cankers on oaks caused by *P. cinnamomi* and other soil-borne *Phytophthora* species typically originate below the soil or occasionally at the soil line and are normally associated with root rot. Although cankers caused by *P. ramorum* are similar in appearance, *P. ramorum* cankers are initiated above the soil level, seldom extend more than a few cm below the soil level, and are not associated with root rot.

Agent Description

Phytophthora species fill an ecological niche similar to various plant pathogenic fungi, but are members of the kingdom Chromista, which includes both diatoms and brown algae. All structures of *Phytophthora* species are microscopic. *Phytophthora* species reproduce asexually through production of swimming spores (zoospores) which are produced in sporangia (*fig. 144*). Species are distinguished based on the sizes and characteristics of sexually produced spores (oospores), sporangia, thick-walled asexual spores (chlamydospores), and swellings in the vegetative filaments (hyphae).

P. cinnamomi produces non-deciduous, nonpapillate sporangia with a slight apical thickening. Sporangia are formed on stalks that are occasionally branched but more often proliferate through empty sporangia. It also produces abundant numbers of chlamydospores and has prominent hyphal swellings. Chlamydospores are rarely produced by *P. cactorum* and *P. citricola*.

Biology

Soil-inhabiting *Phytophthora* spp. can survive in the soil for many years. These pathogens are readily moved via infested soil on equipment and shoes and in infected or infested nursery stock. Disease development is favored by high levels of soil moisture, especially prolonged periods of soil saturation. Under moist conditions, dormant spores (chlamydospores or oospores) can germinate to produce hyphae that can directly infect roots or may form sporangia. In the presence of free water, swimming zoospores can be released from sporangia. Zoospores are spread with splashing or flowing water and are attracted to substances that exude from roots. Zoospores become immobile cysts on or near roots. Zoospore cysts produce hyphae that penetrate and infect roots. Hyphae proliferate through roots, killing root cells, which may be secondarily colonized by other soil

Figure 142. *P. cinnamomi* cankers at base of cork oak. Bark around one canker has been partially removed on left side of trunk.

microorganisms. Sporangia can be produced on infected roots in as little as one to two days after infection and, under favorable conditions, can initiate additional disease cycles. Chlamydospores may be formed in dead roots. Chlamydospores tolerate drying and allow the pathogen to survive for extended periods in the soil. *P. cinnamomi* and *P. citricola* require warm soil temperatures (optimum about 24–28 ˚C) for significant pathogenic activity. *P. cactorum* can grow at temperatures as low as 2 ˚C and can cause disease at cool temperatures (10–20 ˚C).

Figure 143. Bleeding due to *Phytophthora* canker on cork oak.
Photo: Robert Campbell, UC Davis.

Importance

Phytophthora root rots are common causes of decline in transplanted nursery stock and mature trees when soil moisture conditions are favorable for disease development, especially in irrigated landscapes. Disease caused by *P. cinnamomi* has also been seen in some native oaks stands into which the pathogen has been introduced.

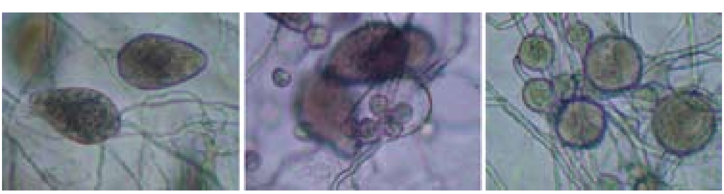


Figure 144. Micrographs of *P. cinnamomi* showing sporangia (left), sporangium releasing zoospores (center) and chlamydospores (right).

Weeping conk

Inonotus dryadeus

Inonotus dryadeus is found throughout much of North America and also occurs in Eurasia. It occurs primarily on oaks and other hardwoods but also occurs on some conifers. In California, it has been observed on coast live oak, Oregon white oak, and tanoak. *I. dryadeus* causes a mottled white rot of the roots and root crown of both living and dead trees. Infections reportedly begin in the roots and spread into the root crown, but decay does not extend much above ground level. Fruiting bodies (basidiocarps) are annual, but old basidiocarps may persist for several years. They develop near the base of the trunk at ground level or from roots below the soil surface. Basidiocarps vary in size, but can be massive, up to 75 cm wide and 15 cm thick (*fig. 145*). Fresh basidiocarps are yellowish to brownish above and may be covered with drops of amber liquid, hence the name "weeping conk" (*fig. 146*). The lower surface is buff with fine circular to angular pores (4–6 per mm), but tubes can become obscured in older basidiocarps. Basidiocarps eventually turn blackish and become cracked. Trees with *I. dryadeus* fruiting bodies have substantial amounts of root decay and an elevated risk of windthrow or root crown failure.

Figure 145. Large basidiocarp of *Inonotus dryadeus*.

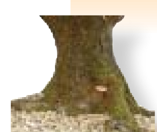
Figure 146. Newly emerging basidiocarp of *I. dryadeus* above small basidiocarp formed the previous year.

Western jack o'lantern fungus

Omphalotus olivascens

Omphalotus olivascens is known only from California and is found on the wood of dead or living hardwoods including coast live and California black oak, tanoak, manzanita, and redbud. Fruiting of this fungus at the base of living oaks suggests that it can attack live trees, but pathogenicity of this species has not been studied. Basidiocarps are stalked, gilled mushrooms (6–25 cm tall) that usually occur in clusters on or near trunks, stumps, or buried wood in the fall and winter (*fig. 147*). The gills extend down the stalk and are olive to yellow-orange and dimly luminescent when fresh. The caps are 4–16 (rarely to 25) cm across, bright golden-yellow to orange, brownish, or reddish, often with olive tones. Basidiocarp caps are initially broadly convex but later become flat to depressed with upturned margins. The spore print is cream to pale yellow.

Figure 147. Basidiocarps of *Omphalotus olivascens*.



Glossary

µm (micrometer) – A metric unit of length equal to one millionth of a meter, or one thousandth of a millimeter.

Acervulus (pl. acervuli) – A small, saucer- or cushion-shaped mass of conidiophores and conidia (asexual spores) that forms beneath the epidermis of leaves or twigs and is eventually exposed as the host tissue ruptures; no fungal tissue encloses the conidiophores.

Aptera (pl. apterae) – Wingless aphids.

Ascocarp – Sexual fruiting body produced by fungi in the Ascomycotina. Common types of ascocarps are perithecia and cleistothecia. Sexual spores are produced in asci within or on the surface of the ascocarp.

Ascomycotina – A taxonomic group (considered variously as a phylum, subphylum, division, or subdivision) of the true fungi which produce sexual spores in asci.

Ascus (pl. asci) – A sac-like structure in which sexual spores develop, produced by fungi in the Ascomycotina.

Basidiocarp – Sexual fruiting body produced by fungi in the Basidiomycotina. These vary widely in shape and size, and include mushrooms and conks. Sexual spores are produced on basidia within or on the surface of the basidiocarp.

Basidiomycotina – A taxonomic group (considered variously as a phylum, subphylum, division, or subdivision) of the true fungi which produce sexual spores on basidia.

Basidium (pl. basidia) – Microscopic club-shaped structures produced by fungi in the Basidiomycotina that produce sexual spores (basidiospores). Basidiospores are produced on the external surface of the basidium at the end of peg-like structures.

Brown rot – A type of fungal wood decay in which cellulose and hemicellulose are preferentially decayed, leaving behind brown-colored lignin.

Chlamydospore – A thick-walled asexual spore. Chlamydospores are commonly resistant spores that are adapted for surviving adverse conditions.

Chlorosis (adj. chlorotic) – Yellowing of leaves or other normally-green plant parts.

Cleistothecium (pl. cleistothecia) – A globose fruiting body (ascocarp) that lacks a natural opening or pore; asci are entirely enclosed by the wall of the ascocarp.

Conidiophore – A fungal hypha, often specialized in structure, that bears one or more conidia.

Conidium (pl. conidia) – An asexually (i.e., vegetatively) produced spore that is typically deciduous at maturity.

Context – The sterile tissue in a basidiocarp between the basidiospore-bearing tubes and the top surface (pileus). In resupinate basidiocarps, which lack a pileus, the context is also referred to as the subiculum; the subiculum is attached directly to the substrate.

Crawler – The young, mobile life stage of a scale insect.

Elytra – The thick, hardened forewings of beetles.

Embryo axis – within a seed, the portion of the embryo that includes the two growing points that develop into the root and shoot. In oaks, the embryo axis is at the pointed end of the acorn.

Flagellum (pl. flagella) – A threadlike or whiplike projection on a cell that functions to propel the cell through fluids.

Frass – Solid insect excrement, especially that produced by larvae. For larvae which feed in wood and/or bark, frass also includes xylem and/or phloem fragments (boring dust).

Honeydew – A sweet liquid excreted by some insects that suck plant sap, including aphids and soft scales.

Hypha (pl. hyphae) – Microscopic thread-like structures which are the simplest vegetative structures of most fungi (see also mycelium).

Inoculum – Units of a pathogen (such as viable spores or mycelium growing through soil) that can initiate infection of a susceptible host.

Instar – The life stage of an immature insect or mite between successive molts.

Intermediate oak subgroup – Also known as the section Protobalanus of the genus *Quercus*, a taxonomic group between genus and species containing oaks that share characteristics including short flower styles; acorns that mature in two years, have a densely hairy inner shell, and are very bitter; leaf lobes, if present, are pointed.

Larva (pl. larvae) – The immature stage between the egg and the pupa in insects that undergo complete metamorphosis (i.e., egg, larva, pupa, adult).

Mycelium – A network or mass of vegetative fungal hyphae.

Necrosis (adj. necrotic) – Death of cells or tissues.

Nymph – The immature stage of an insect which undergoes incomplete metamorphosis (i.e., egg, nymph, adult).

Obovate – Inverted ovate or egg-shaped, with the wide end toward the tip and the narrow end toward the base.

Oviparae – Female aphids, typically wingless, which reproduce sexually and lay eggs.

Oviposition – The process of laying or depositing eggs. Oviposition wounds are damage symptoms that develop at a site where insect eggs are inserted directly into plant tissue.

Papillate – Having a small rounded structure (papillum); in *Phytophthora* sporangia, the papillum is located at the apex from which zoospores are discharged; semipapillate sporangia have a smaller, less distinct apical protrusion; nonpapillate sporangia lack a papillum, but may appear somewhat thickened apically.

Parasite – An organism that lives on or in another living organism (host) and obtains its food from the host without providing any benefit to the host.

Parthenogenic – Capable of asexual reproduction, i.e., without mating or male fertilization.

Pathogen – An organism that causes disease in another organism; pathogens may function as parasites or may kill host tissues and obtain food from the killed tissues.

Pectinate – With branches or elements like the teeth of a comb.

Perithecium (pl. perithecia) – A globose to flask-shaped ascocarp with a defined pore (ostiole) at the apex through which ascospores are disseminated.

Pocket rot – Wood decay that occurs in discrete localized zones or pockets, usually in the heartwood.

Pronotum – A hardened plate on the dorsal (back) surface of the prothorax in insects; in some insects the pronotum is enlarged or otherwise modified.

Prothorax – The first segment of the thorax of an insect, which includes the attachment points for the front pair of legs.

Pycnidium (pl. pycnidia) – A flask-shaped fungal fruiting body containing conidiophores that produce conidia (asexual spores).

Red/black oak subgroup – Also known as the section Lobatae or Erythrobalanus of the oak genus *Quercus*, a taxonomic group between genus and species containing oaks that share characteristics including long flower styles; acorns that mature in two years (except for in coast live oak), have a densely hairy inner shell, and are very bitter; leaf lobes, if present, are pointed; dark gray or blackish bark; reddish brown wood.

Resupinate (referring to a basidiocarp) – Growing flat on the substrate with the spore-bearing surface on the outside surface, lacking ancillary structures such as a stalk or a cap.

Rhizomorph – An elongate, root-like aggregation of fungal hyphae, often differentiated into a dark outer rind and a lighter interior.

Saprophyte – An organism that obtains food from dead organic material, such as dead leaves, bark, or wood; some parasitic organisms can also survive and grow saprophytically.

Sooty mold – Black, superficial mycelial mats that grow on honeydew deposited on plant surfaces by sap-feeding insects; the epiphytic fungi that produce sooty mold are mostly in the family Capnodiaceae.

Sporangium (pl. sporangia) – A sac-like structure in which asexual spores are produced through the conversion of the sporangium's contents into spores.

Stroma (pl. stromata) – A compact mycelial structure which contains or supports fungal fruiting bodies.

Sympodial – A branching pattern in which each successive branch develops behind and to one side of the previous apex where growth has ceased.

Thorax – The middle segment of an insect body, between the head and the abdomen, to which the wings and legs attach.

Webbing – Silken threads produced by an insect, usually used to form a cocoon or other molting structure.

White oak subgroup – Also known as the section Quercus or Lepidobalanus of the genus *Quercus*, a taxonomic group between genus and species containing oaks that share characteristics including short flower styles; acorns that mature in one year, have a hairless inner shell, and are sweet or slightly bitter; leaf lobes, if present, are mostly rounded; light gray or brown bark; light brown or yellowish wood.

White rot – A type of fungal wood decay in which the three major wood components (cellulose, hemicellulose, and lignin) are decayed at the same rate; the wood becomes white as it decays.

List of plants

This list includes common and scientific names for plants referred to in the text. Only the genus name is noted for common names that include multiple species.

Common name	**Scientific name**
acacia	*Acacia*
alder	*Alnus*
almond	*Prunus dulcis*
apple	*Malus domestica*
apricot	*Prunus armeniaca*
ash	*Fraxinus*
aspen	*Populus*
avocado	*Persea americana*
bay, California	*Umbellularia californica*
beech	*Fagus*
birch	*Betula*
bitterbrush, antelope	*Purshia tridentata*
buckeye, California	*Aesculus californica*
ceanothus	*Ceanothus*
chamise	*Adenostoma fasciculatum*
cherry	*Prunus* sp.
chestnut	*Castanea*
chestnut, American	*Castanea dentata*
chinquapin	*Chrysolepis*
citrus	*Citrus*
redwood, coast	*Sequoia sempervirens*
coffeeberry	*Frangula californica* (=*Rhamnus californica)*
cottonwood	*Populus*
currant	*Ribes*
dogwood	*Cornus*
Douglas-fir	*Pseudotsuga menziesii*
elm	*Ulmus*
elm, American	*Ulmus americana*
eucalyptus	*Eucalyptus*

Continues on next pages.

Common and scientific names for plants referred to in the text (continued).

Common name	Scientific name
grape	*Vitis*
hackberry	*Celtis*
hawthorn	*Crataegus*
hazel, hazelnut, filbert	*Corylus*
hazelnut, California	*Corylus cornuta* var. *californica*
hickory	*Carya*
huckleberry, California	*Vaccinium ovatum*
locust	*Robinia*
madrone	*Arbutus*
manzanita	*Arctostaphylos*
maple	*Acer*
mesquite	*Prosopis*
oak, blue	*Quercus douglasii*
oak, California black	*Quercus kelloggii*
oak, canyon live	*Quercus chrysolepis*
oak, coast live	*Quercus agrifolia*
oak, cork	*Quercus suber*
oak, deer	*Quercus sadleriana*
oak, desert	*Quercus turbinella*
oak, eastern black	*Quercus velutina*
oak, Engelmann	*Quercus engelmannii*
oak, English	*Quercus robur*
oak, holly or Holm	*Quercus ilex*
oak, huckleberry	*Quercus vacciniifolia*
oak, interior live	*Quercus wislizeni*
oak, island	*Quercus tomentella*
oak, leather	*Quercus durata*
oak, Muller	*Quercus cornelius-mulleri*
oak, northern red	*Quercus rubra* var. *rubra*
oak, Nuttall's scrub	*Quercus dumosa*
oak, Oregon white	*Quercus garryana*
oak, pin	*Quercus palustris*
oak, post	*Quercus stellata*

Continues on next page.

Common and scientific names for plants referred to in the text (continued).

Common name	Scientific name
oak, scarlet	*Quercus coccinea*
oak, scrub	*Quercus berberidifolia*
oak, Shreve	*Quercus parvula* var. *shrevei*
oak, southern live	*Quercus virginiana*
oak, southern red	*Quercus falcata*
oak, Tucker's	*Quercus john-tuckeri*
oak, valley	*Quercus lobata*
oak, water	*Quercus nigra*
oak, willow	*Quercus phellos*
pear	*Pyrus*
pecan	*Carya illinoinensis*
persimmon	*Diospyros*
plum	*Prunus*
poison oak	*Toxicodendron diversilobum*
pome fruits	*Malus* and *Pyrus*
poplar	*Populus*
pricklyash	*Zanthoxylum*
prune	*Prunus domestica*
pyracantha	*Pyracantha*
quince	*Cydonia oblonga*
redbud	*Cercis*
rose	*Rosa*
stone fruits	*Prunus*
sweetgum	*Liquidambar styraciflua*
sycamore	*Platanus*
tanoak	*Lithocarpus densiflorus*
toyon	*Heteromeles arbutifolia*
walnut	*Juglans*
willow	*Salix*

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Index

in
0
1
2
3
4
5
6
7

Curculio aurivestis, Curculio occidentis, Curculio pardus, Cydia latiferreana, Phryganidia californica, Archips argyrospila, Bucculatrix albertiella, Malacosoma californicum, Malacosoma constictum, Malacosoma disstria, Orgyia vetusta, Eriophyes mackiei, Andricus spp., Antron spp., Callirhytis spp., Disholcaspis spp., Dros spp., Neuroterus spp., Kuwania quercus, Phylloxera spp., Parthenolecanium quercifex, Melanaspis obscura, Asterolecanium minus, Asterolecanium quercicola, Asterolecanium variolosum, Platycotis vittata, Platycotis vittata quadrivittata, Aleuroplatus coronatus, Aleuroplatus gelatinosus, Tetraleurodes stanfordi, Stegophylla querci, Stegophylla quercifoliae, Stegophylla essigi, Styloxus fulleri californicus, Aneflomorpha lineare, Scobicia suturalis, Agrilus angelicus, Monarthrum dentiger, Monarthrum scutellare, Pseudopityophthorus pubipennis, Pseudopityophthorus agrifoliae, Pseudopityophthorus pruinosus, Prionoxystus robiniae, Chrysobothris femorata, Chrysobothris mali, Scobicia declivis, Tremex columba, Prionus californicus, Rosalia funebris, Synanthedon resplendens, Brenneria quercina, Apiognomonia errabunda, Cryptocline cinerescens, Septoria quercicola,Taphrina caerulescens, Brasiliomyces trina, Cystotheca lanestris, Microsphaera extensa curta, Microsphaera penicillata, Phyllactinia angulata, Diplodia quercina, Cryphonectria gyrosa, Phoradendron villosum, Inonotus andersonii, Inonotus dryophilus, Hericium erinaceus f. erinaceus, Hypoxylon thouarsianum, Laetiporus gilbertsonii, Phellinus gilvus, Phellinus robustus, Phytophthora ramorum, Phytophthora nemorosa, Phytophthora pseudosyringae, Armillaria mellea, Ganoderma applanatum, Ganoderma brownii, Ganoderma lucidum, Phytophthora cinnamomi, Inonotus dryadeus, Omphalotus olivascens