GOLDSPOTTED OAK BORER

Integrated Pest Management for Land Managers and Landscape Professionals

The goldspotted oak borer (GSOB), *Agrilus auroguttatus* (Coleoptera: Buprestidae), is a flatheaded borer introduced to San Diego County, California, in the late 1990s or early 2000s and also detected at one site in Riverside County in 2012. It was likely brought into the state on oak firewood collected and transported from the insect's native range in southeastern Arizona or northern Mexico. Although currently confined to San Diego and Riverside counties, this pest will likely invade other areas of California.

Since at least 2000, GSOB has caused extensive injury and mortality to oaks in woodlands and mixed-conifer forests in San Diego County. GSOB prefers mature oak trees but occasionally attacks smaller oaks with a diameter at breast height (dbh) of about 10 inches. It has rarely been recorded in oaks with a dbh of less than 5 inches. Trees with a dbh of 18 inches or greater are the most likely to be killed.

GSOB attacks only oaks and prefers those in the red oak group including coast live oak, *Quercus agrifolia*, and California black oak, *Q. kelloggii*. GSOB also infests canyon live oak, *Q. chrysolepis*, and on very rare occasions Engelmann oak, *Q. engelmannii*. Red oaks are a common component of forests throughout California, and species in this group are at risk throughout the state if GSOB spreads by adult flight dispersal or via human-assisted transport (e.g., in firewood) from its current locations.

Typical damage associated with GSOB-infested trees includes crown thinning and dieback, bark staining on the main stem, bark injury from woodpecker foraging, and D-shaped emergence holes on the main stem and larger branches of the tree. Following several years of extensive and repeated bouts of injury from larval feeding, tree health declines, and trees eventually die.

Figure 1. Dorsal and ventral views of the goldspotted oak borer. The slightly larger adult on the left is a female, whereas the adult on the right is a male, as identified by the groove located on the underside in the first segment of the abdomen and indicated by an arrow.

Figure 2. Tiny (less than 0.25 mm) eggs of the goldspotted oak borer laid in a crevice on the surface of coast live oak bark.

IDENTIFICATION

Adults are about 10 millimeters long and 2 millimeters wide with a bullet-shaped body typical of beetles in the Buprestid family. They are black or iridescent green with six gold-colored pubescent spots on the forewings and two gold-colored spots on the edge of the thorax. Females and males appear nearly identical, but females are generally larger (Figure 1). Adults are rarely observed on trees.

Eggs are very small (less than 0.25 mm in diameter), brown, oval, and are laid singly or in clusters on the bark surface or in fissures of the outer bark (Figure 2). Eggs are extremely difficult to locate on a tree.

Figure 3. Life stages of the goldspotted oak borer. From left: fourth-instar larva, fourth-instar larva in a hairpin configuration and in a constricted form (both prepupal stages), pupa, and adult.

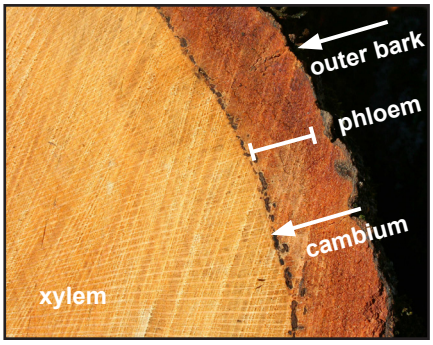

Figure 4. A cross-section of a coast live oak trunk. Goldspotted oak borer larvae feed primarily at the interface of the xylem and phloem. Pupae can be found in the outer bark and at the interface of the outer bark and the phloem.

Larvae are white, legless, and identifiable by C-shaped spiracles (breathing holes) along the side of the body wall and two pincherlike spines at the tip of the abdomen (Figure 3). When first hatched, larvae are about 2 millimeters long but grow to about 20 millimeters before maturing. Developing larvae feed under the bark and primarily at the interface of the xylem and phloem, girdling the cambium (Figure 4). Larvae are visible only if

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you cut deeply into an infested oak. Mature larvae, or prepupae, can be found in the outer bark in a hairpin configuration prior to pupation (Figure 5).

Pupae occur in the outer bark and at the interface of the outer bark and phloem. Pupae are roughly the same size as adults but are white and have soft bodies early in development. Pupae begin to darken and harden prior to transformation to the adult.

LIFE CYCLE

GSOB is believed to have a single generation each year. In its current introduced range in Southern California, adult females lay eggs on host trees primarily from June through September. First-instar larvae hatch from eggs in about two weeks and bore through the outer bark to feed deeper in the tree in the phloem and outer xylem layers. Larvae complete three more instars before maturing and burrowing back to the outer phloem. These mature larvae (or prepupae) occur under and in the bark year-round but are most easily located in the outer phloem of severely infested trees (Figure 5). They form pupal cells near the bark surface and fold into a hairpin configuration. They may remain in this nonfeeding stage from October to as late as June of the following year.

Beginning in April, prepupae begin to constrict in length in the pupal cell and develop into pupae. GSOB pupae may be observed within the outer bark of infested trees from late April through July. Adult emergence occurs from mid-May to September with peak flight activity occurring from late June to early July in Southern California. Following emergence, adults must feed on the foliage of host trees to survive and reach sexual maturity, which takes about two weeks. Mating likely occurs on the foliage and twigs in the crown of the host trees. Adults generally live for several weeks in the field but have survived up to two months in a laboratory environment.

DAMAGE

Larval feeding by GSOB causes the most significant damage to host oaks. Extensive feeding from numerous attacks girdles trees, disrupting water and nutrient uptake and eventually causing the tree to die. Removing bark from heavily infested trees reveals meandering larval galleries tightly packed with dark-colored boring dust and insect excrement (frass) (Figure 6). Pockets of sap may accumulate beneath the bark around the galleries, and trees form callus tissue in the phloem and xylem in response to the injury. Although adults feed on the foliage, this feeding doesn't contribute to the decline of the tree.

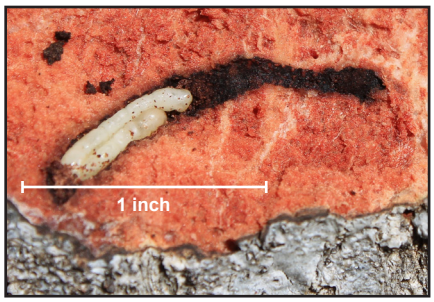

Figure 5. Fourth-instar larva (prepupa) of goldspotted oak borer in a hairpin configuration in a pupal cell found just below the surface of the bark of a coast live oak.

Figure 6. Dark-colored meandering larval galleries of goldspotted oak borer at the interface of the xylem and phloem on coast live oak.

Larval feeding weakens trees, causing signs of decline that include crown thinning and dieback, which are similar to decline resulting from other causes (Figure 7). However, GSOB-injured trees can be distinguished by the presence of D-shaped adult emergence holes, about 4 millimeters wide, which extend through the bark surface on the trunk of the tree or larger branches. These emergence holes are found predominately in the lower 10 feet of the trunk to the root collar and can be clustered or randomly spaced on the main stem (Figure 8). Heavily infested trees can have more than 100 highly visible emergence holes.

Figure 7. Severe crown thinning of coast live oak trees from goldspotted oak borer injury in San Diego County, California.

Figure 8. D-shaped emergence holes (4 mm wide) of the goldspotted oak borer on coast live oak.

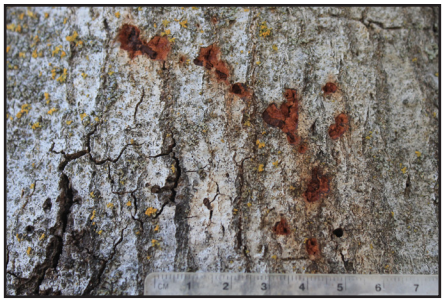

Figure 9. Damage to the bark surface of a coast live oak from woodpeckers foraging for goldspotted oak borer larvae and pupae.

Woodpeckers remove pieces of the outer bark when they forage for GSOB larvae and pupae along the main stem and larger branches, and in some locations this damage is quite noticeable (Figure 9). When foraging for GSOB in

coast live oak, woodpeckers feed shallowly, exposing spots of pink-red phloem where bark has been removed. This damage is distinguishable from other types of woodpecker feeding, where the birds notch out deep holes in the bark down to the xylem, or the uniform pattern of feeding holes that sapsuckers produce. After several weeks or months, the phloem the woodpeckers exposed will fade from red to black and will be less visible.

GSOB infestations also produce staining on the bark surface that appears as dark wet spots or oozing red sap extruding through the bark on the main stem and larger branches (Figure 10). Bark staining is most noticeable during spring and early summer when the soil is more moist. Bark staining can result from numerous other factors besides GSOB, including infection by microorganisms, colonization by other species of insects, and physical wounds. Larval feeding from GSOB can result in cracks in the outer bark that reach as deep as the interface of the xylem and phloem and extend several inches down the trunk of the tree. If no other GSOB injury symptoms, such as D-shaped holes or larval galleries, are visible, then bark staining is probably due to another agent.

Other Oak Pests and Injury

There are several other oak pests that cause injury similar to GSOB. For example, in coastal Northern and Central California, infection by the sudden oak death (SOD) causal agent *Phytophthora ramorum* results in similar staining on the bark of the main stem. Western oak bark beetle attacks can also cause similar patterns of staining, but the stain spots are typically much smaller and centered on the pin-sized entrance holes of the adult bark beetles. Be sure to confirm the presence of GSOB and eliminate the possibility that these other agents have caused the injury to oaks.

Oval and round emergence holes are characteristic of other secondary wood borers and bark beetles. These emergence holes can vary in diameter from the size of a pencil lead to 1/4 inch. Injury from other wood borers may be confined to the inner and outer bark or penetrate more deeply into the wood, whereas injury from GSOB is rarely found in the wood and emergence holes are D-shaped. Table 1 lists common insects that bore into oaks in Southern California along with descriptions of their emergence holes. Note that these pests can occur as complexes such that one oak may be colonized initially by GSOB but later also be colonized by western oak bark beetles, ambrosia beetles, or cerambycid wood borers.

Frass is indicative of insect feeding in trees and can appear as round or oval pellets, fine white or red powder, loosely packed wood shavings, or tightly packed granular wood particles. Frass from other borers can be found on the bark exterior, on the wood surface, or in the wood. GSOB frass is tightly packed and granular, typically black, and found mostly on the surface of the xylem.

Flagging (distinct branch or twig death in the crown) is not frequently associated with GSOB injury. Rather, crowns of oaks infested with GSOB exhibit a more uniform pattern of dieback (Figure 7). When branch flagging is found sporadically throughout the crown and typically on shaded branches, the cause is often the oak twig girdler (*Agrilus angelicus*), canker fungi, or scale insects.

Good sources of information about other pests infesting oaks in California include *Oaks in the Urban Landscape* and *A Field Guide to Insects and Diseases of California Oaks* listed in References.

MONITORING

Signs of GSOB infestation may not be obvious in the early stages of injury. Large diameter oaks (i.e., those greater than 18 inches dbh), which are more susceptible to infestation and mortality, should be surveyed first if a large area is being assessed. Examine trees for all injury symptoms including crown thinning, bark staining, woodpecker foraging, and D-shaped emergence holes. On infested trees, removing bark to expose larval galleries and larvae can assist in confirming the presence of GSOB. Oaks in high-value settings such as landscapes, parks, and recreation areas, or any oaks of special concern should be monitored for infestation once a year by looking for emergence holes and other symptoms. Trees with excessive crown thinning and dieback and more than 100 emergence holes on the lower trunk are considered severely infested and will probably die in the next few years.

Figure 10. Bark staining on coast live oak resulting from goldspotted oak borer larval feeding.

A GSOB infestation should be positively confirmed before initiating management options. D-shaped emergence holes are the most definitive indicator of GSOB infestation and are required to confirm an infested tree. Crown thinning and bark staining alone don't always indicate that GSOB has infested a tree. Refer to the UC IPM publication *Goldspotted Oak Borer Field Identification Guide* listed in References for detailed guidelines about how to assess oak health.

Purple-prism flight-intercept traps have been used in research and detection projects, but trap catches haven't been reliable enough to assist in making management decisions. Neither purple-prism traps nor any other trap is attractive enough to GSOB to be used as a suppression tool.

MANAGEMENT

At present, management programs for GSOB are focused on limiting its spread into new areas and protecting healthy trees. Specific and targeted pest management guidelines for controlling GSOB in infested trees with insecticides or other tools will require additional research. What follows are recommendations based on preliminary research findings and on techniques available from more well-known phloem borers in hardwoods.

Planting Less Susceptible or Resistant Oaks

The primary oak species that GSOB has killed in the currently infested areas of San Diego and Riverside counties are coast live oak and California black oak, both red oaks. Red oaks greater than 10 inches dbh are at risk for injury, and those greater than 18 inches have the highest risk for mortality from GSOB. Canyon live oak may also be injured and killed. Although Engelmann oak may be lightly attacked, it doesn't appear to be seriously injured. There is currently limited information about the susceptibility of other non-native oak species such as cork oak or holly oak.

When planting trees in infested areas, consider planting nonoak species or Engelmann oak. Even trees of susceptible species are unlikely to be attacked or killed when their diameters are less than 10 inches. Insecticide applications shouldn't be required on less susceptible species or small diameter red oaks.

Removing Infested Trees

Some landowners may wish to remove very severely infested trees (e.g., those with severe crown thinning and more than 100 emergence holes on the lower stem). These trees likely can't be saved, and as they die the potential for falling limbs presents a hazard to humans and to structures. Fuel from dead oaks also presents a fire hazard, and this is particularly dangerous around structures.

When removing trees, cut stumps flush to the ground, because GSOB larvae can survive and develop in stumps of cut trees for at least a year. Treat and handle cut wood carefully to prevent GSOB reemergence; see Treating Cut Wood below.

Table 1. Common Borers on Southern California Oaks and their Emergence Holes.

Family	Species	Emergence hole		Injury location
		Shape	Size*	
Beetles (Coleoptera)				
Bostrichidae (false powderpost beetles)	*Scobicia declivis* (lead cable borer)	**round** 	**4 d**	Common on smaller branches less than 5 inches in diameter.
Buprestidae (flatheaded borers)	*Agrilus auroguttatus* (goldspotted oak borer)	**D-shape** 	**4 w**	Located primarily on the lower trunk. Can reach high densities.
	Chrysobothris species (appletree and related borers)	**oblong/ crescent** 	**5–13 w**	Common on the trunk and larger branches.
Cerambycidae (roundheaded borers)	*Xylotrechus nauticus* (oak cordwood borer)	**oval** 	**6–10 w**	Common on the main trunk, especially around wounds from mechanical damage or fire.
Scolytidae (bark and ambrosia beetles)	*Monarthrum* species, *Gnathotrichus pilosus* and *Xyleborinus saxeseni* (ambrosia beetles)	**round** 	**< 2 d (pen-tip sized)**	Frequently on the main stem.
	Pseudopityophthorus species (western oak bark beetle)	**round** 	**> 1 d (pin sized)**	Most common on smaller branches.
Moths (Lepidoptera)				
Sesiidae (clearwing moths)	*Synanthedon resplendens* (western sycamore borer)	**round** 	**5–6 d**	In bark cracks near deteriorated bark and phloem.

*In millimeters, with *w* representing width and *d* diameter.

Replanting in Infested Areas

If GSOB has killed one or more oaks on your property, consider replanting with native nonoak species or the more resistant Engelmann oak. Avoid replanting with susceptible species. Diversifying an area with several tree species is likely to provide a more resilient landscape over the long term.

Treating Cut Wood

Human-assisted movement of infested cut wood or logs represents the most significant threat for spreading GSOB in California and has likely occurred multiple times within San Diego County and between San Diego and Riverside counties already. GSOB develops in and adults emerge readily from firewood-sized pieces of oak wood. Several options are available for handling wood cut from infested oaks. The simplest and easiest is to not move wood from the infested site. Wood that has been cut and seasoned for two years on site should be free of viable GSOB.

Don't leave piles of infested wood directly under or near uninfested oaks—even in infested areas—as this could lead to accidental infestation of new trees.

If cut wood must be moved outside the infested area, it should be treated by tarping or screening (containment) for two years, grinding, or debarking prior to transport. These practices are also prudent in lightly infested areas to slow the movement of beetles into healthy trees. Determining which management option to use depends on the size of the managed area, cost, availability of time, and availability of resources.

Containment. Tarping or screening cut wood can limit GSOB dispersal from small woodpiles. Wrap piles of cut or split wood with a clear, sturdy (at least 6 mil), UV-resistant plastic tarp. Don't use opaque tarps. Seal the edges of the tarp by covering them with soil, and avoid puncturing the tarp; any holes that form must be sealed. Tarping with clear plastic doesn't significantly reduce emergence of GSOB adults from cut wood, but well-sealed tarps will contain any emerging adults and prevent them from infesting new trees.

Alternatively, small woodpiles might be surrounded with screening to prevent the dispersal of adult GSOB. A fine wire-mesh screen (1 mm), small enough so mosquitoes can be excluded, may also be used; screen cages around woodpiles must be completely sealed so emerging beetles can't escape. Fold seams neatly and secure with binder clips, staples, or a combination of the two.

Leave piles of tarped or screened cut wood on site and in full direct sunlight for at least two years, checking them periodically and sealing any holes.

Grinding. Grinding infested wood is probably the best method to ensure beetles won't survive. Grinding to a 3-minus standard—which shreds wood into narrow strips typically no more than 3 inches long, 1 inch wide and 1/2 inch thick—will destroy bark and eliminate all life stages of GSOB. Grinding wood from October through April (i.e., prior to GSOB adult emergence) is recommended for this treatment. This management option is ideal for large amounts of infested cut wood; however, it requires large specialized equipment and thus isn't feasible for many small residential situations where only one or two trees are involved. Many chippers used by landscape professionals will not have the capacity to handle the large diameter rounds of oak wood.

Debarking. Removing the bark from cut wood to be used for firewood will separate GSOB populations from wood. All bark and phloem (Figure 4) must be removed down to the wood, including even small pieces thicker than 1/2 inch. Viable GSOB will remain in the removed bark and shavings, so these must be destroyed, tarped, or left at the wood collection site, as far away from living trees as possible. Removing bark from cut pieces of wood by hand is labor intensive and is most feasible for small quantities (less than one cord) of firewood from GSOB-infested trees.

Figure 11. Adult female of the parasitic wasp *Calosota elongata*, identified by its narrow body and long pointed ovipositor protruding from the end of its abdomen.

Figure 12. Pupae of the parasitic wasp *Calosota elongata* in a goldspotted oak borer pupal cell.

Figure 13. Parasitic mites found on a goldspotted oak borer larva in the outer phloem. The globelike balls are the distended abdomens of the egg-laden female mites.

Biological Control

Three primary natural enemies have been associated with GSOB in Arizona and California, but none is currently believed to be providing significant levels of control. These natural enemies are *Atanycolus simplex* (Hymenoptera: Braconidae) and *Calosota elongata* (Hymenoptera: Eupelmidae) (Figures 11 and 12), both parasitoid wasps that attack and kill GSOB larvae, and a predatory mite, *Pyemotes tritici* (Trombidiformes: Pyemotidae) (Figure 13). *P. tritici* is a

generalist predatory mite with a cosmopolitan distribution that feeds on GSOB larvae, pupae, and adults. Further research is needed in order to show the effectiveness of biological control agents in California.

Woodpeckers also prey on GSOB larvae and pupae in California, but their impact on GSOB populations hasn't been assessed.

Chemical Control

Although research testing various insecticides for GSOB management is underway, results are too preliminary to provide precise guidelines for this newly arrived species. In general, insecticide treatments for controlling wood borers are more effective for preventing infestation of healthy trees than combating existing infestations. Trees with moderate to severe injury are likely to be difficult if not impossible to save with current management tools. Severely infested trees should be removed rather than sprayed and wood from these trees properly managed to prevent GSOB spread. Some of the information provided here is based on research on other related borers, especially the emerald ash borer, *Agrilis planipennis*; see *Insecticide Options for Protecting Ash Trees from Emerald Ash Borer* listed in References.

The insecticide products most likely to be effective against GSOB are available only to state licensed and county registered pesticide applicators (QACs or QALs). Home-use, over-the-counter products may not contain adequate levels of insecticide to control this pest. Property owners should hire a pest control professional who has the experience and proper equipment for treating large oak trees. Inappropriately applied pesticides can have negative health and environmental impacts.

Cover and Barrier Spray Insecticides. The goal of applying cover or barrier sprays to bark is to kill newly hatched larvae as they attempt to bore into the bark and to reduce the population of adults that land on the bark surface to lay eggs. These sprays won't likely control larvae once they are beneath the bark. Drift from application of cover sprays to the upper stem and larger branches may also deliver insecticide to the foliage where it may kill adults as they attempt to feed.

Cover sprays have been somewhat effective against other species of borers and may provide some control of GSOB. Common insecticides labeled for this use are pyrethroids (e.g., permethrin, cyfluthrin, and bifenthrin) and EC formulations of carbaryl. Laboratory research has shown that carbaryl or bifenthrin will kill GSOB adults that come in contact with treated wood or feed on treated leaves. If making cover sprays, be sure to use products labeled for trunk treatments. Applications should be made in early May to slightly precede adult flight activity, which lasts from late May through September. The suggested insecticides have a long residual activity on the bark or foliage surface so that a single spray may be effective through the egg-laying season. Sprays should be applied to completely cover the main trunk and branches that are greater than 5 inches in diameter. Annual treatments are likely to be required. The insecticides used for cover sprays are broad-spectrum persistent toxicants and may pose hazards for water quality, beneficial insects, and nontarget organisms if not handled properly.

Systemic Insecticides. Systemic insecticides are applied into the soil or injected into trunks and taken up through the tree, thereby killing insects feeding within wood or on leaves. Some landscape pest control professionals are making applications of imidacloprid to control GSOB. Although research is underway, there aren't enough data to confirm the effectiveness of these treatments against GSOB. Treatment of ash trees with imidacloprid injections for the related emerald ash borer suppressed the pest and prolonged the life of trees, but ultimately infested trees died even after treatment. Trunk injections of imidacloprid are believed to be more effective than soil injections; however, trunk injections often cause significant wounds. Long cracks in the bark may frequently appear as a wound response to injection of coast live oaks, potentially allowing infection by secondary pathogens.

Formulations of imidacloprid available to homeowners as soil drenches have lower allowable application rates and are less likely to provide control, especially on trees with diameters larger than 18 inches dbh—those most likely to be seriously injured by GSOB. Another systemic insecticide, emamectin benzoate (TREE-äge), received registration for use as a trunk injection in California in April 2012, but its effectiveness against GSOB is still under evaluation.

As with other treatments, if effective, systemic insecticides are probably more likely to be effective in protecting uninfested or lightly infested oaks than oaks with moderate or more severe levels of infestation. Systemic insecticides aren't likely to provide suppression in low-vigor trees, because the active ingredient won't be adequately transported throughout the tree due to lack of uptake and disruption of conductive tissues in the phloem and xylem.

The best time to make trunk injections is from mid-winter to early spring when precipitation is frequent. Watering trees after application may assist with translocating the insecticide within the tree especially if further rains aren't expected. Some arborists may choose to combine systemic insecticides with cover or barrier sprays to high-value healthy trees in GSOB-infested areas; however, there is no reliable research data confirming that these treatments will fully protect trees.

Insecticides to control GSOB shouldn't be used in areas where GSOB isn't currently established. Also, insecticide applications aren't suggested for Engelmann oak or other less susceptible oaks or for trees smaller than 10 inches dbh.

GSOB Integrated Pest Management Plans. Landowners or managers with high-value red oaks in or near GSOB-infested areas should develop a GSOB management plan for their site. These plans should identify and map suscep-

tible trees on the property and outline a plan for regularly monitoring tree health. The plan should also include guidelines for removing severely infested trees, specifications for treating or disposing of cut infested wood, parameters for when using preventive insecticide treatments may be appropriate, and a plan for restoration planting if large numbers of trees must be removed.

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