Trapping Techniques for Siricids and Their Parasitoids (Hymenoptera: Siricidae and Ibaliidae) in the Southeastern United States

BRITTANY F. BARNES,[1] JAMES R. MEEKER,[2] WOOD JOHNSON,[2] CHRISTOPHER ASARO,[3] DANIEL R. MILLER,[4] AND KAMAL J. K. GANDHI[1,5]

Ann. Entomol. Soc. Am. 107(1): 119–127 (2014); DOI: http://dx.doi.org/10.1603/AN13036

ABSTRACT The recent introduction of *Sirex noctilio* F. (Hymenoptera: Siricidae) into North America has raised interest in native siricids and their parasitoids to better understand the potential impact of *S. noctilio*. In the southeastern United States, we assessed various techniques to capture native siricids and their parasitoids using traps, lures, and trap trees. During 2009–2011, in total, 2,434 wasps were caught including *Eriotremex formosanus* (Matsumura), *Sirex nigricornis* (F.), *Tremex columba* (L.), and *Urocerus cressoni* (Norton) (Siricidae), and *Ibalia leucospoides ensiger* Norton (Hymenoptera: Ibaliidae). Traps and trap trees, respectively, captured 14 and 86% of total siricids and hymenopteran parasitoids. Majority of siricids (76%) were caught in Louisiana, where 486 *I. l. ensiger* (28% parasitism rate) were also reared from trap trees. The *Sirex* lure alone and *Sirex* lure with ethanol captured two to five times greater numbers of siricids than unbaited traps. Trap types had no effect on catches of siricids. Fewer siricids were caught in traps baited with ethanol alone than in those baited with other lures in Georgia. We caught three to four times greater numbers of *S. nigricornis* in traps with fresh pine billets (with foliage) as a lure than traps baited with *Sirex* lure in Louisiana. More *S. nigricornis* and *I. l. ensiger* emerged from cut and felled trap trees created in early rather than late November; these trees also had 14 times greater emergence than those treated with Dicamba. Our results indicate that use of host material and timing may be important for monitoring populations and communities of siricids and their parasitoid species in southern pine forests.

KEY WORDS *Ibalia leucospoides ensiger*, parasitoid, *Sirex nigricornis*, *Sirex noctilio*, southeastern United States

The Eurasian siricid, *Sirex noctilio* F. (Hymenoptera: Siricidae), is an exotic woodboring insect accidentally introduced to North America (Haugen and Hoebeke 2005). Since 2004, *S. noctilio* has been discovered in Connecticut, Michigan, New Jersey, New York, Ohio, Pennsylvania, and Vermont (National Agricultural Pest Information System [NAPIS] 2012), and Ontario and Quebec (Canada; de Groot et al. 2006). This species is native to Europe, Asia, and North Africa, and is usually a secondary colonizer of damaged and declining conifer trees in its native habitat (Spradbery and Kirk 1978). In the Southern Hemisphere, *S. noctilio* has caused significant mortality in managed pine stands (*Pinus* spp.; Rawlings 1948, Iede et al. 1998, Madden 1998, Ciesla 2003, Tribe and Cillié 2004, Corley et al. 2007). Tree mortality by *S. noctilio* is caused by a combination of three activities associated with female oviposition: deposition of a phytotoxic mucus and spores of a fungal pathogen (*Amylostereum areolatum* (Fries) Boidin) and eggs oviposited into the tree (Ciesla 2003). The larvae burrow through the xylem, growing and developing into pupae, and emerging as adults from the tree. North American conifer forests are at risk because various native pines are known to be susceptible to *S. noctilio* (Dinkins 2011).

Unlike the Southern Hemisphere, native species of siricids and associated parasitoids are abundant and diverse in the Northern Hemisphere (Long et al. 2009, Schiff et al. 2012). At least 33 siricid species and 21 parasitoid species have been recorded in North America, including both native and nonnative species (Schiff et al. 2006, 2012; Coyle and Gandhi 2012). Native parasitoid species such as *Ibalia leucospoides ensiger* (Norton), *Rhyssa howdenorum* (Townes), and *Rhyssa persuasoria* (L.) have been used or tested in other countries as biological control agents for *S. noctilio* (Cameron 1965, 2012; Taylor 1976; Hurley et al. 2007). At present, relatively little is known about the distribution and ecology of native siricids and their

The use of trade names and identification of firms or corporations does not constitute an official endorsement or approval by the United States Government of any product or service to the exclusion of others that may be suitable.

[1] Daniel B. Warnell School of Forestry and Natural Resources, The University of Georgia, 180 E. Green Street, Athens, GA 30602.

[2] USDA Forest Service, Forest Health Protection, 2500 Shreveport Hwy., Pineville, LA 71360.

[3] Virginia Department of Forestry, 900 Natural Resources Dr. Suite 800, Charlottesville, VA 22903.

[4] USDA Forest Service, Southern Research Station, 320 Green St., Athens, GA 30602.

[5] Corresponding author, e-mail: kjgandhi@uga.edu.

Table 1. Geographical locations and site descriptions for study sites in Georgia, Virginia, and Louisiana for trapping of siricid woodwasps and their hymenopteran parasitoids in 2009–2011

Attributes	Georgia				Virginia	Louisiana
County	Clarke	Baldwin	Jackson	Morgan	Buckingham	Grant
Location	Whitehall Forest	Bartram Forest	Pine Mill, Lumber Yard	Pine Mill, Hardwood Mill	Appomattox–Buckingham State Forest	Kisatchie National Forest
Region	Piedmont	Piedmont	Piedmont	Piedmont	Piedmont	Coastal Plain
Latitude and longitude	33° 53′12″ N 83° 21′42″ W	33° 06′43″ N 83° 12′40″ W	34° 07′36″ N 83° 35′25″ W	33° 35′17″ N 83° 28′21″ W	37° 23′36″ N 78° 43′45″ W	31° 35′16″ N 92° 24′43″ W
Dominant *Pinus* spp.	*P. taeda*	*P. elliottii*	*P. taeda*	*P. taeda*	*P. taeda*, *P. virginiana*, and *P. echinata*	*P. taeda*, *P. palustris*, and *P. echinata*
No. of transects and traps	8 and 24	12 and 36	2 and 10	2 and 10	10 and 30	20 and 60
Pine basal area (m^3/ha)[a]	39	23–28	7–12	7–12	9–23	13–16
Pine tree age (years)[a]	15–18	15–20	10–15	10–15	15–20	60–70

[a] Estimated values.

parasitoids in southeastern pine ecosystems. The last major field collection of siricids and hymenopteran parasitoids in the Southeast was conducted ≈40 yr ago (Kirk 1974). Assessing the current regional species complex of native siricids and parasitoid species is needed to better understand whether and how *S. noctilio* may impact these communities after it arrives in this region. To accomplish this goal, we need standardized methods to collect and study both siricids and their parasitoids in their native habitats.

Various types of traps have been used to capture woodboring insects, including bucket, drainpipe, flight intercept, multiple-funnel, panel, silhouette interception, and sticky traps (Chénier and Philogène 1989, McIntosh et al. 2001, Allison et al. 2011, Coyle et al. 2012). The multiple funnel trap, designed to imitate the silhouette of a host tree, consists of black plastic funnels aligned vertically that overlap with a wet collection cup at the bottom (Lindgren 1983). The panel trap is made of a lightweight, water-proof, corrugated plastic that bisects in the middle to form a 90° angle (Czokajlo et al. 2001). Other studies have modified the funnel or panel traps in various ways (e.g., enlarging the funnels and adding a surfactant as a lubricant) to increase capture efficacy (Morewood et al. 2002, de Groot and Nott 2003, Miller et al. 2013). Allison et al. (2011) showed that adding a lubricant to funnel and panel traps did not increase catches of siricids but did increase catches of *I. l. ensiger*.

Woodboring insects are generally attracted to monoterpenes and ethanol that are released by stressed trees. Monoterpenes are defensive compounds and ethanol is a byproduct of anaerobic respiration that is released when the trees are stressed (Allison et al. 2004). A commercial *Sirex* lure that consists of 70% α-pinene and 30% β-pinene was developed to monitor *S. noctilio* (Simpson and McQuilkin 1976). The ethanol and *Sirex* lures along with the funnel or intercept panel trap are the most common lures and traps used to capture siricids in national survey programs.

Trap trees are extremely efficient in capturing siricids (Madden 1971). Trap trees are created either by injecting herbicide into live pine trees (chemical girdling) or by cutting down the entire tree to attract siricids (Minko 1981, Zylstra et al. 2010). In the northeastern United States, trap trees are more effective and reliable as a survey tool than traps baited with a semiochemical lure although timing is a critical issue (Zylstra et al. 2010). Trees girdled 1 mo before or up to the beginning of peak flight for *S. noctilio* are most attractive for woodwasps (Spradbery and Kirk 1978, Zylstra et al. 2010). Similar studies on effectiveness of trap trees and trap types in attracting greater catches and species of siricids in the southeastern United States are currently lacking. Our major research objective for this 3-yr project (2009–2011) was to assess the efficacy of various trapping techniques (traps and lures, and trap trees) for capturing these hymenopteran species.

Materials and Methods

Study Sites. In 2009–2011, siricids were sampled in three states, each representing specific physiographic regions in the southeastern United States: Piedmont (Georgia and Virginia) and Coastal Plains (Louisiana; Table 1). To maximize the catches and diversity of siricid wasps, all sampling took place in forests that were either recently disturbed because of windstorms, bark beetle activity, commercial thinning, and ice-storms, or in overstocked pine forests.

In Georgia, sampling was conducted in 2009 in the Whitehall Experimental Forest in Clarke County, Athens (Table 1). The sampled site in Whitehall Forest was a natural pine forest dominated by loblolly pines (*Pinus taeda* L.) intermixed with *Quercus* spp., *Carya* spp., and *Liquidamber styraciflua* L. Sampling was also conducted in the Bartram Educational Forest in slash pine (*Pinus elliottii* Engelm.) stands located in the Baldwin State Forest in Baldwin County. In 2010, sampling was conducted on two sites each in Jackson and Morgan Counties, GA. We focused on wood-processing mills and lumber storage yards in an effort to increase the number of siricid captures, as there was a constant large volume of attractive and fresh host type at all these sites. All traps were placed at the edges of these mills and yards in mixed loblolly pine and *Quercus* spp. forests. Site 1 (Jackson Co.) was located near a pine-processing mill located ≈800 m away from the manufacturing site. Site 2 (Jackson Co.) was located in a log storage area along the border of the facility. Site 3 (Morgan Co.) was located at a pine-processing mill, at which traps were placed in two different locations ≈800 m apart in surrounding forests. Site 4 (Morgan Co.) was located at a hardwood chip mill where traps were also placed in two different locations ≈600 m apart in surrounding forests.

In Virginia, sampling was conducted in 2009 in the Appomattox–Buckingham State Forest on three different sites: 1) a thinned loblolly pine stand previously damaged because of an ice storm; 2) a highly overstocked, predominantly Virginia pine (*Pinus virginiana* Mill.) stand experiencing decline because of windstorms and bark beetle infestations (southern pine beetle, *Dendroctonus frontalis* Zimmermann); and 3) a heavily thinned shortleaf pine (*Pinus echinata* Mill.) stand (Table 1).

In Louisiana, sampling was conducted in 2009 and 2010 on the Kisatchie National Forest (Grant Parish; Table 1). In 2009, the study was conducted in loblolly, shortleaf, and longleaf (*Pinus palustris* Mill.) pine sawtimber stands thinned in October 2008. In 2010, sampling was conducted within days of commercial thinning in mixed loblolly and longleaf pine sawtimber stand in the same national forest.

Experiment 1: Assessment of Sirex *vs. Ethanol Lure.* Sampling of siricids was conducted in the fall season (September–December) of each year during their peak flight times, especially for *Sirex* spp. At each site, 30 intercept panel traps (Alpha Scents, Inc., Portland, OR) were hung 25 m apart along a linear transect. In Georgia (during 10 October–17 December 2009) and Virginia (21 September–18 November 2009), all traps were hung between two trees, with the trap cup 1–1.5 m off the ground. Traps in Louisiana (16 October–22 December 2009) were hung on 2.4 m-tall metal poles, with the collection cup ≈1.5 m off the ground. Intercept panel traps were placed on 10 different transects with three traps per transect (in total, 30 traps). Transects and traps were spaced by >50 and 25 m from each other, respectively, to reduce adjacent trapping effects. Each intercept panel trap had one of the following lures: 1) *Sirex* ultra high release (UHR) lure (70:30 α-pinene: β-pinene; 1,500–2,500 mg/d release rate; ultra-high release device; Synergy Semiochemicals, Corp., Burnaby, British Columbia, Canada); 2) *Sirex* UHR + 95% ethanol (1,000–2,000 mg/d release rate; 95% chemical purity; ultra-high release device; ConTech Enterprises Inc., Victoria, British Columbia, Canada); or 3) an unbaited, control trap. Lures were replaced after 6 wk.

Experiment 2: Assessment of Two Trap Types. To compare the efficiency of different trap types, in addition, we used 8-unit Lindgren funnel traps in 2009 using the same lure types as intercept panel traps at the same sites and times in Georgia (ConTech Enterprises Inc.). In 2009, traps were installed at the following sites: 1) Whitehall Forest, where we installed three intercept panel traps with the same lures in experiment 1 on each of four transects, and installed a similar configuration using funnel traps; and 2) Bartram Forest, where we installed three intercept panel traps with the same lures in experiment 1 on each of six transects, with a similar configuration for funnel traps. Hence, in total, 70 traps were used. Transects and traps were spaced by >50 and 25 m from each other, respectively.

Experiment 3: Assessment of Host Attractants and Bark Beetle Semiochemicals. To better understand the effectiveness of host attractants and bark beetle lures to catch siricid wasps, traps were established at four different sites in Georgia (during 14 October–20 December 2010). At each site, traps were baited with either: 1) *Sirex* UHR alone; 2) *Sirex* + Ethanol (EtOH); 3) EtOH alone; 4) *Sirex* + EtOH + ipsdienol (0.1–0.2 mg/d release rate; 95% chemical release rate; +50/−50 enantiomeric composition; bubble cap release device) + ipsenol (0.1–0.2 mg/d release rate; 95% chemical release rate; +50/−50 enantiomeric composition; bubble cap release device; referred to as SEII hereafter); or 5) an unbaited, control trap (ConTech Enterprises Inc.). Traps and transects were installed and operated similarly to studies conducted in 2009. Hence, all four sites contained, in total, 40 traps consisting of 20 Lindgren funnel and 20 intercept panel traps.

Experiment 4: Assessment of Pine vs. Sirex *Lures.* To test the effectiveness of host material (freshly cut pine billets) compared with commercially available lures as an attractant for siricids, 30 intercept panel traps were used in 2010 in Kisatchie National Forest, LA. Ten linear transects were established with three traps in each transect. Each trap had one of the following lures: 1) *Sirex* UHR lure (70:30 α-pinene: β-pinene); 2) fresh pine lure, a nylon mesh bag (Amber Lumite screen of mesh size 81 by 81 mesh/cm, and 24 by 85 cm in size) containing 10–12 split loblolly pine billets (created by quartering 7.5- to 10-cm-diameter pine bolts) and 10–12 pine boughs (including the foliage); and 3) an unbaited, control trap. Traps suspended from 2.4-m-tall metal poles, with the collection cup ≈1.5 m from the ground, were spaced 25 m apart. Trapping was conducted during 20 October–8 November 2010, and again during 23 November–27 December 2010. Pine bags and *Sirex* lures were replaced on 27 October and 23 November 2010.

All trap cups contained 7–8 cm of propylene glycol (Peak RV and Marine Anti-freeze, Old World Industries Inc., Northbrook, IL) to catch and preserve the insects. Insect catches were collected at least every 2 wk from October to December in 2009–2010, and sorted. Siricid species were identified using available taxonomic literature (e.g., Schiff et al. 2006, 2012). A voucher collection has been deposited in the Georgia Museum of Natural History, University of Georgia, Athens, GA.

Experiment 5: Sampling With Trap Trees. Trap trees were created using three treatment methods: 1) trees injected using the herbicide Dicamba, hereafter referred to as Dicamba trap trees; 2) healthy, unaltered trees felled but not bucked into smaller portions; and 3) healthy, unaltered trees felled, bucked into 1.1-m sections and stacked crosswise on the ground adjacent to the severed tree top.

In 2009, trap trees were created in Virginia and Louisiana. In Appomattox–Buckingham State Forest, VA, three loblolly trees (mean DBH [diameter in breast height] = 19.3 ± 0.31 cm) were created by felling but left intact in September 2009. The felled trees stayed in the forest for ≈11 mo to allow siricids to oviposit, their progeny to complete most of their life cycle, and for parasitoids to attack siricids. In August 2010, before emergence of adults, the felled trees were cut into logs (1 m in length) and transported directly back to Athens, GA. Logs were placed into screen emergence tents sized 3.9 by 2.7 m (Ozark Trail Polyester Dome Screen House). Logs remained in the tents from early September to early January 2010 where insects were collected daily and identified. Eighteen logs were then chosen randomly based on position of each tree: six logs each from the top, middle, and bottom of each tree. Logs were cut and split to retrieve any remaining larvae or pupae of siricids that were identified by the presence of posterior cornus on the last abdominal segment (Smith and Schiff 2002).

In Louisiana, in total, 12 loblolly pine trap trees (mean DBH = 12.4 cm) were created in 2009 in a loblolly pine plantation located adjacent to a pine sawmill that produces plywood. Four trap trees were created on 23 September 2009 by applying 1 ml of 20% (wt:vol) aqueous herbicide Dicamba (56.8% active ingredient [a.i.] is diglycolamine salt; 480 g/liter; Vanquish, Syngenta Crop Protection, Inc., Greensboro, NC) in a distilled water solution into a 6- to 7-cm-deep and 10-mm-diameter predrilled hole every 10 cm around the tree's circumference. Holes were ≈15 cm above ground level and drilled at a downward 45° angle (Neumann et al. 1982, Neumann and Morey 1984). The number of drilled holes ranged from five to eight per tree and the absolute amount of the a.i. per tree ranged from 2 to 3.2 g. On 3 November 2009, typically early in the pine siricids flight period, four trap trees were felled and cut into 1.1-m logs and stacked crosswise atop each other adjacent to the intact crown (hereafter abbreviated as FT 1–4). Log stacks and crowns for each tree lay inside the stand at least 15 m apart. This same process was repeated on four additional trees on 18 November 2009 (hereafter abbreviated as FT 5–8). An intercept panel trap was suspended from a 2.4-m aluminum pole adjacent to all trap trees. Traps were deployed at the Dicamba and FT 1–4 trap trees on 4 November; traps were deployed at trap trees FT 5–8 on date these trees were felled (18 November 2009). Traps were collected every 1–7 d until 24 March 2010.

Dicamba-created trap trees were left standing until 29 September 2010, when they were felled and cut into 1.3-m long logs. These trap trees as well as the logs from the eight nonherbicide trap trees (FT 1–8) were placed in 3.5- by 3.5-m-sized screen tents (one tree per tent; REI Screen House, Nylon/mesh). Siricids and parasitoids were collected weekly from the emergence tents. Further, we placed emergence cages measuring 60 by 60 by 60 cm on stumps of 12 trees in 2010 to collect any insects emerging from stumps.

In October 2010, trap trees were created in Georgia's Whitehall Forest. Ten loblolly pine trees (mean DBH = 18.3 ± 0.42 cm) were felled and cut into 1-m logs (up to the crown) and stacked crosswise atop each other adjacent to the intact crown. Log stacks and crowns for each tree lay inside the stand at least 15 m apart in a linear array (cut, buck, and stacked). Cut trees were left in the stand for 1 yr. In October 2011, all trees were moved into emergence tents where siricids and parasitoids were collected weekly from the tents until the following spring.

Statistical Analyses. Trap data were standardized to catches per 2 wk per trap to account for disturbed traps and variation in sampling period. Similarly, insect emergence from trap trees was standardized to per cubic meter to account for different tree sizes across treatments and states. Tree volume was calculated using the following formula: $[(\text{one-thirds})\times(\pi)\times(\text{radius at base})^2\times(\text{tree height})]$. Standardized trap catch data for each state and emergence data from trap trees was analyzed for normality and constant variance (PROC Univariate normal, SAS 2010). Data were not normal and since transformations failed to achieve normality, all data were analyzed using nonparametric tests, such as Kruskal–Wallis and Mann–Whitney *U* tests. Following tests were conducted to assess differences in insect catches among: 1) lure types separately for Virginia and Louisiana in 2009 (experiment 1); 2) lure types and trap types for Georgia in 2009 (experiment 2); 3) lure types for Georgia in 2010 (experiment 3); 4) lure types for Louisiana in 2010 (experiment 4); 5) trap tree types in Louisiana in 2009 separately for siricid and parasitoid species (experiment 5); and 6) panel traps placed adjacent to trap tree types in Louisiana in 2009 for siricid species (experiment 5; SAS Institute 2010).

Results

Sampling of Wasps with Traps. In total, 274 siricids (all females) were collected over the 2 yr in the three different states using intercept and funnel traps (excluding traps placed next to trap logs in Louisiana; Table 2). The majority of catches were of *Sirex nigricornis* (F.) (that includes what was formerly known as *Sirex edwardsii* Brullé; 92.7%), followed by *Tremex columba* (L.) (3.7%), *Eriotremex formosanus* (Matsumura) (1.8%), and *Urocerus cressoni* (Norton) (1.8%). In addition, *E. formosanus, S. nigricornis, T. columba*, and *U. cressoni* were trapped in Virginia; *S. nigricornis* and *U. cressoni* in Georgia; and *E. formosanus, S. nigricornis*, and *T. columba* in Louisiana.

Lure type was a significant factor for trap catches of siricids in 2009 in Georgia (χ^2 = 8.597; P = 0.014), Virginia (χ^2 = 11.93; P = 0.003), and Louisiana (χ^2 = 8.922; P = 0.012; Fig. 1). *Sirex* lure alone and *Sirex* + EtOH lure captured two to five times greater numbers of siricids than the unbaited trap (Fig. 1). While too few *I. l. ensiger* were collected to draw conclusions, one specimen was collected in an intercept panel trap baited with the *Sirex* + EtOH lures on 6 November 2009, and another collected on 13 November 2009 in a trap baited with the *Sirex* lure alone in Louisiana. There was no difference in siricid trap catches between intercept and funnel trap in Georgia (P =

Table 2. Total numbers of siricids and parasitoids caught in 2009–2011 traps baited with various lures, and trap logs in Georgia, Virginia, and Louisiana

Hymenoptera species	Lure type						Trap logs[h]	Trap next to trap logs[g]	Total
	Unbaited	*Sirex*[a]	S + EtOH[b]	EtOH[c,d]	S + E + I + I[d,e]	Pine bags[f,g]			
Siricidae									
Sirex nigricornis (F.)	12	74	36	1	13	116	1,609	64	1,925
Urocerus cressoni (Norton)	0	2	3	0	0	0	0	0	5
Tremex columba (L.)	1	6	3	0	0	0	0	0	10
Eriotremex formosanus (Matsumura)	1	2	2	0	0	0	0	0	5
Ibaliidae									
Ibalia leucospoides ensiger Norton	0	1	1	0	0	0	486	1	489
Total numbers	14	85	45	1	13	116	2,095	65	2,434

[a] *Sirex*: *Sirex* lure.
[b] S + ETOH: *Sirex* + Ethanol.
[c] EtOH: ethanol alone.
[d] Only used in Georgia in 2010.
[e] S + E + I + I: *Sirex* + Ethanol + Ipsenol + Ipsdienol.
[f] Pine: fresh pine billets.
[g] Only used in Louisiana in 2010.
[h] Emerged from trap tree logs and were not collected in traps.

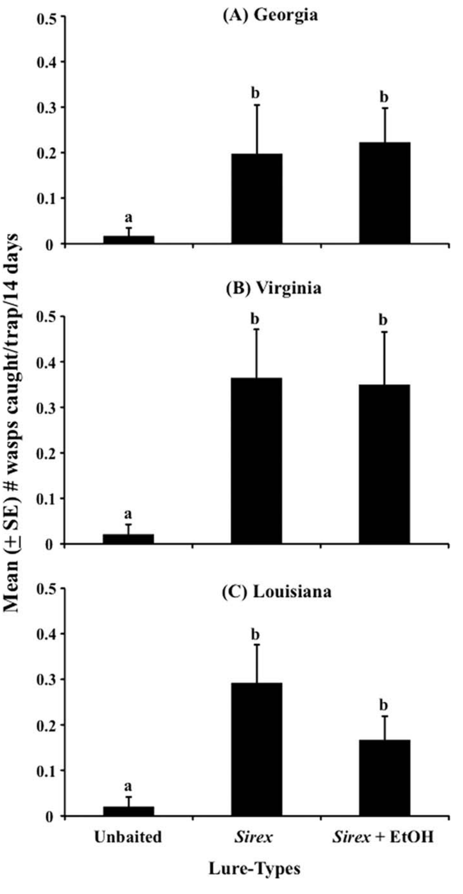

Fig. 1. Mean (±SE) number of siricid adults caught per 14 d per trap in (A) Georgia, (B) Virginia, and (C) Louisiana in 2009. Trap catches for funnel and intercept panel traps were pooled in Georgia.

0.553). Lure type was also a significant factor for trap catches in 2010 in Georgia ($\chi^2 = 9.679$; $P = 0.046$; Fig. 2). Traps baited with EtOH lure alone caught significantly lower numbers of siricids than *Sirex*, *Sirex* + EtOH, and SEII lures (Fig. 2). Similar to 2009, there was no difference in trap catches of siricids between intercept and funnel traps in Georgia ($P = 0.451$). In Louisiana in 2010, there was a significant difference in *S. nigricornis* trap catches among traps baited with fresh pine bags, *Sirex* lure alone, and unbaited traps ($\chi^2 = 18.23$; $P < 0.001$; Fig. 3). Traps baited with pine bags captured about three to four times more *S. nigricornis* than other lures, while traps baited with the *Sirex* lure caught twice as many *S. nigricornis* as the unbaited trap (Fig. 3). No *I. l. ensiger* were collected in this experiment.

Sampling of Wasps with Trap Trees. In total, 1,609 siricids and 486 parasitoids emerged 1 yr after trap trees were created and attacked in all three states (Table 2). The only two wasp species that emerged from trap trees were *S. nigricornis* and *I. l. ensiger*. In total, 82 *S. nigricornis* (42 males: 40 females; 1.1:1 ratio) but no parasitoids emerged from trap trees in 2010 in Virginia. In total, 299 *S. nigricornis* (141 males: 158 females; 0.89:1) emerged from trap trees in 2011 in Georgia, with no parasitoids. In total, 1,228 *S. nigricornis* (899 males: 329 females; 2.73:1) and 486 *I. l. ensiger* emerged from the trap trees in 2010 in Louisiana indicating that there was a 28% parasitism rate by *I. l. ensiger*. No targeted insects emerged from cages placed on 12 tree stumps.

There were significant differences in the total numbers of siricids ($\chi^2 = 9.27$; $P = 0.091$) and parasitoids ($\chi^2 = 8.12$; $P = 0.017$) emerging among trap trees created using Dicamba, and early and late cut in Louisiana (Fig. 4). Both of the cut, bucked, and stacked (early and late) trees had >14 times more siricid emergence than those trees that were injected with Dicamba, with the greatest numbers coming from trees felled on the early cut date. Twice as many *I. l. ensiger* emerged when the trees were

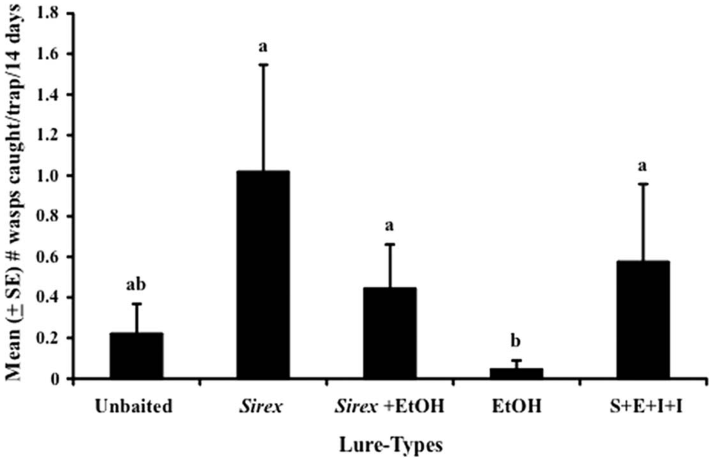

Fig. 2. Mean (±SE) number of siricid adults caught per 14 d per trap in baited (funnel and intercept panel) traps in Georgia in 2010. Baits included *Sirex* lure, *Sirex* + EtOH: *Sirex* lure and ethanol, and SEII: *Sirex* lure + Ethanol + Ipsenol + Ipsdienol. Data for funnel and intercept panel traps are combined in this graph.

cut, bucked, and stacked early compared with using Dicamba, but there was no difference between cutting the trees in early and late November or between cutting the trees later and using Dicamba (Fig. 4).

In total, 64 *S. nigricornis* and 1 *I. l. ensiger* were caught in intercept panel traps hung next to trap trees in Louisiana. There were no significant differences between number of siricids caught in panel traps next to Dicamba, and early and late cut trap trees ($P = 0.061$). Interestingly, only one *I. l. ensiger* was collected during 5–24 March 2010 from a trap tree felled on the second cut date.

Discussion

In our 3-yr study, we caught four (three native and one exotic [*E. formosanus*]) species of siricid woodwasps in Georgia, Virginia, and Louisiana. In Arkansas, Keeler (2012) reported five siricid species (including *Urocerus taxodii* (Ashmead)) from ice-damaged pine stands. As there are 33 known native species of Siricidae in North America (Schiff et al. 2012), our study indicates that the southeastern region contains at least 12% of the known North American fauna. Virginia is the only state in which we trapped all four species, with three and two species, respectively, in Louisiana and Georgia. There are likely more species present in these states than were captured in our study. For example, Kirk (1974) reported *Sirex cyaneus* F. (=*Sirex abbottii* (Kirby)) from the same location (Whitehall Forest) in Georgia where traps were operated in our study. It is unlikely that *S. cyaneus* is entirely absent from Georgia, but rather that the population may be restricted and is therefore, much less likely to be trapped. Another possibility is that the baits and traps used in our studies were perhaps not optimal for catching this species.

We collected more adult *I. l. ensiger* in Louisiana than in the other two states. Similar methods were used in 2009 in Louisiana for trap trees (cut buck and stack), and in 2010 in Georgia. However, 486 *I. l.*

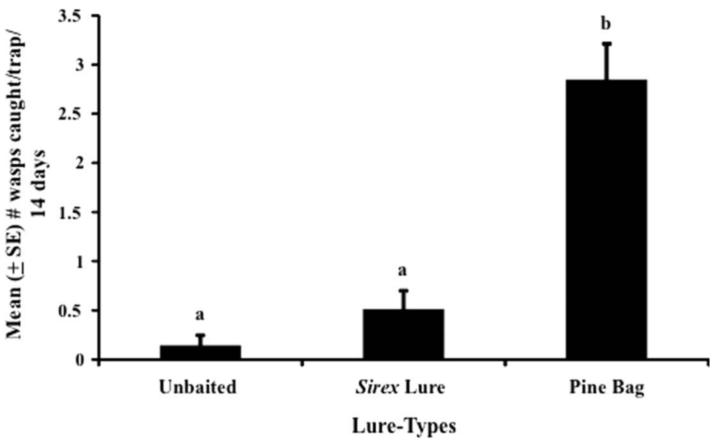

Fig. 3. Mean (±SE) number of *S. nigricornis* adults caught per 14 d per trap in baited traps in Louisiana in 2010. Baits included *Sirex* lure and Pine Bags (consisted of fresh pine billets and foliage).

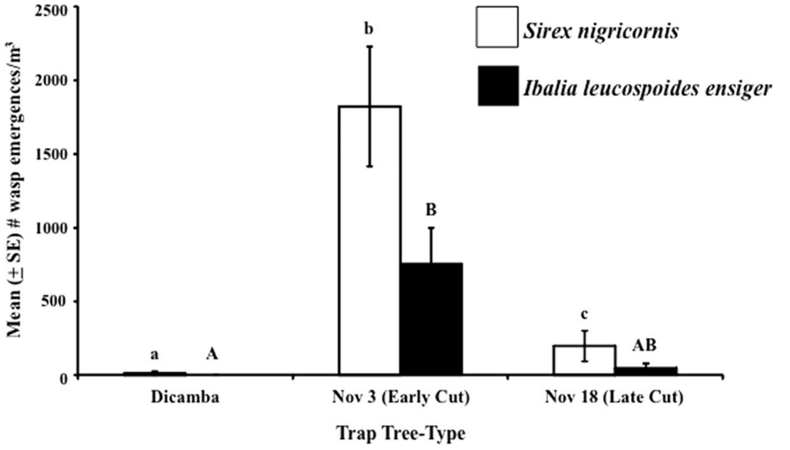

Fig. 4. Emergence of *S. nigricornis* and *I. l. ensiger* adults from trees killed with Dicamba and by cutting in early and late November in 2010 in Louisiana. Data were analyzed separately for each of the two species; lower-case letters refer to the siricid species, and upper-case letters refer to the parasitoid species.

ensiger emerged from trap trees in Louisiana, whereas none emerged in Georgia. These results could represent differences in population levels, host types, site-specific host availability, and stand structure and composition between the two states. Another possibility is that differences in timing of trap trees, as Louisiana trap trees were created in early November and immediately before and coincident with the peak of the wild population flight, and in Georgia they were created in early October. Because *I. l. ensiger* parasitizes egg and first-instar stage of siricids (Middlekauff 1960), we may have missed collecting *I. l. ensiger* in Georgia, as the hosts may have already been in an advanced stage by the peak flight of parasitoid species.

Greater numbers of siricids were caught in baited than unbaited traps. In 2009, there was no difference in siricid catches in traps baited with *Sirex* lure alone or *Sirex* lure with ethanol. In Georgia in 2010, ethanol alone was relatively ineffective in capturing native siricids, as in the Great Lakes Region (Coyle et al. 2012). However, in 2010 in Louisiana, traps baited with the fresh pine bags collected significantly more *S. nigricornis* than those baited with the *Sirex* lure. These results suggest that the *Sirex* lure may be missing some important host volatile component(s), there may be differences in elution rates between *Sirex* lure and pine bags, or both.

There were no differences in catches of siricids between intercept and funnel traps, although we caught only 74 siricids in Georgia. Studies in Australia have found that intercept panel traps captured 40% more *S. noctilio* than the multiple funnel trap (Bashford 2008). Similar to our results, there were no differences in native siricid catches between the two trap types in South Dakota (Costello et al. 2008), and for *S. noctilio* in New York (Dodds and de Groot 2012). These regional differences indicate that intercept panel and funnel traps may capture similar numbers of native siricids and *S. noctilio* in the Northern Hemisphere.

In Louisiana, more *S. nigricornis* emerged from cut, bucked, and stacked trap trees than from those treated with Dicamba. Further, cutting trap trees close to but before the peak of *S. nigricornis* flight in the area (early November) captured significantly more siricids and parasitoids than cutting the trees 2 wk later. Hartshorn (2012) documented that greater numbers of *S. nigricornis* oviposited on newly cut logs than on 15- and 30-d old logs in Arkansas possibly because of higher moisture content present in fresh logs. A confounding issue is timing, as trees were treated with Dicamba in late September, which is in the early part of (or even before) the siricid flight season. In the Southern Hemisphere, trap trees for detection of *S. noctilio* were created 2–3 mo before peak flight period (Neumann et al. 1982). In New York, injecting Dicamba into the tree stem 1 mo before peak flight or at flight season captured the greatest numbers of *S. noctilio* (Zylstra et al. 2010). Late October to early December is the peak flight period of the most commonly collected siricid in this study (*S. nigricornis*); treating trap trees with Dicamba in late September could have been too early to sample our native species. However, Johnson et al. (2013) demonstrated the relative ineffectiveness of herbicide created trap trees for attracting *S. nigricornis* in Louisiana, regardless of timing (e.g., mid-August, early September, mid-October, and early November).

Trap trees were found to be a more effective way to sample populations of *S. nigricornis* than using traps with semiochemical lures. Overall, eight times more siricids emerged from trap trees than were caught in funnel and intercept traps. Furthermore, baited traps caught little or no siricid parasitoids. Our results are consistent with those of Zylstra et al. (2010), which found that hanging funnel traps over trap trees did catch *S. noctilio*, but the actual trap trees themselves had seven times more *S. noctilio* emergence than what was caught in the traps. One problem with traps was that the openings of the traps were frequently clogged with leaf and needle litter (because of fall trapping time), possibly preventing insects from falling in the collection cups. In support, we observed that captures were greater in 2010 than in 2009 in Louisiana when traps were collected once a day as compared with once a week.

Of interest, the cut, bucked, and stacked trap trees in Louisiana appeared more effective than traps baited with lures in detecting the associated egg and early instar parasitoid, *I. l. ensiger.* In addition to pine volatiles that may elicit a kairomonal effect, attacked logs likely also included *Sirex* eggs and the *Amylostereum* spp. fungi when *I. l. ensiger* specimens were collected in traps adjacent to the log piles. Recent findings in 2012 also indicate the ichneumonid wasp, *R. howdenorum,* an idiobiont parasitoid of larval *S. nigricornis,* can be collected during spring months (March–April; J.R.M., unpublished data) in funnel traps suspended over cut, bucked, and stacked trap trees not treated with the herbicide. This suggests that our trap timing may not be appropriate for *Rhyssa* and *Megarhyssa* species.

Only female siricids were caught in traps, whereas both males and females emerged from trap logs. Males tend to remain mostly in the tree canopy and females fly at different heights to find suitable hosts (Schiff et al. 2006) that could lead to their greater capture in traps. Conversely, male siricids may not be attracted to these lure types. We found considerable variation in sex ratio of *S. nigricornis* emerging from trap logs in three states ranging from 0.89 to 2.73 males per female. Fewer males than females emerged from logs in Georgia, whereas more males emerged in Louisiana. Similar variation in sex ratio has been observed for *S. noctilio* where more males are typically caught than females because of haplo–diploid sex determination especially when siricids are in early stages of colonization in a new area (Taylor 1981, Long et al. 2009, Ryan and Hurley 2012, Ryan et al. 2012).

To conclude, our study provides information about the species composition, distribution, timing, and trapping methods for native siricids (primarily *S. nigricornis*) and associated parasitoid species (primarily *I. l. ensiger*) in the southeastern United States. Results indicate that using host material (pine billets and foliage) and trap trees created by felling healthy trees (though costly and labor-intensive to produce) are optimal for monitoring populations of *S. nigricornis* and the associated parasitoid *I. l. ensiger.* The most opportune time to create trap trees in the coastal plain region appears to be in early November for maximizing catches of *S. nigricornis* and *I. l. ensiger;* however, this date likely varies with latitude. Further studies may be conducted to determine the timing of this treatment for detecting native siricids and parasitoids in more northern latitudes.

Acknowledgments

We thank laboratory and field assistance provided by the entire Forest Entomology Laboratory at the University of Georgia; Billy Bruce, Kevin Dodds, Donald Duerr, Alex Mangini, Jacob Hudson, and Chris Steiner from the U.S. Department of Agriculture (USDA) Forest Service, Forest Health Protection; and Chip Bates, James Johnson, and Eric Mosely from the Georgia Forestry Commission. Comments from two anonymous reviewers greatly improved the manuscript. Financial support for the project was provided by the USDA Forest Service, 2009 Request for Research and Technology Development Proposals to Improve the Management and Detection of *Sirex noctilio,* and the Daniel B. Warnell School of Forestry and Natural Resources, University of Georgia.

References Cited

Allison, J. D., J. H. Borden, and S. J. Seybold. 2004. A review of the chemical ecology of the Cerambycidae (Coleoptera). Chemoecology 14: 123–150.

Allison, J. D., W. Johnson, J. Meeker, B. Strom, and S. Butler. 2011. Effect of aerosol surface lubricants on the abundance and richness of selected forest insects captured in multiple-funnel and panel traps. J. Chem. Ecol. 104: 1258–1264.

Bashford, R. 2008. The development of static trapping systems to monitor for wood-boring insects in forestry plantations. Aust. For. 71: 236–241.

Cameron, E. A. 1965. The Siricinae (Hymenoptera: Siricidae) and their parasites. CBIC Technical Report 5, p. 31.

Cameron, E. A. 2012. Parasitoids in the management of *Sirex:* looking back and looking ahead, pp. 103–117. *In* B. Slippers, P. de Groot, and M. J. Wingfield (eds.), The *Sirex* Woodwasp and Its Fungal Symbiont: Research and Management of a Worldwide Invasive Pest. Springer, New York, NY.

Chénier, J.V.R., and B.J.R. Philogène. 1989. Evaluation of three trap designs for the capture of conifer feeding beetles and other forest coleopteran. Can. Entomol. 121: 159–167.

Ciesla, W. M. 2003. European woodwasp: a potential threat to North America's conifer forests. J. For. 101: 18–23.

Corley, J. C., J. M. Villacide, and O. A. Bruzzone. 2007. Spatial dynamics of a *Sirex noctilio* woodwasp population within a pine plantation in Patagonia, Argentina. Entomol. Exp. Appl. 125: 231–236.

Costello, S. L., J. Negron, and W. R. Jacobi. 2008. Trap and attractants for wood-boring insects in Ponderosa pine stands in the Black Hills, South Dakota. J. Econ. Entomol. 101: 409–420.

Coyle, D. R., and K.J.K. Gandhi. 2012. The ecology and biological control potential of hymenopteran parasitoids of woodwasps (Hymenoptera: Siricidae) in North America. Environ. Entomol. 41: 731–749.

Coyle, D. R., J. A. Pfammatter, A. M. Journey, T. L. Pahs, V. J. Cervenka, and R. I. Koch. 2012. Community composition and phenology of native Siricidae (Hymenoptera) attracted to semiochemicals in Minnesota. Environ. Entomol. 41: 91–97.

Czokajlo, D., D. Ross, and P. Kirsh. 2001. Intercept panel trap, a novel trap for monitoring forest Coleoptera. For. Sci. 47: 63–65.

de Groot, P., and R. W. Nott. 2003. Response of *Monochamus* (Coleoptera: Cerambycidae) and some Buprestidae to flight intercept traps. J. Appl. Entomol. 127: 548–552.

de Groot, P., K. Nystrom, and T. Scarr. 2006. Discovery of *Sirex noctilio* (Hymenoptera: Siricidae) in Ontario, Canada. Great Lakes Entomol. 39: 49–53.

Dinkins, J. E. 2011. *Sirex noctilio* host choice and no-choice bioassays: woodwasp preferences for southeastern U.S. pines. M.S. thesis, University of Georgia, Athens.

Dodds, K. J., and P. de Groot. 2012. *Sirex,* surveys and management challenges of having *Sirex noctilio* in North America, pp. 256–286. *In* B. Slippers, P. de Groot, and M. J. Wingfield (eds.), The *Sirex* Woodwasp and Its Fungal Symbiont. Springer, Dordrect, The Netherlands.

Hartshorn, J. A. 2012. Effects of felled shortleaf (*Pinus echinata* Mill.) moisture loss on oviposition preferences and survival of *Sirex nigricornis* F. (Hymenoptera: Siricidae). M.S. thesis, University of Arkansas, Fayetteville, AR.

Haugen, D. A., and E. R. Hoebeke. 2005. Pest alert: *Sirex* woodwasp - *Sirex noctilio* F. (Hymenoptera: Siricidae). United States Department of Agriculture, Forest Service. NA-PR-07-05. (www.na.fs.fed.us/spfo/pubs/pest_al/sirex_woodwasp/sirex_woodwasp.htm).

Hurley, B. P., B. Slippers, and M. J. Wingfield. 2007. A comparison of control results for the alien invasive woodwasp, *Sirex noctilio*, in the southern hemisphere. Agric. For. Entomol. 9: 159–171.

Iede, E. T., S.R.C. Penteado, and E. G. Schaitza. 1998. *Sirex noctilio* problem in Brazil: detection, evaluation, and control, pp. 45–52. *In* E. T. Iede, S. Penteado, R. C. Reardon, and S. T. Murphy (eds.), Proceedings of a Conference: Training in the Control of *Sirex noctilio* by the Use of Natural Enemies. USDA Forest Service, Morgantown, WV.

Johnson, C. W., J. R. Meeker, W. G. Ross, S. D. Petty, B. Bruce, and C. Steiner. 2013. Detection and seasonal abundance of *Sirex nigricornis* and *Eriotremex formosanus* (Hymenoptera: Siricidae) using various lures and trap trees in Central Louisiana, U.S. J. Entomol. Sci. 48: 173–183.

Keeler, D. M. 2012. Flight period and species composition of *Sirex* (Hymenoptera: Siricidae) and associated *Deladenus* (Nematoda: Neotlenchidae) within Arkansas pine forests. M.S. thesis. University of Arkansas, Fayetteville, AR.

Kirk, A. A. 1974. Siricid woodwasps and their associated parasitoids in the southeastern United States (Hymenoptera: Siricidae). Geo. Entomol. Soc. 9: 139–144.

Lindgren, B. S. 1983. A multiple funnel trap for scolytid beetles (Coleoptera). Can. Entomol. 115: 299–302.

Long, S. J., D. W. Williams, and A. E. Hajek. 2009. *Sirex* species (Hymenoptera: Siricidae) and their parasitoids in *Pinus sylvestris* in eastern North America. Can. Entomol. 141: 153–157.

Madden, J. L. 1971. Some treatments which render Monterey pine (*Pinus radiata*) attractive to the wood wasp *Sirex noctilio* (F). B. Entomol. Res. 60: 467–472.

Madden, J. L. 1998. *Sirex* management: silviculture, monitoring, and biological control (An introduction), pp. 15–17. *In* E. T. Iede, S. Penteado, R. C. Reardon, and S. T. Murphy (eds.), Proceedings of a Conference: Training in the Control of *Sirex noctilio* by the use of Natural Enemies. USDA Forest Service, Morgantown, WV.

McIntosh, R. L., P. J. Katinic, J. D. Allison, J. H. Borden, and D. L. Downey. 2001. Comparative efficacy of five types of trap for woodborers in the Cerambycidae, Buprestidae and Siricidae. Agric. For. Entomol. 3: 113–120.

Middlekauff, W. W. 1960. The siricid woodwasps of California (Hymenoptera: Symphyta), p. 77. Bulletin of the California Insect Survey, vol. 6. University of California Press, Berkeley and Los Angeles.

Miller, D. R., C. M. Crowe, B. F. Barnes, K.J.K. Gandhi, and D. A. Duerr. 2013. Attaching lures to multiple-funnel traps targeting saproxylic beetles (Coleoptera) in pine stands: inside or outside funnels? J. Econ. Entomol. 106: 206–214.

Minko, G. 1981. Chemicals for non-commercial thinning of *Pinus radiata* by basal stem injection. Aust. Weeds 1: 5–7.

Morewood, W. D., K. E. Hein, P. J. Katinic, and J. H. Borden. 2002. An improved trap for large woodboring insects, with special reference to *Monochamus scutellatus* (Coleoptera: Cerambycidae). Can. J. For. Res. 32: 519–525.

(NAPIS) National Agricultural Pest Information System and Purdue University. 2012. Survey status of *Sirex* woodwasp–*S. noctilio* (2009 to present). (http://pest.ceris.purdue.edu/map.php?code=ISBBADA&year=3year).

Neumann, F. G., and J. L. Morey. 1984. Influence of natural enemies on the *Sirex* woodwasp in herbicide-treated trap trees of radiata pine in north-eastern Victoria. Aust. For. 47: 218–224.

Neumann, F. G., J. A. Harris, F. A. Kassaby, and G. Minko. 1982. An improved technique for early detection and control of the *Sirex* woodwasp in *Radiata* pine plantations. Aust. For. 45: 117–12.

Rawlings, G. B. 1948. Recent observations on the *Sirex noctilio* population in *Pinus radiata* forests in New Zealand. N Z. J. For. 5: 411–421.

Ryan, K., and B. P. Hurley. 2012. Life-history and biology of *Sirex noctilio*, pp. 15–30, *In* B. Slippers, P. de Groot, and M. J. Wingfield (eds.), The *Sirex* Woodwasp and Its Fungal Symbiont: Research and Management of a Worldwide Invasive Pest. Springer, New York, NY.

Ryan, K., P. de Groot, and S. M. Smith. 2012. Evidence of interaction between *Sirex noctilio* and other species inhabiting the bole of *Pinus*. Agric. For. Entomol. 14: 187–195.

SAS Institute. 2010. SAS Institute version 9.1. SAS Institute, Cary, NC.

Schiff, N. M., S. A. Valley, J. R. LaBonte, and D. R. Smith. 2006. Guide to the siricid woodwasps of North America. U.S. Department of Agriculture Forest Service, Forest Health Technology Enterprise Team. Morgantown, WV.

Schiff, N. M., H. Goulet, D. R. Smith, C. Boudreault, A. D. Wilson, and B. E. Scheffler. 2012. Siricidae (Hymenoptera: Symphyta: Siricoidea) of the Western Hemisphere. Can. J. Arth. Inden. 21: 1–305.

Simpson, R. F., and R. M. McQuilkin. 1976. Identification of volatiles from felled *Pinus radiata* and the electroantennograms they elicit from *Sirex noctilio*. Entomol. Exp. Appl. 19: 205–213.

Smith, D. R., and N. M. Schiff. 2002. A review of the siricid woodwasp and their Ibalid parasitoids (Hymenoptera: Siricidae, Ibaliidae) in the eastern United States, with emphasis on the mid-Atlantic region. P. Entomol. Soc. Wash. 104: 174–194.

Spradbery, J. P., and A. A. Kirk. 1978. Aspects of the ecology of siricid woodwasps (Hymenoptera: Siricidae) in Europe, North Africa and Turkey with special reference to the biological control of *Sirex noctilio* F. in Australia. B. Entomol. Res. 68: 341–359.

Taylor, K. L. 1976. The introduction and establishment of insect parasitoids to control *Sirex noctilio* in Australia. Entomophaga 21: 429–440.

Taylor, K. L. 1981. The Sirex woodwasp: ecology and control of an introduced forest insect, pp. 231–248. *In* R. L. Kitching and R. E. Jones (eds.), The Ecology of Pests: Some Australian Case Histories. CSIRO, Melbourne, Australia.

Tribe, G. D., and J. J. Cillié. 2004. The spread of *Sirex noctilio* Fabricius (Hymenoptera: Siricidae) in South African pine plantations and the introduction and establishment of its biological control agents. Afr. Entomol. 12: 9–17.

Zylstra, K. E., J. K. Dodds, A. K. Joseph, and V. Mastro. 2010. *Sirex noctilio* in North America: the effect of stem-injection timing on the attractiveness and suitability of trap trees. Agric. For. Entomol. 12:243–250.

Received 21 March 2013; accepted 18 September 2013.