Predators and Parasitoids Associated with Scolytinae in Persea Species (Laurales: Lauraceae) and Other Lauraceae in Florida and Taiwan

Authors: Peña, Jorge E., Weihman, Scott W., McLean, Stephen, Cave, Ronald D., Carrillo, Daniel, et al.

Source: Florida Entomologist, 98(3) : 903-910

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.098.0314

Predators and parasitoids associated with Scolytinae in *Persea* species (Laurales: Lauraceae) and other Lauraceae in Florida and Taiwan

Jorge E. Peña[1,], Scott W. Weihman[2], Stephen McLean[3], Ronald D. Cave[4], Daniel Carrillo[1], Rita E. Duncan[1], Gregory Evans[5], Stephen Krauth[6], M. C. Thomas[7], S. S. Lu[8], Paul E. Kendra[9], and Amy L. Roda[2]*

Abstract

The redbay ambrosia beetle, *Xyleborus glabratus* Eichhoff (Coleoptera: Curculionidae: Scolytinae), due to its association with *Raffaelea lauricola* T.C. Harr., Fraedrich & Aghayeva (Ophiostomatales: Ophiostomataceae), a pathogen that causes laurel wilt, is considered one of the most damaging pests of *Persea* species (Laurales: Lauraceae) including avocado. Currently, there is no satisfactory method to control this pest. Biological control is being examined as an additional tool to be used to lower the pest population and slow its spread. The objective of this study was to determine the natural enemy community associated with *X. glabratus* in Florida and Taiwan by using 3 methods: 1) field-collected wood naturally infested with *X. glabratus* (Florida), 2) bolts of avocado artificially infested with *X. glabratus* (Florida) and 3) direct collection of natural enemies from a trap area baited with infested wood and known *X. glabratus* lures (Florida and Taiwan). Among the predacious insects, there were 8 species of Laemophloeidae, an unidentified species of Staphylinidae, *Microsicus* spp. (Zopheridae), and *Europs* sp. (Monotomidae) (all Coleoptera). Among the parasitoids, hymenopterans of the families Braconidae, Eulophidae, Pteromalidae, Encyrtidae, Eupelmidae, and Bethylidae emerged from wood containing various species of Scolytinae. However, the only specimens that emerged from logs in which *X. glabratus* was present were Bethylidae, Braconidae, Encyrtidae (perhaps *Closterocerus* sp.), and Scelionidae. Four hymenopteran species were collected using attractants in Florida and Taiwan. However, more studies are needed to clarify their role as natural enemies of *X. glabratus*.

Key Words: red bay ambrosia beetle; predator; parasitoids; avocado

Resumen

El barrenador del laurel rojo, *Xyleborus glabratus* Eichhoff (Coleoptera: Curculionidae: Scolytinae) es una plaga que afecta especies del género *Perse*a (Laurales: Lauraceae) y gracias a su asociación con el patógeno *Raffaelea lauricola* T.C. Harr., Fraedrich & Aghayeva (Ophiostomatales: Ophiostomataceae), causa la marchitez del laurel. Actualmente no hay métodos satisfactorios de controlar esta plaga. El control biológico se está examinando a ver si puede utilizarse como una táctica que pueda mermar la población de la plaga y por ende disminuir su dispersión. Los objetivos de este estudio fueron el determinar la comunidad de enemigos naturales asociados con *X. glabratus* en Florida y Taiwan. Se utilizaron 3 métodos: 1) troncos de árboles afectados naturalmente con *X. glabratus* y otras especies de escolítidos, 2) pedazos de troncos de aguacate infestados artificialmente con *X. glabratus* en Florida y 3) colección directa de enemigos naturales atraídos a madera infestada con escolítidos y a cebos atrayentes (Florida y Taiwán). Entre los insectos depredadores hubo 8 especies de Laemophloeidae, una especie de estafilínidos no identificado, *Mircosicus* sp. (Zopheridae) y *Eruros* spp. (Monotomidae). Entre los parasitoides himenópteros de las familias Braconidae, Eulophidae, Pteromalidae, Encyrtidae, Eupelmidae y Bethylidae emergieron de madera que contenia varias especies de escolítidos. Los únicos himenópteros que emergieron de madera infestada con *X. glabratus* fueron especímenes no identificados de las familias Bethylidae, Braconidae, Encyrtidae y Scelionidae. Cuatro especies de himenópteros fueron atrapados utilizando atrayentes. Se necesitan realizar más estudios para determinar el papel de estos parasitoides como enemigos naturales de *X. glabratus.*

Palabras Clave: barrenador del laurel rojo; depredadores; parasitoides; aguacate

[1]University of Florida, Tropical Research and Education Center, 18905 SW 280th Street, Homestead, FL 33031, USA
[2]USDA, APHIS PPQ CPHST, Miami, Florida, USA
[3]University of Florida, Entomology and Nematology, Gainesville, Florida, USA
[4]University of Florida, Indian River REC, Fort Pierce, Florida, USA
[5]USDA, APHIS, NIS, Beltsville, Maryland, USA
[6]University of Wisconsin, Madison, Wisconsin, USA
[7]Florida Department of Agriculture and Consumer Services, Gainesville, Florida, USA
[8]National Institute of Forestry, Taiwan
[9]USDA, ARS, Miami, Florida, USA
*Corresponding author; E-mail: jepena@ufl.edu

The redbay ambrosia beetle (RAB), *Xyleborus glabratus* Eichhoff (Coleoptera: Curculionidae: Scolytinae), is an invasive pest of Asian origin and vectors *Raffaelea lauricola* T.C. Harr., Fraedrich & Aghayeva (Ophiostomatales: Ophiostomataceae), a fungus that causes laurel wilt in plants of the family Lauraceae (Crane et al. 2008; Fraedrich et al. 2008; Hanula et al. 2008). In the USA in natural hammocks of Georgia, Florida, and North and South Carolina (Hanula et al. 2008; Mayfield et al. 2008), laurel wilt has decimated redbay, *Persea borbonia* (L.) Spreng. (Laurales: Lauraceae), and swamp bay, *P. palustris* Sarg. The disease is now present in commercial avocado (*P. americana* Mill.) orchards of south Florida (FDOACS 2012). Enhancing the disease effect, other species of ambrosia beetles (i.e., *Xylosandrus crassiusculus* [Wood], *Xyleborinus saxeseni* [Reitter]), appear to be responsible for the horizontal spread of the pathogen (Carrillo et al. 2014).

Research to control the spread of the beetle has focused on the beetle's biology (Brar et al. 2012), seasonality (Brar et al. 2013), host preferences (Kendra et al. 2014a), development of attractants (Kendra et al. 2012b, 2014b; Kuhns et al. 2014a,b), repellents (Peña et al. 2011), and chemical control of the vector (Peña et al. 2011; Carrillo et al. 2013), but little effort has been directed toward determining the presence or absence of natural enemies of *X. glabratus*. Studies on natural enemies of Scolytinae have provided mixed results. For instance, Wood (1982) reported that natural enemies efficiently caused reduction of more than 90% of a bark beetle brood in a given generation whereas other reports focus on the potential of parasitoids and predators against important pests such as the coffee berry borer, *Hypothenemus hampei* Wood & Bright (Coleoptera: Curculionidae: Scolytinae) (Vega et al. 1999; Perez-Lachaud et al. 2002), without an evaluation of their effectiveness. Although bark and ambrosia beetles fill a slightly different niche and differ somewhat in their biology, they do have other attributes in common and may share natural enemies. For the purposes of this work, we considered all cases of scolytine predator/prey relationships.

The diversity and richness of key natural enemies of *X. glabratus* across the Florida landscape or in its areas of origin (i.e., Japan, India, Myanmar, Taiwan, and Bangladesh) are unknown (Rabaglia et al. 2006). During a survey conducted during 2010 in Taiwan by the senior and junior authors (JEP and SSL) *X. glabratus* was only collected in *Cinnamomum osmophloeum* Kanehira (Laurales: Lauraceae) but not on other reported original host trees such as *Lindera latifolia* Hook. fil., *Litsea elongata* (Nees) Bentham & Hooker, *Phoebe lanceolata* (Nees) (Laurales: Lauraceae), *Shorea robusta* Gaertner (Malvales: Dipterocarpaceae), *Lithocarpus edulis* (Makino) Nakai (Fagales: Fagaceae), and *Leucaena glauca* L. (Fabales: Fabaceae), indicating that RAB densities are not prominent in that area (Peña & Lu, unpublished data). Natural enemies could be a biological factor regulating *X. glabratus* populations in Taiwan and thereby limiting the host range in the pest's native range.

Finding natural enemies of bark and ambrosia beetles can be a complex task due to the concealed nature of the insects. Direct observations of predators or parasitoids attacking the beetle are difficult. The ambrosia beetle may also be rare in an area, thereby compounding the difficulty in finding any associated natural enemies. In addition, multiple scolytines and other insects may also be infesting field-collected wood making it difficult to determine what insect or group of insects were the target of a particular natural enemy. Placing laboratory-reared insects in the field (called the sentinel system) is one technique to lure the natural enemies to specifically attack a target pest. This technique has been quite useful in locating natural enemies in a wide range of host/prey systems (Meurisse et al. 2008). One of the advantages of this portable technique includes the ability to place infested logs in an array of environments. However, there are disadvantages as well. For instance, the sentinel system might lack enough prey to provide the important cues that natural enemies use to locate their prey. It also is unknown whether an artificially cut small log may attract most natural enemies seeking prey.

A search for natural enemies should include a variety of techniques in order to help obtain the most diverse and comprehensive collection of potential natural enemies. The objectives of this study were to determine the natural enemy community associated with *X. glabratus* in Florida and Taiwan using 3 different methods: 1) field-collected wood naturally infested with *X. glabratus* and other scolytines (Florida); 2) bolts of avocado artificially infested with *X. glabratus* in the laboratory (Florida); and 3) direct collection of natural enemies attracted to a trap area baited with infested wood and known *X. glabratus* lures (Florida and Taiwan).

The purpose of this work was to explore the possibility of finding natural enemies to help control the scolytine vectors of the fungus that leads to laurel wilt disease. The surveys in Taiwan centered on classical biocontrol. However, most efforts were focused on finding native or previously introduced natural enemies. A classical biocontrol program takes long to implement, and the threat of this disease is an immediate concern. Finding an endemic or naturalized predator or parasitoid may make a big difference in saving the avocado industry of Florida, which is a US$ 13 million industry (FDOACS 2012).

Materials and Methods

NATURAL ENEMIES ASSOCIATED WITH *RAFFAELEA LAURICOLA*-INFESTED *PERSEA* SPP. TREES

Wood samples from avocado trees infected by laurel wilt (*R. lauricola*) were collected from different counties in Florida (Table 1). Trees were cut and bolts approx. 75 cm long and over 3 to 4 cm in diameter were placed in emergence chambers constructed from a 167 L container (Rubbermaid, Pleasant Prairie, Wisconsin, USA) with a Mason jar (0.946 L with a 76 mm diameter mouth) attached to one side to collect emerging beetles. In addition, wood samples were collected from avocado (*P. americana*) trees in commercial groves in Homestead (Miami-Dade County, Florida, USA) that were infected by a different *Raffaelea* species. All emerged ambrosia beetles, hymenopterans, and other coleopterans were sent for identification to the Florida Department of Agriculture and Consumer Services, Gainesville, Florida, USA (M. C. Thomas), the United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA APHIS), National Identification Services, Beltsville, Maryland, USA (G. Evans), the Insect Research Collection, University of Wisconsin, Madison, Wisconsin, USA (S. Krauth), and/or to the University of Florida (UF), Tropical Research and Education Center, Homestead, Florida, USA (R. E. Duncan).

NATURAL ENEMIES FROM LABORATORY-INFESTED AVOCADO LOGS

Approximately forty 25 to 30 cm bolts of *P. americana* 'Booth 7' were cut in Miami-Dade County during fall 2010 and spring, summer, and fall 2011. Bolts were infested with 30 adult male and female *X. glabratus* taken from a colony reared at the UF Entomology and Nematology Department (Gainesville, Florida, USA), then held in the laboratory at 25 ± 2 °C under complete darkness for 4 wk (Brar et al. 2013). The infested *X. glabratus* bolts were hung approx. 1 m above the ground in shady bay stands (*Persea* spp.) located in Alachua (29°44.84'N, 82°12.60'W), Brevard (28°13.006'N, 82°10.2024'W), Highlands (27°25.35ˈN, 81°9.42ˈW), Osceola (29°24.445'N, 82°09.756'W), St. Luc-

Table 1. Hymenoptera and Coleoptera associated with *Persea* spp., trees infected with *R. lauricola* and *Raffaelea* spp.

			Curculionidae: Scolytinae															Anobiidae	Carabidae	Cerambycidae	Colydiidae	Colydiidae	Corylophidae	Curculionidae	Laemophloeidae	Monotomidae	Phalacridae	Platypodidae	Silvanidae	Staphylinidae	Trogositidae	Zopheridae
Hymenopteran Family	Location	Plant species	*Raffaelea lauricola*	*Ambrosiodmus develuxus*	*Ambrosiodmus lecontei*	*Corthylus papulans*	*Hypothenemus* sp.	*Premnobius cavipennis*	*Xyleborinus andrewesi*	*Xyleborinus gracilis*	*Xyleborinus saxesenii*	*Xyleborus affinis*	*Xyleborus bispinatus*	*Xyleborus ferrugineus*	*Xyleborus glabratus*	*Xyleborus volvulus*	*Xylosandrus crassiusculus*	Unidentified sp.	*Apenes* sp.	Unidentified sp.	*Colydium lineola*	*Synchita fuliginosa*	*Arthropilus* sp.	*Caulophilus* sp.	Two genera and 8 sp.	*Europs* spp.	*Litochrus pulchellus*	*Euplatypus parallelus*	*Cathartosilvanus opaculus*	Unidentified sp.	*Tenebroides* sp.	*Microsicus* sp.
Aphelinidae	Dade	*Pa*	no		x		x				x					x	x				x				x	x						x
Bethylidae	St. L	*Pa*	yes		x	x	x				x	x		x	x	x	x				x	x			x	x			x			
	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
Braconidae	High	*Pb*	yes	?	?	?	?	?	?	?	?	?	?	?	x	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	Dade	*Pa*	n		x		x		x		x			x	x	x	x	x		x												
Encyrtidae	Dade	*Pp*	yes		x					x	x	x	x	x	x							x				x				x		
Eulophidae	Dade	*Pp*	yes		x					x	x	x	x	x	x							x				x				x		
	St. L	*Pa*	yes		x	x	x				x	x		x	x	x	x				x	x			x	x			x			
	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
	Dade	*Pa*	no		x		x				x					x	x				x			x	x							x
	Dade	*Pa*	no		x		x				x					x	x				x			x	x							x
	Dade	*Pa*	no		x		x				x					x	x				x			x	x							x
Eupelmidae	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
Ichneumonidae	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
Mymaridae	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
Pteromalidae	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
Scelionidae	IR	*Pb*	yes	?	?	?	?	?	?	?	?	?	?	?	x	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
	St. L	*Pa*	yes		x	x	x				x	x		x		x	x				x	x			x	x			x			
	Dade	*	-												x																	
	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
	Dade	*Pa*	no	x			x	x		x	x	x		x		x			x		x	x	x	x	x		x	x	x	x	x	x
	Dade	*Pa*	no		x						x											x										
	Dade	*Pa*	no		x		x				x					x	x				x				x	x						x

Plant species: *Pa* = *Persea americana; Pp* = *Persea palustris; Pb* = *Persea borbonia*
Florida Counties: Dade = Miami-Dade County; High = Highlands County; IR = Indian River County; St. L = St. Lucie County

ie (27°25.576'N, 80°24.354'W), Miami-Dade (25°43.37'N, 80°28.12'W), and Indian River (27°35.285'N, 80°24.410'W) Counties, all known to have established populations of *X. glabratus.* The bolts were left for 1 mo to allow additional colonization by *X. glabratus,* by other scolytines, and by natural enemies. Exposed bolts were then collected and held in 15 × 45 cm cardboard containers (Single Wall Air Sea Containers, Miami, Florida, USA) at the UF (Gainesville, Florida, USA) indoor insectary (25 ± 2 °C; 75–80% RH) and at the Indian River Research and Education Center in Fort Pierce, Florida, USA, at similar temperature and humidity conditions. Sixty days were given for insects to develop and emerge in the sealed containers. After this time, adult insects (scolytines and/or natural enemies) were collected from all interior surfaces and grooves of cardboard containers, and on the surface and under the bark of bolts and stored in 70% ethanol until identification. Second generation *X. glabratus* adults emerge from bolts approx. 60 d after the first infestation (Brar et al. 2013); therefore, exposed bolts were considered to host cohorts of different ages and possibly the parent adults. Insects collected from the bolts were sent to the taxonomic identification resources mentioned above for identification.

USING BAIT STATIONS TO ATTRACT NATURAL ENEMIES OF *XYLEBORUS GLABRATUS* IN FLORIDA

To attract beetles and parasitoids, bait stations consisting of branches or trunks of host plants infested with *X. glabratus* and manuka oil lures were used to attract *X. glabratus* following a method developed by Kendra et al. (2012a). It is unknown what cues a potential natural enemy of a scolytine uses to locate hosts or prey. This technique was designed to capture natural enemies that may be attracted to ambrosia beetle kairomones or the host cues that attract the beetles themselves. Specimens were collected at Hickory Hammock (Highlands County, Florida, USA; 27°25.35'N, 81°9.42'W) and at a natural area near the west end of Bird Road (Miami-Dade County, Florida, USA; 25°43.37'N, 80°28.12'W). Hickory Hammock consists of a 1,618 ha natural preserve, bordered on the east by the Kissimmee River and on the south by the Istokpoga Canal. The hammocks are composed predominantly of oaks (*Quercus* spp.; Fagales: Fagaceae) and swamp bay (*P. palustris*) surrounded by upland pastures. This site was known to have laurel wilt and *X. glabratus* populations since 2009. Bird Road consists of a mixture of swamp bay and Australian pine (*Casaurina* spp.; Fagales: Casaurinaceae) bordered on the south by a canal. This site was declared positive for laurel wilt in 2011. At Hickory Hammock, 3 bait stations consisting of swamp bay logs collected from *X. glabratus*-infested trees were placed with a manuka lure on top of a white cotton sheet near the trail of the Equestrian Center, approx. 10 m from each other. One person monitored each bait station for *X. glabratus* and potential natural enemies, totaling 3 persons per site. Approaching insects were aspirated, and key specimens were segregated and sent for identification subsequently. Key specimens were considered insects belonging to groups known to include species of predators or parasitoids. After identification, these key species were further restricted after consulting literature, which indicated whether the species in question was a known predator of scolytines. Monitoring started around 8:30 AM and concluded at approx. 6:00 PM. A similar monitoring procedure was carried out in the Miami-Dade County site, during 22 Jun 2011 and 18 Nov 2011 and was conducted from approx. 3:30 PM to 6:30 PM.

USING BAIT STATIONS TO ATTRACT NATURAL ENEMIES OF *XYLEBORUS GLABRATUS* IN TAIWAN

During May 2011, JEP and S.S. Lu (Taiwan Institute of Forestry [TIF], Taipei City, Taiwan) selected an area at the Xian Xian Nursery of the Institute (25.0333°N, 121.6333°E) planted with 23 *C. osmophloeum* varieties known to host *X. glabratus*. Three *C. osmophloeum* trees that showed symptoms of scolytine infestation were selected. Besides infestation from scolytines, the trees showed signs of infestations by other stem borers, i.e., termites (Isoptera) and longhorned beetles (Cerambycidae). To attract beetles and parasitoids, bait stations were prepared using 2 manuka lures and branches or trunks of *C. osmophloeum* placed in the middle of a 2 m^2 white plastic sheet as described above. Activity of scolytines and natural enemies attracted to the log and bait was recorded from approx. 8:00 AM to 6:00 PM. *Xyleborus glabratus* adults were captured using an aspirator, either when they approached the baited logs or when they landed on infested trees in the surrounding area. All scolytines and potential natural enemies were collected with an aspirator and stored in ethanol.

Results

NATURAL ENEMIES ASSOCIATED WITH *RAFFAELEA LAURICOLA*-INFESTED *PERSEA* SPP. TREES

Fourteen species of Scolytinae emerged from 3 species of *Persea* in Florida (Table 1). The species included *Amrosiodmus devexulus*, *A. lecontei*, *Corthylus papulans*, *Hypothenemus* sp., *Premnobius cavipennis*, *Xyleborinus andrewesi*, *X. saxesenii*, *X. gracilis*, *Xyleborus affinis*, *X. bispinatus*, *X. ferrugineus*, *X. glabratus*, *X. volvulus*, *Xylosandrus crassiusculus*, and numerous species of Anobiidae, Cerambycidae, Curculionidae, and Platypodinae. Among the predacious insects, the most common were 2 genera and 8 species of Laemophloeidae, an unidentified genus of Staphylinidae, *Microsicus* spp. (Zopheridae), and *Europs* sp. (Monotomidae). Hymenopterans of the families Braconidae, Eulophidae, Pteromalidae, Encyrtidae, Eupelmidae, and Bethylidae emerged from wood containing various species of Scolytinae. However, the only specimens that emerged from logs where *X. glabratus* was present were Bethylidae, Braconidae, Encyrtidae (poss. *Closterocerus* sp.), and Platygastridae (Scelioninae) (Table 1).

NATURAL ENEMIES FROM LABORATORY-INFESTED AVOCADO LOGS

Other species of Scolytinae and other beetles emerged from the avocado logs infested with *X. glabratus*. Along with *X. glabratus*, the following beetles emerged from the avocado logs: *X. affinis*, *X. bispinatus*, *Xylosandrus crassiusculus*, *X. ferrugineus*, *Xyleborinus saxeseni*, and *Ambrosiodmus lecontei*; also encountered were *Caulophilus oryzae* (Coleoptera: Curculionidae), unidentified cerambycid and elaterid larvae, as well as psocids and lepidopteran larvae (Table 2). During 2010, no parasitoids emerged from the exposed logs. However, during these dates, several predacious insects emerged, including: *Laemophloeus fasciatus* (Coleoptera: Laemophloeidae), *Androthrips ramachandrai* (Thysanoptera: Phlaeothripidae), and *Calliodis* spp. (Hemiptera: Anthocoridae). During 2011 and 2012, a few hymenopterans were collected from the infested logs, including: species of Signiphoridae, Platygastridae (*Trisacantha* spp.), Eulophidae (*Tetrastichus* spp.), and Braconidae (*Chelonus* spp.) (Table 2).

USING BAIT STATIONS TO ATTRACT NATURAL ENEMIES OF *XYLEBORUS GLABRATUS* IN FLORIDA

Four hymenopteran species were collected using attractants. Those included *Leptacis* sp. (*n* = 1) and *Telenomus* sp. (both Platygastridae) (*n* = 1) in Miami-Dade County and *Prosacantha* sp. (*n* = 4), *Telenomus* sp.

Table 2. Arthropods associated with *Persea americana* logs infested with the red bay ambrosia beetle in different Florida counties in 2010–2012. The date indicates when the logs were deployed.

Site	County	Date	Order	Family	Subfamily	Species	Quantity	Natural enemy role
Austin Cary	Alachua	20-VIII-2010	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	13	
						X. affinis	6	
				Curculionidae		*Caulophilus oryzae*	11	
				Laemophloeidae		*Laemophloeus fasciatus*	10	Predator?
				Mycetophagidae		*Litargus* sp.	1	Fungivore
			Thysanoptera	Phlaeothripidae		*Androthrips ramachandrai*	1	Predator?
Ordway	Alachua	20-VIII-2010	Coleoptera	Curculionidae	Scolytinae	*X. glabratus*	10	
						Xylosandrus crassiusculus	1	
				Curculionidae		*Apteromechus ferratus*	1	
						Caulophilus orizae	3	
				Cerambycidae		unknown	1	
				Laemophloeidae		*Laemophloeus fasciatus*	2	Predator?
						Placonotus zimmerman	1	Predator?
			Lepidoptera			unknown	9	
			Psocoptera			unknown	2	
Vero Beach	Indian River	20-XII-2010	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	29	
				Monotomidae		*Europs* sp.	11	Predator
				Laemophloeidae		*Laemophloeus fasciatus*	1	Predator?
			Acarina	Oribatidae		unknown		
				Acaridae		*Cosmoglyphus* spp.	5	Fungivore?
			Hemiptera	Anthocoridae		*Calliodis* spp.	1	Predator?
			Lepidoptera	Cosmopterigidae		*Perimedes eransella*	3	
Fort Pierce	Indian River	20-XII-2010	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	18	
				Curculionidae		*Caulophilus orizae*	5	
Lake Placid	Highlands	27-IV-2011	Coleoptera	Laemophloeidae		*Laemophloeus* sp.	8	Predator?
				Signiphoridae		unknown	16	
Bird Road	Miami-Dade	27-IV-2011	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	3	
			Hymenoptera	Signiphoridae		unknown	7	Hyperparasitoid?
			Psocoptera			unknown	9	
			Thysanoptera	Thripidae		unknown	1	
Vero Beach	Indian River	27-IV-2011	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	2	
						X. ferrugineus	1	
				Smicripidae		unknown	10	??
				Cerambycidae		unknown	9	
Merritt Island	Brevard	27-IV-2011	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	1	
					Scolytinae	unknown	2	
				Cerambycidae		unknown	1	
				Elateridae		unknown	5	
			Hymenoptera	Scelionidae		*Trisacantha* sp.	1	Parasitoid
				Eulophidae		*Tetrastichus* sp.	2	Parasitoid
				Formicidae		unknown	15	Predator
			Lepidoptera			unknown	1	

Table 2. (Continued) Arthropods associated with *Persea americana* logs infested with the red bay ambrosia beetle in different Florida counties in 2010–2012. The date indicates when the logs were deployed.

Site	County	Date	Order	Family	Subfamily	Species	Quantity	Natural enemy role
Canoe Creek	Osceola	27-IV-2011	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	2	
					Scolytinae	unknown	3	
				Curculionidae		unknown	1	
				Colydiidae		unknown	3	Predator?
				Buprestidae		unknown	1	
			Hymenoptera	Formicidae		unknown	27	Predator?
			Thysanoptera			unknown	2	
			Psocoptera			unknown	3	
Austin Cary	Alachua	11-VII-2012	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	21	
						X. saxseni	1	
						X. ferrugineus	1	
						X. volvulus	1	
				Curculionidae		*Caulophilus orizae*	1	
				Laemophloeidae		*Laemophloeus fasciatus*	2	Predator?
			Hymenoptera	Braconidae		*Chelonus* spp.	3	Parasitoid
			Thysanoptera			unknown	2	
Citra	Alachua	11-VII-2012	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	2	
						X. affinis	1	
				Colydiinae		*Microsicus sp.*	1	Predator/parasitic?
			Acarina			unknown	21	
			Psocoptera			unknown	1	
Merritt Island	Brevard	11-VII-2012	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	7	
						X. saxeseni	4	
						X. affinis	1	
				Curculionidae		*Caulophilus oryzae*	2	
				Corylophidae?		unknown	8	Fungivore?
				Laemophloeidae		unknown	1	Predator?
			Hymenoptera	Braconidae		*Heterospilus*	1	Parasitoid
				Eulophidae		unknown	2	Parasitoid
				Formicidae		unknown	7	Predator?
			Lepidoptera			unknown	8	
			Diptera			unknown	1	
Canoe Creek	Osceola	11-VII-2012	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	34	
						Ambrosiodmus lecontei	1	
				Laemophloeidae		unknown	1	
				Corylophidae		unknown	1	Fungivore
Fort Pierce	Indian River	11-VII-2012	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	8	
				Cerambycidae		unknown	1	
				Nitidulidae		unknown	1	
				Laemophloeidae		unknown	4	Predator
				Corylophidae		unknown	2	Fungivore?
				Zopheridae		*Microsicus* sp.	1	Predator/parasitic?
			Hemiptera	Anthocoridae		*Calliodis* spp.	1	Predator

Table 2. (Continued) Arthropods associated with *Persea americana* logs infested with the red bay ambrosia beetle in different Florida counties in 2010–2012. The date indicates when the logs were deployed.

Site	County	Date	Order	Family	Subfamily	Species	Quantity	Natural enemy role
Vero Beach	Indian River	11-VII-2012	Coleoptera	Curculionidae	Scolytinae	*Xyleborus glabratus*	10	
						X. saxeseni	3	
						X. affinis	8	
						X. bispinatus	4	
				Monotomidae		*Europs* sp.	1	Predator
			Hemiptera	Anthocoridae		*Calliodis* spp.	3	Predator

(*n* = 1) (Platygastridae), and *Anteon xanthothorax* (Dryinidae) (*n* = 1) in Highlands County.

USING BAIT STATIONS TO ATTRACT NATURAL ENEMIES OF *XYLEBORUS GLABRATUS* IN TAIWAN

A large number of micro-hymenopterans, all identified to the family Platygastridae by Dr. G. Evans (USDA APHIS), were collected on the logs but also on newly cut *C. osmophloeum* branches. Most of the wasps were collected in the morning hours, whereas the beetles were collected in the late afternoon hours.

Discussion

Parasitoids. Among the collected parasitoids from this survey, we report *Tetrastichus* (Eulophidae), *Heterospilus*, and *Chelonus* (Braconidae), which were noted by Wood (1982) as genera that parasitize Scolytinae. We also report *Trisacantha* spp. (Platygastridae: Teleasinae). However, this genus has not previously been reported from Scolytinae. Because the other collected parasitoids were identified only to the family level, i.e., Bethylidae, Platygastridae, Pteromalidae, their identification to the genus or species level is necessary in order to determine whether they could be associated with the Scolytinae reported in this survey. Wood (1982) reported among the Hymenoptera containing parasitoids of scolytines the families Braconidae, Bethylidae, Chalcididae, Diapriidae, Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae, Gasteruptiidae, Ichneumonidae, Mymaridae, Podagrionidae, Proctotrupidae, Pteromalidae, and Torymidae. *Cephalonomia stephanoderis* and *Prorops nasuta* (Bethylidae) were reported as parasitoids of *Hypothenemus hampei* (Perez-Lachaud et al. 2002), but their importance as mortality factors is open for discussion. However, Vega et al. (1999) reported that *C. stephanoderis* was the most abundant coffee berry borer parasitoid in Cote d'Ivoire, followed by *Phymasticus coffeae* (Eulophidae). Moreover, Boone et al. (2009) reported that from a survey of hymenopterans attracted to logs colonized by *Ips pini* Woods & Bright (Coleoptera: Curculionidae: Scolytinae) in western Montana, pteromalids were the most important group related to Scolytinae, but less than 1% of the trapped specimens were associated with Scolytinae. These lists and examples are of dubious worth because they are primarily parasites of the less-hidden bark beetles. There is not much information available concerning ambrosia beetle parasites, but the previously listed families and genera may be good places to start.

Predators. Wood (1982) also cited the coleopteran families Cleridae, Colydiidae (= Zopheridae), Cucujidae, Elateridae, Histeridae, Cybocephalidae, Rhizophagidae (Monotomidae), Staphylinidae, and Trogositidae as reported by Chamberlin (1939) as major predators of Scolytidae. Here we report undetermined species of the genera *Microsicus* (Zoopheridae) and *Laemophloeus* as possible predators associated with arthropods inhabiting the logs. For instance, *Laemophloeus junipterici* (Grouvelle) has been cited as the most important predator of *Phloeotribus scarabeoides* (Bern.) (Scolytinae) in olive groves (Gonzalez & Campos 1990), and *Leptophloeus* near *punctatus* was observed preying on *H. hampeii* larvae in Cote d'Ivoire (Vega et al. 1999). Among the Thysanoptera, we report *A. ramachandrai*, which has not been associated with Scolytinae but as a predator of insects causing galls (Boyd & Held 2006). The genus *Europs* (Monotomidae) is also reported. Whereas we could not find reports of this genus as a predator of Scolytinae, it is important to note that other Monotomidae (*Rhizophagus grandis* Gyllenhal) have been reported as specific predators of the great spruce bark beetle, *Dendroctonus micans* Erichson (Coleoptera: Curculionidae) (Meurisse et al. 2008).

Problems arose by using laboratory-infested avocado bolts. First, these bolts desiccated quickly, which might have increased beetle mortality. Second, avocado is not one of the preferred hosts of *X. glabratus*, nor is it a host in which the beetle reproduces in high numbers as it does in *P. palustris* (Brar et al. 2012). For example, the numbers of *X. glabratus* collected from the set of sentinel logs per site averaged 10 and ranged from 0 to 34. These 2 factors might have influenced the results. Therefore, we suggest that in other surveys, other *Persea* species, such as *P. borbonia* and *P. palustris* should be used as sentinel logs.

Use of attractants proved to be a fast and easy method of parasitoid collection. However, as with the other studies, this method does not offer the assurance that the parasitoids caught are indeed parasitoids of Scolytinae.

It is necessary to determine whether native parasitoids are key mortality factors of *X. glabratus* in its areas of invasion. Also, if similar surveys are conducted in those states that were invaded earlier by *X. glabratus* (i.e., Georgia, South Carolina), a richer natural enemy fauna than the one found in Florida, which was invaded during 2007, will likely be found. Surveys of natural enemies associated with *X. glabratus* in its different areas of "origin" in Asia should be conducted in order to determine the existence or lack of any key mortality factor.

Acknowledgments

We thank D. Long (USDA ARS) for technical assistance, and H. Frank (University of Florida) and Ken Bloem (USDA APHIS) for critical reviews of the manuscript. This research was financially supported by 2 grants to JEP from USDA APHIS PPQ.

References Cited

Boone CK, Six D, Krauth S, Raffa K. 2009. Assemblage of Hymenoptera arriving at logs colonized by *Ips pini* (Coleoptera: Curculionidae: Scolytinae) and its microbial symbionts in western Montana. 2009. Canadian Entomologist 141: 172-199.

Boyd DW, Held DW. 2006. *Androthrips ramachandrai* (Thysanoptera: Phlaeothripidae): an introduced thrips in the United States. Florida Entomologist 89: 455-458.

Brar GS, Capinera JL, McLean S, Kendra PE, Ploetz RC, Peña JE. 2012. Effect of trap size, trap height, and age of lure on sampling *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae), and its flight periodicity and seasonality. Florida Entomologist 95: 1003-1011.

Brar GS, Capinera JL, Kendra PE, Mclean S, Peña JE. 2013. Life cycle, development, and culture of *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae). Florida Entomologist 96: 1158-1167.

Carrillo D, Crane JH, Peña JE. 2013. Potential of contact insecticides to control *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae), a vector of laurel wilt in avocados. Journal of Economic Entomology 106: 2286-2295.

Carrillo D, Duncan RE, Ploetz J, Campbell A, Ploetz R, Peña JE. 2014. Lateral transfer of a phytopathogenic symbiont among native and exotic ambrosia beetles. Plant Pathology 63: 54-62.

Crane HJ, Peña JE, Osborne JL. 2008. Redbay Ambrosia Beetle–Laurel Wilt Pathogen: A Potential Major Problem for the Florida Avocado Industry. HS 1136. Horticultural Science Department, University of Florida, Gainesville, Florida, USA. http://edis.ifas.ufl.edu/HS379 (last accessed 17 Aug 2009).

FDOACS. 2012. Florida Department of Agriculture and Consumer Services Identifies Laurel Wilt Disease in Avocado Production Area of Miami-Dade County. Downloaded as: http://www.freshfromflorida.com/newsroom/press/2012/05012012.html (last accessed 10 Jul 2013)

Fraedrich SW, Harrington T, Rabaglia RJ, Ulyshen MD, Mayfield AE, Hanula JL, Eicwort JM, Miller DR. 2008. A fungal symbiont of the redbay ambrosia beetle causes a lethal wilt in redbay and other Lauraceae in the southeastern United States. Plant Disease 92: 215-224.

Gonzalez R, Campos M. 1990. Evaluation of natural enemies of the *Phloeotribus scarabaeoides* (Bern.) (Coleoptera: Scolytidae) in Granada olive groves. Acta Horticulturae 286: 355-358.

Hanula JL, Mayfield AE, Fraedrich SW, Rabaglia RJ. 2008. Biology and host associations of the redbay ambrosia beetle, *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae), exotic vector of laurel wilt killing redbay (*Persea borbonia*) trees in the southeastern United States. Journal of Economic Entomology 101: 1276-1286.

Kendra PE, Montgomery W, Sanchez J, Deyrup M, Niogret J, Epsky N. 2012a. Method for collection of live redbay ambrosia beetles, *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae). Florida Entomologist 95: 513-516.

Kendra PE, Niogret J, Montgomery WS, Sanchez JS, Deyrup MA, Pruett GE, Ploetz RC, Epsky ND, Heath RR. 2012b. Temporal analysis of sesquiterpene emissions from manuka and phoebe oil lures and efficacy for attraction of *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae). Journal of Economic Entomology 105: 659-669.

Kendra PE, Montgomery WS, Niogret J, Pruett GE, Mayfield AE, MacKenzie M, Deyrup MA, Bauchan GR, Ploetz RC, Epsky ND. 2014a. North American Lauraceae: terpenoid emissions, relative attraction and boring preferences of redbay ambrosia beetle, *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae). PLoS ONE 9: e102086.

Kendra PE, Montgomery WS, Niogret J, Schnell EQ, Deyrup MA, Epsky ND. 2014b. Evaluation of seven essential oils identifies cubeb oil as most effective attractant for detection of *Xyleborus glabratus*. Journal of Pest Science 87: 681-689.

Kuhns EH, Martini X, Tribuiani Y, Coy M, Gibbard C, Peña J, Hulcr J, Stelinski LL. 2014a. Eucalyptol is an attractant of the redbay ambrosia beetle, *Xyleborus glabratus*. Journal of Chemical Ecology 40: 355-362.

Kuhns EH, Tribuiani Y, Martini X, Meyer W, Peña JE, Hulcr J, Stelinski LL. 2014b. Volatiles from the symbiotic fungus *Raffaelea lauricola* are synergistic with manuka lures for increased capture of the redbay ambrosia beetle *Xyleborus glabratus*. Agricultural and Forest Entomology 16: 87-94.

Mayfield AE, Crane JH, Smith JA, Peña JE, Branch CL, Ottoson ED, Hughes M. 2008. Ability of redbay ambrosia beetle (Coleoptera: Curculionidae: Scolytinae) to bore into young avocado (Lauraceae) plants and transmit the laurel wilt pathogen (*Raffaelea* sp.). Florida Entomologist 91: 485-487.

Meurisse N, Couillien D, Grégoire JC. 2008. Kairomone traps: a tool for monitoring the invasive spruce bark beetle *Dendroctonus micans* (Coleoptera: Scolytinae) and its specific predator *Rhizophagus grandis* (Coleoptera: Monotomidae). Journal of Applied Ecology 45: 537-548.

Peña JE, Crane JH, Capinera JL, Duncan RE, Kendra PE, Ploetz RC, McLean S, Brar G, Thomas MC, Cave RD. 2011. Chemical control of the redbay ambrosia beetle, *Xyleborus glabratus*, and other Scolytinae (Coleoptera: Curculionidae). Florida Entomologist 94: 882-896.

Perez-Lachaud G, Hardy CW, Lachaud JP. 2002. Insect gladiators: competitive interactions between three species of bethylid wasps attacking the coffee berry borer, *Hypothenemus hampei* (Coleoptera: Scolytidae). Biological Control 25: 231-238.

Rabaglia RJ, Dole SA, Cognat AI. 2006. Review of American Xyleborina (Coleoptera: Curculionidae: Scolytinae) occurring north of Mexico, with an illustrated key. Annals of the Entomological Society of America 99: 1034-1056.

Vega FE, Mercadier G, Damon A, Kirk A. 1999. Natural enemies of the coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae) in Togo and Cote d'Ivoire, and other insects associated with coffee beans. African Entomology 7: 243-248.

Wood SL. 1982. The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae), a taxonomic monograph. Great Basin Naturalist Memoirs 6: 1359 pp.