# Scolytid beetles and associated fungal symbionts threaten California hardwoods

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## Background

Scolytid beetles play an extremely important role in forest ecology, including the recycling and decomposition of wood. Despite their diminutive size, they can have a significant impact on our forests and urban landscapes. Most bark beetles attack stress-weakened trees. Some of the more common factors causing plant stress include: drought, air pollution, soil salinity, certain nutrient imbalances, over-crowding, or plant disease. Some beetles, however, are capable of attacking healthy trees and can cause appreciable damage. Others are capable of vectoring important plant pathogens, for example Dutch elm disease. In recent years, a number of different beetle-associated disease complexes have emerged in California. The historic drought and the extensive movement of infested wood have likely contributed to the expansion and increased severity of these diseases.

## Scolytid beetles

Scolytid (skoe LYE tid) beetles belong to the insect subfamily Scolytinae, which contains many small, cylindrical wood-boring beetles that are generally brown to black in color. There are two broad groups: bark and twig beetles, and ambrosia beetles. Under field conditions, distinguishing different species morphologically can be difficult. Most adults are smaller than a grain of rice (1.5 to 4mm long), though some of the larger *Dendroctonus* beetles measure up to 8mm in length (Furniss and Carolin, 2002). A 10X or greater magnification handlens or a dissecting microscope may be required for accurate identification. Field identification of beetles may be easier and more reliable based on the host and the damage they cause or the pattern of their gallery (tunneling) systems.

Bark and twig beetles typically bore through the bark of a tree until they reach the soft, succulent phloem (inner bark) tissue that transports carbohydrates, and the cambium just below. Once they reach the innermost bark tissue, females bore galleries (tunnels) in the phloem and outer xylem, parallel to the surface of the wood, to lay eggs. The developing larvae feed in the carbohydrate-rich phloem tissue, typically engraving the outer xylem as they develop. Most 'bark beetles' prefer to colonize larger diameter wood, such as trunks or large limbs, while 'twig beetles' prefer smaller twigs and branches. The name

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Figure 1. (Left) Dead arroyo willows in the Tijuana River Valley. This damage is from Fusarium dieback, and its vector, Kuroshio shot hole borer. *Photo: Akif Eskalen*

Figure 2. (Right) A polyphagous shot hole borer infested boxelder tree (*Acer negundo*), in Ontario, CA. *Photo: Akif Eskalen*

**Figure 3. (Left) Infested sycamore in Riverside, CA, showing typical staining symptoms associated with infestation.** ***Photo: Akif Eskalen***

**Figure 4. (Right) Cross section of shot hole borer in coast live oak (*Quercus agrifolia*).** ***Photo: Akif Eskalen***

'shothole borer' has no taxonomic significance but is loosely applied to various beetle species to describe the riddled appearance of the host's bark following a mass beetle attack. The bark appears as if peppered by a shotgun blast. Bark beetles are best diagnosed by peeling away damaged bark to reveal the intricate and characteristic galleries. Some bark beetles keep their galleries clean while others pack them full of fine, dusty frass. For reference guides to bark beetle species and their respective galleries, please see: **http://ipm.ucanr.edu/PMG/PESTNOTES/pn7421.html and http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5384837.pdf**.

Unlike bark beetles, ambrosia beetles don't feed in the phloem or cambial tissue. Instead, they bore straight into the wood of the tree, where they then construct elaborate galleries. The females inoculate the gallery walls with a symbiotic fungus carried in specialized organs called mycangia. The fungus associated with California's native bark beetles, *Rafaelea brunnea*, was once named *Ambrosiella* (Greek for "food of the gods"), hence the name "ambrosia beetle". As the fungus colonizes the gallery walls, it provides a food source for the larva and young adults. Ambrosia beetles act as farmers for their symbiotic fungus, using the host tree as the farm. The parent beetles help keep the tunnels clear of frass, which in some species collects in copious amounts in bark crevasses below the entry hole. Depending on the host, different responses are seen on the bark exterior, including foaming, water-soaking, gumming, and bark-staining.

Most scolytid beetles are associated with one or more fungi which vary from facultative associates to obligate mutualists (Six and Wingfield, 2011). Twigs and small branches with tiny entrance holes that may or may not be plugged with frass (fecal material mixed with boring dust) or gummy exudate are diagnostic of twig borer infestations. Although damage from these beetles varies based on host and severity of the infestation, extensive damage of the vasculature can girdle a tree, and can be even more severe if the bark beetle vectors (carries and transmits) symbiotic fungal pathogens. Even if the beetle itself doesn't kill the tree, the fungus, if transmitted and pathogenic, may do so in time.

## Fusarium dieback and the Polyphagous Shot Hole Borer (PSHB) and Kuroshio Shot Hole Borer (KSHB)

Fusarium dieback is a lethal disease that has killed tens of thousands of trees in Southern California (Lynch et al. 2016, Boland, J. 2016). (**Figs. 1-2**) Symptoms of the disease, which vary among host species, include staining (**Fig. 3**) , gumming, sugar exudate (also called sugar volcano), and frass. The beetle's entry and exit holes, which are about 0.03 inch (0.85 mm) in diameter, can be located below or near where symptoms have developed. Advanced fungal infections will eventually cause branch dieback (**Fig. 4**) and tree mortality (Eskalen and Faber, 2016). The dieback is the result of water and nutrient disruption following infection by the fungus. (**Fig. 5**) The fungal pathogen has a broad host range and is vectored by two morphologically similar bark beetle species that seem to prefer healthy trees, which is unusual for scolytid beetles. The higher moisture content in healthy host trees apparently results in better reproductive success of the beetles. The two beetle species, Polyphagous Shot Hole Borer (PSHB) and Kuroshio Shot Hole Borer (KSHB) are regarded as closely related, yet previously undescribed, species of *Euwallacea*. They were likely introduced into California within the past few years. They are impossible to distinguish morphologically, and their host ranges overlap substantially. (**Fig. 6**) Accurate identification therefore requires molecular analysis. If the beetle is not detected on a suspect tree, the cause of the infestation and disease may be inferred if the fungal symbionts are cultured by the lab, as

**Figure 5. Beetle galleries and associated fungal discoloration in a cross section of a box elder trunk.** ***Photo: Akif Eskalen***

**Figure 6. An adult PSHB or KSHB female is only 1.5-1.67mm long. *Photo: Akif Eskalen***

the fungi appear to be specific to the beetle species in question.

Like all ambrosia beetles, PSHB and KSHB carry and inoculate their host trees with their own fungal symbionts, which include *Fusarium euwallaceae, Graphium euwallaceae* and *Paracremonium pembeum* for PSHB and new, as yet unnamed species of both *Fusarium* and *Graphium* for KSHB (Lynch at al. 2016). These new beetles are more aggressive than our native ambrosia beetles, as they seem to prefer healthy plants. Similarly, their fungal symbionts appear to be more aggressive than our native ambrosia beetles' symbiont, *R. brunnea*, as they can infect living tissue, typically killing their host tree within a couple of years. The reproductive hosts for PSHB and KSHP extends across many different plant families and currently includes 49 hosts (Eskalen et al 2013). Please see (**http://eskalenlab.ucr.edu/pshb.html**) for the most current host list. Currently both KSHB and PSHB and their associated diseases are confined to Southern California, though both have been moving steadily northward and have been found as far north as Santa Barbara and San Luis Obispo. While both species can fly, the movement of infested wood is the most likely means for long distance dispersal of the pathogens and the beetles. The Eskalen lab website (**http://ucanr.edu/sites/pshb/Map/**) has the most current maps depicting beetle recovery for the species of concern. Since recovery sites may not accurately reflect the current distribution of the beetles, some caution is warranted if and when interpreting these as "distribution maps."

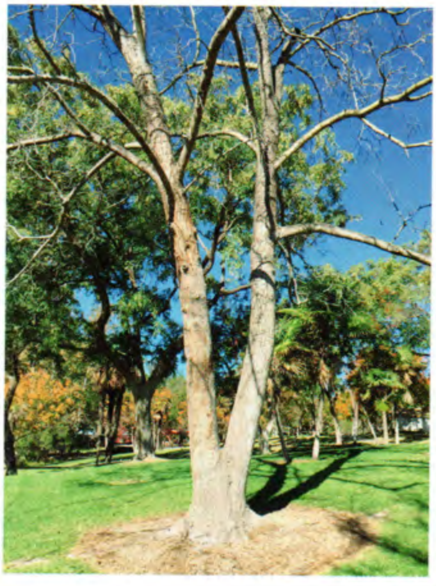
## Thousand Cankers Disease and *Pityophthorus juglandis*

The walnut twig borer, *Pityophthorus juglandis*, is a long-naturalized beetle species exotic to California. Historically, it has not been regarded as a serious pest. However, within the last decade, walnut twig borers have acquired a fungal symbiont, *Geosmithia morbida*, which causes Thousand Cankers Disease. This disease has caused significant losses of walnut (*Juglans* spp.) in at least 9 western states and a few eastern states. (**Fig. 7**) Beetle activity and feeding allows the fungus to colonize the phloem tissue and results in small necrotic cankers. As the galleries and cankers enlarge, they coalesce to girdle the branches or trunks. (**Fig. 8**) Although this beetle is only known to colonize walnut, the disease is frequently fatal and there are serious concerns of further spread. For more information see: (**http://ipm.ucanr.edu/PMG/menu.thousand-cankers.html or http://na.fs.fed.us/pubs/palerts/cankers_disease/thou-**

**Figure 7. (Left) Walnut (*Juglans* sp.) killed by thousand cankers disease. *Photo: Akif Eskalen***

**Figure 8. (Center) Surrounding walnut twig borer strikes, *Geosmithia morbida* cankers coalesce under the bark of a walnut tree. *Photo: Richard Bostock***

**Figure 9. (Right) English walnut (*Juglans regia*) showing bark staining symptoms following infection with thousand cankers disease. *Photo: Akif Eskalen***



sand_cankers_disease_screen_res.pdf ). (Fig. 9)

**Figure 10. (Left) Alcohol flux (a bacterial infection) on a mimosa tree (*Albezia julibrissin*) in San Rafael, CA. *Photo: Steven Swain***

**Figure 11. (Right) Wetwood, another form of bacterial infection, is frequently associated with included bark or wounds, as seen at the cable anchor sites on this avocado tree (*Persea americana*) in SanFrancisco, CA. *Photo: Steven Swain***

## Foamy bark canker and western oak bark beetle

Since its discovery in 2012, foamy bark canker has killed many coast live oaks (*Quercus agrifolia*) in Southern California (Lynch at al. 2014). In recent years, the disease has been found on other oak species as well in Northern California (Suzanne Rooney-Latham, personal observation). Although there has been a lot of mortality due to this disease, there are also numerous cases where trees have been infected but remain alive. Initial symptoms include a sticky, cream-colored foamy liquid emanating from boring holes. At this stage, the disease somewhat resembles bacterial diseases commonly called alcohol flux (Fig. 10), slime flux, or wetwood (Fig. 11), (hereafter, fluxes) or polyphagous/Kuroshio shot hole borer attack. However, unlike flux infection sites, small round beetle holes can be seen at beetle strike sites once the foam has been wiped away. (Fig. 12) After a few days, the foamy exudate subsides, leaving a watery stain on the bark. Like the previous diseases, trees infected with foamy bark canker exhibit vascular discoloration, and sometimes branch dieback as well.

Foamy bark canker is vectored by the Western Oak Bark Beetle (WOBB), *Pseudopityopthorus pubipennis*. WOBB has been documented in California for over 150 years, but only recently has emerged as an important vector of foamy bark canker. This suggests that perhaps the pathogen was introduced to California within the past decade. Two other closely related oak bark beetles (*P. agrifoliae* and *P. pulvereus*) are substantially similar in habit and lifestyle, but more limited in distribution. All of these beetles typically attack stressed oaks (*Quercus* spp), and are often identified by the occurrence of fine orange frass outside the gallery entrance. Like other true bark beetles, WOBB does not bore deeply into wood, but only to the cambium. Once there, a fungus in the genus *Geosmithia* that sometimes contaminates the beetles' elytra can invade the host tissue and sporulate in the galleries. (Fig. 13) Although early reports identified the pathogen as *Geosmithia pallida*, it is now considered to be a new, yet to be named species, currently referred to as *Geosmithia* sp. 41. Similar to thousand cankers disease, this fungus is capable of causing necrotic cankers, resulting from the colonization of the fungus in the beetle galleries. (Fig. 14)

**Figure 12. Foam bubbling out from a freshly excised hole in the bark of coast live oak (*Quercus agrifolia*). *Photo: Steven Swain***

Foamy bark canker has been recovered from multiple oak species and has an expanding geographic range. It will be the subject of a follow-up article in ***Western Arborist.***

## Other important beetles

Fusarium dieback and foamy bark canker are similar in that they both involve beetle-mediated transmission of a fungal pathogen into hardwood species (WOBB only attacks oak species) in both natural and landscaped settings. They also share a similar geographical range, in that they were discovered in Southern California, and have been moving northward over the past few years. Damage from these two complexes is easily confused with that from native bark beetles that are already well established in California.

California's native hardwood ambrosia beetles, *Monarthrum scutellare* and *M. dentiger* are only known to attack stressed, recently felled, or dying oak trees, and occasionally buckeye (*Aesculus californica*). While these beetles are found throughout California, they are more common in the northern portions of the state.

Their fungal symbiont, *Raffaelea brunnea*, (=*Ambrosiella brunnea*), coats the beetles' galleries with a black lining, and may on occasion cause the galleries to foam or produce an exudate. Extensive beetle damage or fungal infection can lead to tree failure, even in instances where the tree appears to be green and healthy from a distance.

Other exotic ambrosia beetles commonly encountered in the Western United States include the European shothole borer, *Xyleborus dispar*, and the lesser shothole borer, *Xyleborinus saxeseni*. These are occasionally found in California with *X. dispar* occasionally found in the northern part of the state, and *X. saxeseni* throughout the entire state. Both species have exceptionally broad host ranges, but are especially problematic on stressed fruit trees. While both species are primarily attracted to weakened or stressed trees, the European shothole borer is the more aggressive of the two, and the lesser shothole borer often colonizes trees following other beetles. Symptoms of infestation include pinhole-sized tunnels with fine frass on the outside, as is characteristic of most ambrosia beetles.

Another commonly encountered beetle, especially in California fruit trees, is the fruit tree borer or shothole borer, *Scolytus rugulosus*. This true bark beetle attacks the phloem tissue of stressed trees in the rose family, including apple, pear, stone fruits, and almond trees as well as other related species such as Portuguese laurel and English laurel. While it prefers stressed hosts, small healthy trees may be attacked if population densities are sufficiently high. Minor damage can be tolerated by most trees, but extensive damage may girdle and kill branches. Symptoms include clustered emergence holes, often with traces of frass in bark crevasses despite the fact that larvae pack the tunnels with it, and sometimes with sap oozing from tunnel entrances **http://ipm.ucanr.edu/PMG/r611302711.html.**

**Figure 13. (Left) Geosmithia fungal spores inside a tunnel made by the western oak bark beetle.** ***Photo: Suzanne Latham***

**Figure 14. (Right) Coast live oak branch cankers start from beetle strikes and begin to coalesce.** ***Photo: Steven Swain***

### What to do

These newly emerging insect/disease complexes pose challenges for practitioners attempting to field diagnose hardwoods that exhibit signs of scolytid beetle infestation (round holes in the bark measuring ~1mm diameter) and subsequent fungal infections (foam or fluid exuding from entry holes). Historically, identification of the scolytid beetles was relatively straightforward because the beetles tended to be specialists on one or several closely related tree species. This typically narrowed the number of species attacking the tree to just a few possibilities. However, the introduction of exotic scolytids with much larger hardwood host ranges has made identification more complex. Because these exotic species can potentially transport lethal plant pathogens that are not currently distributed across the western United States, the ecological,

### If you suspect trees of being infested with an exotic bark beetle, what steps should you take?

Step 1: Identify the tree

Step 2: Identify the beetle:

a). If it's an exotic, contact your County Agricultural Commissioner

Step 3: Determine the tree's likely outcome:

a). If the tree is heavily infested, especially with one of the more aggressive ambrosia beetles, consider removing the tree and disposing of the debris. For assistance in dealing with infested green waste, please see: http://eskalenlab.ucr.edu/handouts/decisionmaking.pdf

b). If you have a native bark beetle and/or foamy bark canker, consider trying to retain the tree by reducing stress to improve the vigor. The tree may need to be inspected by a TRAC Qualified Risk Assessor to determine risk potential.

financial and legal consequences of misdiagnosis can be significant. Furthermore, we can expect the known ranges of exotic species to expand as they disperse to fill their newfound ecological niches, while native species ranges will likely shift as global warming and other factors alter the environmental parameters of their hosts.

## Treatment

Once trees are infected and/or infested, treatment is usually impractical. The best course of action is to keep trees as healthy and stress-free as possible to maintain natural resistance to native bark beetles. While PSHB and KSHB are known to attack healthy trees, these trees are also believed to be more resilient to attack.

## Cultural control

Trees during the early stage of infestation, or those with only few foamy bark cankers, may recover if given proper care. Ensure that proper cultural practices, such as irrigation, are favorable for the affected host species. Avoid unnecessary pruning and fertilization. Pruning can cause additional stress or attract certain bark beetles. Soil nutrient deficiencies are seldom a problem in natural stands or in most urban landscapes. During years of normal rainfall, mature native oaks generally do not require supplemental water, and are prone to developing root diseases if irrigated regularly in the summer. However, because bark and ambrosia beetles are particularly attracted to drought-stressed trees, deep supplemental watering once or twice during summer, in years when rainfall is well below normal, may greatly reduce a tree's susceptibility to infestation by most bark beetles.

Other species that are not drought-adapted may become severely drought stressed if not irrigated adequately or if irrigation is greatly reduced or curtailed to conserve water. Consider the species, soil characteristics, topography, exposure, drainage patterns, and climate zone, etc., when determining an irrigation plan for each species.

Avoid disturbances within the root zone to prevent damage to the root system or adversely affecting soil conditions. Trees stressed by root-loss injury, changes in grade, changes in

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drainage, excess irrigation, soil compaction, etc., are more likely to be attacked by bark beetles.

Insure that tools are clean. Although the beetle is the main vector for transmitting the fungi discussed above, contaminated tools can also transmit some of these pathogens. Disinfect all tools, e.g., handsaws, chainsaws, climbing spurs, injection needles, etc., that can cause wounding when used on a tree known or suspected to be infected, before using on another tree. A 10% bleach solution works quickly and well, but is corrosive to tools. Common household disinfectants such as Lysol or Pine-Sol also work well, and have relatively short kill times. While 95% ethanol is also non-corrosive, laboratory tests have shown that kill times can be in the neighborhood of two minutes for some of the less manageable pathogens, making this a less-than-ideal choice for many field applications.

The process of chipping infested wood into pieces smaller than one inch, kills *most* beetles, but some survive in the green waste. When properly done, covering the wood chips and cut 'firewood' in clear, heavy plastic sheeting, and then exposing the material to direct sunlight (solarization) can kill the remaining beetles, reducing their spread. Composting infested material at a commercial facility is likely to be the most effective way to eliminate the fungal symbionts from wood chips. If transporting logs and/or chips to a disposal facility, be sure to tarp the load to prevent beetle escape (Jones and Paine, 2015).

While many of the beetles discussed are widely distributed, some are not. Prevention of new infestations is one of the most important ways of keeping trees healthy. It is important that infested green waste and firewood remain in the area where it was cut, unless it will be moved to a commercial disposal facility. Do not transport firewood from one region to another. ***Burn it where you buy it.*** (**http://firewood.ca.gov/**).

### Chemical control

If further protection is desired, once proper cultural practices are in place, pyrethroid insecticides have been shown to reduce infestation rates, but only if applied before beetles penetrate the bark. Pyrethroid effectiveness declines over time, so repeat applications may be necessary to insure effectiveness. Exact treatment timing and rates will vary by formulation and geographical location, so consult your pest control applicator. Once beetles have colonized a tree, insecticides are largely ineffective. Even systemic neonicotinoid insecticides such as dinotefuran and imidacloprid have *not* shown good efficacy against bark beetles, and even less against ambrosia beetles.

Systemic fungicides are ineffective against the symbiotic fungi carried by ambrosia beetles. Fungicides tend to move in the phloem, leaves, roots, and cambial tissues. Wood is more inert, and does not accumulate or transport systemic fungicides. As such, these compounds will have little or no effect on xylophagous fungi (fungi that eat wood).

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