Tales of Two Hardwood Borers: Polyphagous Shot Hole Borer and Goldspotted Oak Borer

National Plant Diagnostic Network, 4th National Meeting
Advancing Diagnostics for Emerging Pathogens and Pests Affected by Global Trade and Climate Change
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Polyphagous Shot Hole Borer/Goldspotted Oak Borer
Contrasts and Overview

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### Impacts of Feeding Groups of Insects on Forest Trees

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<td>Folivores: end of season or prior-year's leaves</td>
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<td>Diprionidae</td>
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<td>Root free feeders</td>
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<td>Curculionidae, Scarabaeidae</td>
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<td>Arctiidae, Lymantriidae, Notodontaide, Saturniidae</td>
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<td>Phloem/cambium/sapwood borers: root and root crown</td>
<td>Most</td>
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<tr>
<td>Suprestitidae, Curculionidae, Scolytidae</td>
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<tr>
<td>Phloem/cambium/sapwood borers: main stem</td>
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<td>Suprestitidae, Cerambycidae, Sesiidae, Scolytidae</td>
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Ecological and Economic Impacts of Scolytids

Urban Tree Mortality

Shade, aesthetic, property values

Forest Tree Mortality

Agents of ecosystem disturbance
Impacts on values: wildlife habitat, watershed quality, recreation, and wood production
How are Big Trees Killed by Small Beetles?
Aggregation Behavior in Bark/Ambrosia Beetles

*Dendroctonus*
- Female colonizes first
- Female- and male-produced pheromone
- Monogynous mating system

*Ips*
- Male colonizes first
- Male-produced pheromone
- Polygynous mating system
Stem of a boxelder tree mass attacked by PSHB near the point of original discovery, Whittier Narrows Recreation Area, LA Co.

Stem of a sycamore tree mass attacked by KSHB at the Sycaun Resort, San Diego Co. (T.W. Coleman, photos).
A New Ambrosia Beetle Complex: Polyphagous Shot Hole Borer and Kuroshio Shot Hole Borer in California

Shot Hole Borer/Fusarium Wilt of Hardwoods

An ambrosia beetle (woodborer) that is well adapted to invade new habitats
Haplodiploidy, parthenogenesis, many hosts, etc.
Polyphagous shot hole borer (PSHB), *Euwallacea* sp.: An ambrosia beetle

- First detected in California in 2003
  - Whittier Narrows Recreation Area (LA Co.). This insect/pathogen complex was not linked to tree injury and mortality until 2012 in LA Co.
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- Recent molecular analyses suggest that the CA species of *Euwallacea* is likely a new species (R. Stouthamer Laboratory, UCR)
  - The same species attacks hardwood trees and shrubs in Israel
Distribution of PSHB in CA as of 2013

El Cajon (San Diego Co.): Recent detection of PSHB
- Population may be from Taiwan
Distribution of PSHB in CA as of 2014

- Infested counties:
  - Los Angeles
  - Orange
  - Riverside
  - San Bernardino
  - San Diego
Distribution of PSHB in CA as of 2015
Polyphagous shot hole borer vs. Kuroshio shot hole borer

GC-MS Analysis of Cuticular Hydrocarbon Profiles Provides species-level diagnosis of bark/ambrosia beetles

Insect Cuticular Hydrocarbon Analysis Methods

Sample (25-300 dry adult insects) → Surface Extraction (10 ml hexane) → Filtration (silica gel) → GC-MS Analysis (non-polar fraction)
Comparative GC-MS Analysis of Cuticular Hydrocarbon Profiles of Polyphagous and Kuroshio Shot Hole Borers

PSHB
245 females

KSHB
245 females
Comparative GC-MS Analysis of Cuticular Hydrocarbon Profiles of Polyphagous and Kuroshio Shot Hole Borers

PSHB
245 females

1) \text{C29:1}
2) 15-; 13-; 11\text{-meC29}
3) 13,17-; 11,15-dimeC29 + 2\text{-meC29}
4) 7,X-dimeC29 + 3\text{-meC29}
5) 5,15-dimeC29
6) \text{C31:1}
7) 13,17-dimeC31; + 7,19; 7,17-dimeC31
8) 15,19-; 13,17-; 11,21-; 9,21-dimeC33

KSHB
245 females

10  15  20  25  30  35  40  45  50  55  60

Abundance

Time (min)
Comparative GC-MS Analysis of Cuticular Hydrocarbon Profiles of Polyphagous and Kuroshio Shot Hole Borers

1) C29:1
2) 15; 13; 11-meC29
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8) 15,19; 13,17; 11,21; 9,21-dimeC33
PSHB colonizes the main stem from the root collar to the smaller branches. Note the density of entrance holes.

Sycamore

Boxelder

Coast live oak

Boxelder
Polyphagous Shot Hole Borer Galleries
Cross Section of Sycamore Stem,
Glendora, CA
Fusarium wilt: Fungi associated with PSHB

- New species of *Fusarium* and *Graphium* are associated with PSHB
  - Eskalen (UCR) is conducting virulence tests with each fungus

- The same *Fusarium euwallaceae* is found in CA and Israel
PSHB-Impacts and Potential Impacts

I) Urban forest - Street trees, parks/arboreta, golf courses

II) Wildland forest - Riparian zones

III) Agriculture?
## Preliminary Survey Data for PSHB:

~800 trees surveyed across four LA County sites
(Arcadia Wilderness Park, Glendora, Pasadena Glen, Whittier Narrows Park)

(TW Coleman, USDA FS FHP, San Bernardino, CA, unpublished data)

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<th>% Infested</th>
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<td>30%</td>
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<td>5%</td>
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<td>2%</td>
</tr>
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<td>71%</td>
<td>16%</td>
</tr>
<tr>
<td>Fremont’s cottonwood (N=52)</td>
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<td>61%</td>
<td>4%</td>
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<tr>
<td>Ash spp. (N=66)</td>
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<tr>
<td>Coast live oak (N=92)</td>
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Native hardwood stands in southern California riparian areas
PSHB attacks and kills native riparian trees

Angeles National Forest

Potential impacts on 1) threatened/endangered species; 2) water quality; and 3) structure/composition of fuel load.

Red willow
White alder
California sycamore

Willow flycatcher, least Bell’s vireo, arroyo toad, yellow-legged frog, western yellow-billed cuckoo, gray vireo, 3 bat species, and 6 snake species
Kuroshio Shot Hole Borer: San Diego County

Damage to arroyo willow in the Tijuana River Delta, San Diego Co.

John Boland, photo
Adrian Poloni, photo
What about interactions of PSHB Impact and Agriculture?

- PSHB attacks avocados
- California produces 90% of the nation’s avocado crop
- ~21,000 ha of avocados planted from San Luis Obispo to San Diego
- Crop valued at $382,000,000/yr
What about the Central Valley?
Distribution of Walnuts in California

California
Annual Value of *J. regia* Nut Crop: $500 Million to $1 Billion

Central Valley
A “carpet” of walnut, almond, and pistachio trees

Slide Courtesy of A.D. Graves, USDA FS FHP Albuquerque
PSHB: 2014 and 2015 No-choice Host Range Tests

A PSHB gallery showing all life stages
PSHB: 2014 No-choice Host Range Tests
Based on the presence of male or pupal PSHB in a gallery

CA (9 spp.)
Boxelder
California ash*
California bay laurel*
California sycamore
Castor bean
English walnut*
Fremont’s cottonwood
Interior live oak*
Red willow

LA (3 spp.)
Black willow*
Red maple*
Southern red oak*

NM (4 spp.)
Box elder*
Quaking aspen*
Narrow-leaf cottonwood*
*Salix sp.*

* = Newly found host plants
PSHB: 2015 Laboratory No-choice Host Range Tests

—July 2015: Removed green branch sections (2-3” dia. x 24”long) from five English walnut cultivars from the Wolfskill UCD Stuke Collection (Chandler, Chico, Payne, Serr, and Tulare);

—Removed ends of branch sections (cut to 18 inch lengths), added 2-3 branch sections to 19 liter containers and added 40 to 60 female PSHB;

—“Incubated” females with potential host branch sections for at least 2 months;

—Split logs and looked for presence of new adult males or pupae = positive host;

—**Lab Results**: Chandler, Chico, and Payne were positive; Serr and Tulare yielded PSHB larvae, which suggests at least partial reproduction in the latter hosts.
Tales of Two Hardwood Borers: Polyphagous Shot Hole Borer and Goldspotted Oak Borer
New Pest in California:
The Goldspotted Oak Borer, *Agrilus coxalis* Waterhouse

The goldspotted oak borer (GSOB) was first detected in 2004 in San Diego Co., California by the California Department of Food and Agriculture during a survey for exotic wood borers. In 2008, it was found in the same county attacking coast live oak, *Quercus agrifolia*, canyon live oak, *Q. chrysolepis*, and California black oak, *Q. kelloggii*, on the Cleveland National Forest. GSOB is playing a major role in ongoing oak mortality on federal, state, private, and Native American lands in southern California. GSOB larvae make the bark primarily at the interface of the sapwood and phloem on the main stem and larger branches. Larvae kill patches and strips of phloem and cambium, resulting in limb and branch die back and, eventually, tree death. Although the exact origin of the California population is unknown, GSOB has been previously collected in Arizona, Mexico, and Guatemala. Because of host distribution, GSOB has the potential to spread further north in California and cause similar tree mortality. Since very little published information is available on this insect, additional research is needed to determine the life cycle, behavior, and management strategies. The movement of infested firewood likely represents a significant pathway for introducing GSOB into non-infested areas.

**Identification**

Adults are about 10 mm long and 2 mm wide (Fig. 1). They are bullet-shaped and can be identified by the six golden-yellow spots on the dark green forewings. Mature larvae are about 18 mm long and 3 mm wide. They are legless, white, and have a long slender appearance (Fig. 2). The larvae possess two pincher-like spines at the tip of the abdomen. Pupae are found in the outer bark and resemble adults, but are commonly white in color. Eggs are probably laid in bark crevices like other *Agrilus spp.*, but have not been observed by the authors.

**Distribution and Hosts**

The native distribution of GSOB likely coincides with that of Emory oak, *Q. emoryi* Torrey, including the Coronado National Forest in southeastern Arizona and floristically related regions in northern Mexico, southern New Mexico, and southwestern Texas. Specimens of GSOB have only been collected from Arizona, California, and Mexico. In southeastern Arizona, GSOB feeds primarily on *Q. emoryi* and silverleaf oak, *Q. hypoleucoides* A. Camus (both Section *Lobatae*). Larval feeding injures the phloem and outer xylem of these red oak species, with most feeding activity and occasional cases of tree mortality noted in large-
Goldspotted Oak Borer
Take Home Messages

I) GSOB is not always associated with a pathogenic fungus.

II) GSOB appears to have originated from the Southwest (AZ/NM); so far it has only invaded southern California.

III) GSOB prefers to attack and kill large diameter red oaks (>18” dbh); it takes a long time (conservatively 3 to 5 yrs) to kill these trees.

IV) The key to limiting future expansion of the invaded range of GSOB is preventing the movement of infested firewood.
Adults feed on foliage; larvae feed on phloem
GSOB life stages

Only life stages causing significant tree injury
- One generation per year

- Adults fly primarily between May and September

- Pre-pupae found nearly year round
GSOB mature larva

Tom Coleman

May 2008

4 mm
Agrilus auroguttatus

Agrilus coxalis

Coleman and Seybold (2008)
Pan-Pacific Entomologist 84: 288-300

Known Collection Records for Agrilus coxalis
- Quercus agrifolia
- Quercus devia
- Quercus hypoleucoides
- Quercus kelloggii
- Other Quercus

0 | 145 | 290 Kilometers
Created by Meghan Woods
Fig. 2. The four mountain ranges (Santa Catalina, Santa Rita, Huachuca, and Chiricahua) in the Coronado National Forest in southeastern Arizona where historical collections of *Agrilus auroguttatus* were made. General localities (X) are noted on the four mountain ranges, but a few exact localities (●) were available from collection labels.
Fig. 2. The four mountain ranges (Santa Catalina, Santa Rita, Huachuca, and Chiricahua) in the Coronado National Forest in southeastern Arizona where historical collections of *Agrilus auroguttatus* were made. General localities (X) are noted on the four mountain ranges, but a few exact localities (○) were available from collection labels.
Population genetics of goldsploted oak borer, *Agrilus auroguttatus* Schaeffer (Coleoptera: Buprestidae): investigating the origin of an invasive pest of native oaks in California

Vanessa M. Lopez · Paul F. Rugman-Jones · Tom W. Coleman · Mark S. Hoddle · Richard Stouthamer

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Abstract The goldsploted oak borer, *Agrilus auroguttatus* Schaeffer, is an invasive woodborer in California USA that is native to oak woodlands across southern Arizona USA. Developing a classical biological control program for this pest in southern California is a high priority due to the continuing ecological and economic damage caused by this insect since its recent introduction into the area. In an attempt to determine the area of origin for this invasive beetle, analyses of the mitochondrial cytochrome oxidase and abdominal nuclear D2 domain of the 28S gene regions were undertaken and provided insight into the phylogeographic relationship between and within populations of *A. auroguttatus* in Arizona and California. The area of origin for the invasive population of goldsploted oak borer in California was not determined conclusively, although our molecular data suggests the Dragoon Mountains in Cochise Co., Arizona as a possible source for the California population of *A. auroguttatus*. Results also confirmed that individuals collected from populations across southern Arizona and California are all *A. auroguttatus*, and are not part of a cryptic species complex comprised of the morphologically similar *A. castalli*. Future surveys for natural enemies of *A. auroguttatus* will focus on the Dragoon Mountains as a potential source for co-evolved enemies for use in a classical biological control program against this invasive woodborer in southern California.

Keywords *Agrilus auroguttatus* · Biological control · Cytochrome oxidase I · Phylogeography · Wood-borer

Introduction

The goldsploted oak borer, *Agrilus auroguttatus* Schaeffer, (Coleoptera: Buprestidae) is an invasive wood-boring beetle that aggressively attacks native oak trees in southern California, USA. Native to Arizona, this beetle was initially detected in the Descanso Ranger District, Cleveland National Forest (ORR-CNF), San Diego County, California, in 2004, but was likely introduced accidentally several years earlier through movement of infested oak firewood (Coleman and Seybold 2008a; Coleman et al. 2012a). Infestation of *A. auroguttatus* in southern California currently covers approximately 213,000 ha across San Diego, and Riverside Counties (Jones et al. 2013), and
mtDNA and nuclear DNA analyses suggest that the CA population is most similar to populations in southeastern AZ.

Likely transported to CA on firewood.
GSOB larval hosts

California

Arizona

Mexico

Q. peduncularis

Q. conzatti

(A. coxalis)
Host size preference

- White bars: uninfested
- Black bars: infested

Larger size-classes preferred by GSOB

Sap stain on outer bark of several oak species
Signs/Symptoms: Woodpeckering and Bleeding Wounds
D-Shaped Emergence Holes and Galleries Beneath the Bark
High density larval mining by GSOB in oak phloem
GSOB’s impact in California

- Mean infestation rate
  - 61% in San Diego Co
  - <4% in AZ and MX
  - In CA, 90% infestation in areas with tree mortality for about a decade

- Mean oak mortality with GSOB injury
  - 13% in San Diego Co
  - <2% in AZ and MX
  - In CA, 50% in areas with tree mortality for about a decade
Aerial Detection of Southern California Oak Mortality
Distribution of Southern California Oak Mortality Documented Annually through Aerial Sketch Mapping (USDA Forest Service FHM, 2014)

Laurel Haavik


Figure 1 Location of research sites in southern California relative to the distribution of oak mortality documented annually by aerial sketch mapping (USDA Forest Service FHM, 2014) and modified from Coleman et al. (2012a). Large circles represent the standard distance, a measure of the degree that oak mortality was concentrated or dispersed around its geometric mean center (i.e., the black triangle), and characterize the area potentially affected by Agrilus, auroguttatus by year.
GSOB Risk Assessment

Initial Risk Assessment, 2008/2009

Based on:

Range of Potential Hosts
**GSOB Risk Assessment**

**Initial Risk Assessment, 2008/2009**

Rob Venette  
USDA FS  
Northern Res. Station  
St. Paul, MN

**Advanced Risk Assessment, 2015**

Based on:
- Temperature/Precipitation
- Freeze Tolerance
- Host Susceptibility
- Dispersal Capacity

Figure 1—Composite risk map for *Agrilus auroguttatus* depicting the degree of climate suitability and potential extent of natural spread from 2013 – 2022 within the range of confirmed and suspected hosts. United States states outside New Mexico, Arizona, California, and Oregon are presumed to have little to no risk based on the current understanding of host and climate requirements for this insect.
This flies faster than GSOB...
This flies faster than GSOP...  
......and further than GSOP!
Polyphagous Shot Hole Borer/Goldspotted Oak Borer
Contrasting Overview

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PSHB Management: Don’t Move Infested Wood; Chip in Place

Sycamore, red willow, coast live oak, and boxelder were chipped into ~1 inch pieces

(TW Coleman, USDA FS FHP, San Bernardino, CA, unpublished data)
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Chipping wood was >99% effective at killing PSHB

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Beetles emerged from control wood pieces for 4 to 6 mo. after trees were cut and experiment was initiated.

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Female: male sex ratio was 90%.

(TW Coleman, USDA FS FHP, San Bernardino, CA, unpublished data)
2014: Effective Sanitation through Chipping
California sycamore, *Platanus racemosa*

![Graphs showing the number of Euwallacea sp. over time for both female and male samples, with data points for Chipped and Control treatments.](image-url)
Treatments: Management of Wood from Infested Areas

Debarking

Grinding

Removal timing

Solarization
2011: Survival and Management of GSOB in Firewood (Grinding, 3" Pieces)

PSHB: What about the Central Valley?
Distribution of Walnuts in California

California
Annual Value of *J. regia* Nut Crop: $500 Million to $1 Billion

Central Valley
A “carpet” of walnut, almond, and pistachio trees

Slide Courtesy of A.D. Graves,
USDA FS FHP Albuquerque
Doomsday Scenario?

We would rather not see what will happen to oaks if GSOB and SOD join forces.
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Goldspotted Oak Borer
Field Identification Guide


Distribution of Oak Hosts for Goldspotted Oak Borer

Coast live oaks and California black oaks are naïve hosts for this pest.

Coast live oak, Cleveland National Forest
San Diego Co.
Figure 2. Aerially mapped oak mortality (red stippling) associated with the goldspotted oak borer in San Diego County in southern California (2002-2013). Disjunct infested areas (satellite populations indicated by *) occur in San Diego County (San Diego); Riverside County (Idyllwild) and Orange County (Orange).

Host size preference

- White bars: uninfested
- Black bars: infested

Larger size-classes preferred by GSOB

Tree mortality begins—dismissed as drought

2002

Tree mortality linked to GSOB and nothing known about the species

2008

Research on GSOB biology and detection efforts begin

2009

GSOB found in Idyllwild (Riverside Co.)

2010

GSOB research: biology, managing infested wood, insecticides, trap development, biocontrol, risk assessment

2011

2012

2013

GSOB found in Idyllwild (Riverside Co.)

2014

GSOB found in Orange/Weir Cyn (Orange Co.)

2015

GSOB research: insecticides, trap development, risk assessment, fuel impacts

Aug. 2015

GSOB found in Green Valley (Los Angeles Co.)

GSOB research: insecticides, fuel impacts