Arboreal Insects Associated With Herbicide-Stressed *Pinus resinosa* and *Pinus sylvestris* Used as *Sirex noctilio* Trap Trees in New York

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ABSTRACT   In September of 2004, *Sirex noctilio* F. (Hymenoptera: Siricidae) was detected in New York State and later found to be established over a larger area, including parts of southeastern Canada and the northeastern United States. A key component of *S. noctilio* detection and management plans in other parts of the world where *S. noctilio* has become established are chemically girdled trap trees. Trap tree usage in North America is confounded by the presence of diverse communities of organisms that inhabit dead and dying trees. We trapped a portion of the arboreal insect community arriving at *Pinus resinosa* Ait. and *Pinus sylvestris* L., trap trees girdled 3 mo before (April), one month before (June), and at *S. noctilio* flight (July) in central New York. Multiple-funnel traps attached to trap trees captured 30,031 individuals from 109 species of Scolytinae, Cerambycidae, and Siricidae. *Ips pini* (Say) and *Ips grandicollis* (Eichhoff) accounted for almost 50% of the scolytines captured at trap trees and were present on all girdling dates. Significantly more scolytines and cerambycids were captured on *P. sylvestris* compared with *P. resinosa*, but species richness of captured insects did not differ between the two trees. More total and conifer-inhabiting scolytines and cerambycids were captured in traps on trees girdled in April and June and higher observed species richness was found on trees girdled in April and controls. Results from this study suggest a large community of arboreal insects and associated organisms are attracted to chemically girdled trap trees and likely interact with *S. noctilio*.

KEY WORDS   saproxylic, Cerambycidae, Scolytinae, host finding, *Ips*

In 2004, *Sirex noctilio* F. (Hymenoptera: Siricidae) was detected in New York State and later found over a wide geographic area stretching from Ontario south to central Pennsylvania (Dodds and de Groot 2012). *Sirex noctilio* has a long history (100 yr or more) as a successful invader and has become established in nine countries outside its natural range (Ciesla 2003, Hoebeke et al. 2005, de Groot et al. 2006). Although capable of causing economic damage in pine plantations in regions where it has been introduced (Neumann and Minko 1981, Neumann et al. 1987) limited damage has been observed in infested North American pine stands to date (Dodds et al. 2010a).

Sirex noctilio has been found in several pine species in the infested region of North America, including *Pinus resinosa* Ait., *Pinus banksiana* Lamb., *Pinus strobus* L., and *Pinus sylvestris* L. (Dodds and de Groot 2012). These pine species already support complex insect and microbial communities (Aukema et al. 2004) and at least some members of this guild may influence *S. noctilio* reproduction within trees (Ryan

et al. 2011a). On dead and dying pines, various insect species colonize tree material as decay progresses (Savely 1939, Wallace 1953). Insects concurrently colonizing trees with *S. noctilio* in North America include native (e.g., *Ips* spp., *Monochamus* spp.) and exotic [e.g., *Tomicus piniperda* (L.)] scolytines and woodborers (Dodds and Miller 2010, Ryan et al. 2011a). In its native range, *S. noctilio* is a member of a large community of insects that colonize trees in various stages of decline (Spradbery and Kirk 1978, Wermelinger et al. 2008) and encounters complex communities of cohabiting arthropod and microbial species in trees as it colonizes North American forests. Introductions throughout the Southern Hemisphere have been largely in exotic commercial pine plantations with limited pine-inhabiting native or exotic insects. Although pine-inhabiting species are present in some Southern Hemisphere exotic pine plantations (Flechtmann et al. 2001, Stone et al. 2010), few interactions with *S. noctilio* have been documented. One notable exception is *Ips grandicollis* (Eichhoff) in Australia where it cohabits trap trees with *S. noctilio* (Carnegie and Bashford 2012).

Sirex noctilio typically is found in weakened or stressed pine trees (Neumann and Minko 1981, Dodds et al. 2010a). This habit of colonizing stressed trees led to the development of trap trees as a key tool in detection and management of *S. noctilio* in the Southern Hemisphere (Madden 1971, Madden and Irvine

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1971, Neumann et al. 1982). These trees provide a strong detection tool, while also providing a critical substrate where biological control nematodes are inoculated into the environment. Where trap trees have been successfully implemented, however, limited insect or fungal competitors are generally present in the exotic commercial pine forests. The pine-inhabiting arthropod community present in North America has potential to complicate trap tree use in this region compared with Southern Hemisphere countries (Zylstra et al. 2010).

Trap trees in North America will provide an easily exploitable resource for native and exotic arboreal insects and associated organisms. Interactions among early arriving arboreal insects and *S. noctilio* may influence trap tree effectiveness. In addition, *S. noctilio* and its symbiotic fungi, *Amylostereum areolatum* (Fr.) Boidin, interacts with other insects and fungi leading to important implications for population dynamics of the woodwasp (Ryan et al. 2011a,b) and potential biological control programs (Carnegie and Bashford 2012). Documenting the insect community arriving at trap trees could provide important information for better understanding potential interactions with native and exotic insects.

The objective of this study was to investigate a subset of the arboreal insect community arriving at *P. resinosa* and *P. sylvestris* trap trees created for *S. noctilio* detection and identify conifer-inhabiting species that may interact with the invasive woodwasp within trees. Scolytinae (Coleoptera: Curculionidae), Cerambycidae (Coleoptera), and Siricidae (Hymenoptera) arriving at trees girdled during three dates (April, June, July) were captured and trap catches were compared among dates to determine if girdling timing influenced the total species composition or conifer-inhabiting insects arriving on trees. Further, species abundance was compared between *P. resinosa* and *P. sylvestris* trap trees. Species richness and diversity of both the total arboreal insects (Scolytinae, Cerambycidae, Siricidae) and conifer-inhabiting species arriving at the two tree species also were estimated.

Materials and Methods

Study Sites. All sites used in this experiment were within an 80-km radius of Syracuse, NY. Twenty replicates were set-up, with 10 occurring in *P. resinosa* and 10 in *P. sylvestris* stands. Detailed stand information has been published previously (Zylstra et al. 2010). Most sites were even-aged ($\approx$30–40 yr old) pure stands, overstocked, and generally unmanaged since stand initiation. Within each site, four treatment groups of three trees each were established at least 50 m apart. Four treatment groups were selected based on estimated initiation of *S. noctilio* flight: 1) nongirdled control, 2) girdled 3 mo before *S. noctilio* flight (April), 3) girdled 1 mo before *S. noctilio* flight (June), and 4) girdled at onset of *S. noctilio* flight (July). Treatment groups are hereafter referred to as control, April, June, and July. Trees that formed each treatment group generally were separated by <5 m. Trees were assessed for the presence of *S. noctilio* or other damaging agents with only apparently healthy trees selected for trap trees. Care was taken to select trees of approximately the same diameter at breast height and whenever possible suppressed trees were selected in an effort to increase the likelihood of *S. noctilio* attraction. However, in many stands suppressed and overtopped trees were not available and intermediate and codominant trees were used as trap trees.

Girdling Treatments. Trap trees were created at the beginning of each treatment month with chemical girdling occurring in April, June, and July. Holes were drilled into the sapwood ($\approx$5–10 cm deep, depending on diameter of the tree) every 10 cm around the circumference of each tree near the base by using a gas-powered drill (Stihl Inc., VA Beach, VA) fitted with a 1.3-cm-diameter auger drill bit (Irwin Industrial tools, Dewitt, NE). Holes were drilled at $\approx$45° angles to act as herbicide reservoirs and chemical uptake points. Approximately 4.0 ml of a 1:1 solution of water to Banvel (48.2% dimethylamine salt of dicamba) (BASF Corp., Florham Park, NJ) was injected into each drilled hole. The approximate amount of active ingredient injected into each hole was 0.96 ml; 1.04 g. No holes were drilled into control trees, nor was any herbicide applied to them.

Insect Trapping. On each tree of a treatment group, a 12-unit Lindgren multiple-funnel trap fitted with a wet collection cup was hung with the top at $\approx$6 m above the ground and 0.3 m from the tree bole to catch incoming insects. Selection of this trapping height was based on preliminary trapping results using sticky panel traps that suggested this height was optimal for capturing *S. noctilio* (K.E.Z., unpublished data). Horizontally placed ropes were tied between trees making up the trap tree cluster and individual traps were hung from these ropes. Pulleys were used to allow traps to be lowered for trap collections. Propylene glycol was used as the collection agent. Traps were hung from 240 trees in total (20 replicates, four treatment groups of three trees with a trap each). Traps were checked once every 2 wk from 26 June 2007 to 21 September 2007. At each visit, the contents of each trap cup were strained using a paint filter to separate captured insects from collection liquid. Specimens from the collections were placed in a Whirl-Pak sampling bag (Nasco, Fort Atkinson, WI) and covered with ethanol for preservation until sorting and identification could be conducted. Laboratory processing of trap samples comprised of sorting scolytines, cerambycids, and siricids. Several taxonomic keys were used to identify Scolytinae (Wood 1982, Rabaglia et al. 2006); Cerambycidae (Lingafelter 2007); and Siricidae (Schiff et al. 2006) to species. Difficult taxa (e.g., *Pityophthorus* spp.) were grouped at the genera level. Voucher specimens are housed at the U.S. Forest Service, Durham Field Office, Forest Insect Collection. To investigate species that may interact more closely with *S. noctilio* in trees, conifer-inhabiting insects were separated from total insects captured for some analyses. Because of limitations on host tree information for some spe-

cies, insect species were not differentiated further than conifer-inhabiting.

Statistics. Because the three trap trees that constituted a treatment group were not independent replicates, trap catches from each trap tree were combined to provide a total of catches for the group. Trap catches throughout the sampling period then were pooled over the trapping season. Because treatments represented temporal differences, total catches for each girdling date were unbalanced with April girdled trees having more collections than June or July treatments. Instead of using total trap catches over the entirety of the study, trap collections from the first five collection periods after the date of girdling were pooled and used for comparisons. All sample collections were used for control trees.

Data were analyzed using a generalized linear mixed model (Proc GLIMMIX) via maximum likelihood estimation technique in SAS 9.2. Comparisons of insect catches between *P. resinosa* and *P. sylvestris* were carried out with pine species as a fixed effect. Sites were a random factor and treatment was a fixed factor. Comparison of insect catches among the three treatments and control also was analyzed with GLIMMIX, but with site and tree species as random effects and treatment as a fixed effect. In most cases, data were modeled using the negative binomial function with log link (SAS version 9.2). However, for several tests data were modeled with the geometric function with log link. Tukey's HSD ($\alpha = 0.05$) was used to make all pairwise comparisons among the mean insect abundances caught in each treatment. Only insects where >100 individuals were captured were used for comparisons between tree species and among girdling treatments.

Simpson's index (1-D) and Berger–Parker dominance index were calculated for assemblages of the total and conifer-inhabiting insects arriving at *P. resinosa* and *P. sylvestris* and for each girdling treatment occurring on each tree species by using PAST version 2.15 (Hammer et al. 2001). Diversity estimates of insects captured on each tree species were based off of pooled data that included all girdling treatments. Data from within a tree species and individual treatments also were pooled for treatment level estimates. Simpson's index was chosen to estimate species diversity because it is commonly used and considered to be a strong estimate (Magurran 2004). Simpson's index and Berger–Parker index estimates were compared between tree species by using the bootstrapping technique in PAST that uses 1,000 random pairs selected from the samples to allow comparisons.

Individual based rarefaction estimates of conifer-inhabiting insects were created by pooling treatments within each tree species and using these combined data to determine curves using PAST. Therefore, species richness estimates represented only conifer-inhabiting scolytines, cerambycids, and siricids captured on *P. resinosa* or *P. sylvestris* by treatment throughout the study. Chao1 estimates of species richness (Chao 2005) for total and conifer-inhabiting insects on each tree species and treatment also were calculated using

Table 1. List of exotic Scolytinae species captured in central New York arriving at *S. noctilio* trap trees

Species	Pine species where captured	% of total scolytine
Tomicus piniperda	Both	1.6
Xylosandrus germanus	Both	1.3
Hylastinus obscurus	Both	0.14
Xyleborinus saxeseni	Both	0.13
Xyleborinus alni	Both	0.06
Xyleborus seriatus	*P. resinosa*	0.02
Scolytus multistriatus	Both	0.02
Scolytus mali	Both	0.02
Hylastes opacus	Both	0.02
Euwallacea sp.	*P. resinosa*	0.004
Scolytus rugulosus	*P. sylvestris*	0.004

the software SPADE (Chao and Shen 2010). The cutoff for rarity was set at five based off of prior knowledge of scolytines, cerambycids, and siricids captured in host volatile baited traps or colonizing pine in the northeastern United States.

Results

In total, 30,031 scolytines, cerambycids, and siricids from 109 species were captured in traps hanging from *P. resinosa* and *P. sylvestris* trap trees. *Ips pini* (Say) and *Anisandrus sayi* Hopkins represented 60% of total trap catches, with *Dryocoetes affaber* (Mannerheim) and *I. grandicollis* the next most abundant at 15 and 6%, respectively. Forty-four percent of the specimens were captured less than five times, with 21% of the total number of species captured only once. With the exception of *S. noctilio*, no woodborers accounted for more than 1% of total trap catches.

Scolytinae. Traps on *P. resinosa* and *P. sylvestris* captured 28,301 scolytines from 49 species. Two species of *Ips*, *I. pini*, and *I. grandicollis*, accounted for ≈50% of all beetles sampled. *Anisandrus sayi* and *D. affaber* accounted for 23.5 and 16.3% of the total number of scolytines collected, respectively. Twenty-seven species were captured <10 times, with 10 of those species collected only once. Of the 49 species captured, 11 are exotic to New York (Table 1). On *P. resinosa*, 8,375 scolytines from 38 species were captured, whereas traps on *P. sylvestris* collected 19,924 scolytines from 43 species. Of the 49 species captured, 59% are known to inhabit conifers.

Significantly more total scolytines ($F = 11.15$, d.f. = 1, 18; $P = 0.0037$) and conifer-inhabiting scolytines ($F = 7.33$, d.f. = 1, 18; $P = 0.0144$) were captured in traps on *P. sylvestris* than *P. resinosa* (Table 2). Higher catches of *D. affaber* ($F = 39.67$, d.f. = 1, 18; $P < 0.0001$), *Monarthrum mali* (Fitch) ($F = 29.73$, d.f. = 1, 18; $P < 0.0001$), and *T. piniperda* ($F = 37.14$, d.f. = 1, 18; $P < 0.0001$) occurred on *P. sylvestris* trap trees (Table 2). Higher catches of *I. grandicollis* ($F = 53.2$, d.f. = 1, 18; $P < 0.0001$) and *Xylosandrus germanus* (Blandford) ($F = 10.41$, d.f. = 1, 18; $P = 0.0.0047$) occurred on *P. resinosa* trap trees (Table 2). However, for the majority of species, including *A. sayi* ($F = 4.11$, d.f. = 1, 18; $P = 0.0578$), *Dendroctonus valens* LeConte

Table 2. Mean (± SE) number of Scolytinae and Cerambycidae captured on *P. resinosa* and *P. sylvestris* trap trees

Species	Pinus resinosa	Pinus sylvestris	P value
Total Scolytinae	837.5 ± 153.8	1992.4 ± 365.5	**0.0037**
Conifer Scolytinae	577.8 ± 144.0	1499.6 ± 373.4	**0.0144**
Anisandrus sayi	243.1 ± 46.9	422.2 ± 81.2	0.0578
Dendroctonus valens	14.3 ± 4.2	11.7 ± 3.4	0.634
Dryocoetes affaber	5.0 ± 2.6	454.9 ± 225.9	**<0.0001**
Gnathotrichus materiarius	36.2 ± 11.6	24.4 ± 7.9	0.3968
Ips grandicollis	165.3 ± 28.6	26.4 ± 4.8	**<0.0001**
Ips pini	279.6 ± 157.7	883.0 ± 497.9	0.1666
Monarthrum mali	5.5 ± 1.8	64.1 ± 19.6	**<0.0001**
Orthotomicus caelatus	3.9 ± 1.5	6.9 ± 2.5	0.2859
Polygraphus rufipennis	29.9 ± 11.6	26.4 ± 10.2	0.8230
Tomicus piniperda	3.7 ± 1.1	41.5 ± 10.7	**<0.0001**
Xylosandrus germanus	30.5 ± 10.5	6.1 ± 2.2	**0.0047**
Total Cerambycidae	72.4 ± 6.5	100.6 ± 8.9	**0.0178**
Conifer Cerambycidae	41.9 ± 4.8	35.0 ± 4.1	0.2826
Acanthocinus pusillus	8.8 ± 1.5	3.4 ± 0.9	**0.0028**
Clytus ruricola	10.7 ± 2.1	13.5 ± 2.6	0.4173
Monochamus scutellatus	5.4 ± 1.9	5.3 ± 1.9	0.9706
Tetropium sp.	12.0 ± 2.8	5.5 ± 1.4	**0.0375**

($F = 0.23$, d.f. $= 1$, 18; $P = 0.634$), *Gnathotrichus materiarius* (Fitch) ($F = 0.75$, d.f. $= 1$, 18; $P = 0.3968$), *I. pini* ($F = 2.08$, d.f. $= 1$, 18; $P = 0.1666$), *Orthotomicus caelatus* (Eichhoff) ($F = 1.21$, d.f. $= 1$, 18; $P = 0.2859$), and *Polygraphus rufipennis* (Kirby) ($F = 0.5$, d.f. $= 1$, 18; $P = 0.8230$) there were no significant differences between catches in traps hanging from *P. resinosa* or *P. sylvestris* trap trees (Table 2).

There were significant differences in the total numbers of scolytines ($F = 27.65$, d.f. $= 3, 57$; $P < 0.0001$) and conifer-inhabiting scolytines ($F = 14.7$, d.f. $= 3, 57$; $P < 0.0001$) captured in the five collections after girdling date (Table 3). There were significant differences in the response of all individual species of scolytines to the girdling times, including *A. sayi* ($F = 95.31$, d.f. $= 3, 57$; $P < 0.0001$), *D. valens* ($F = 15.35$, d.f. $= 3, 57$; $P < 0.0001$), *D. affaber* ($F = 3.34$, d.f. $= 3, 57$; $P = 0.0255$), *G. materiarius* ($F = 6.94$, d.f., $3, 57$; $P =$

0.0004), *I. grandicollis* ($F = 20.59$, d.f. $= 3, 57$; $P < 0.0001$), *I. pini* ($F = 4.81$, d.f. $= 3, 57$; $P < 0.0001$), *M. mali* ($F = 4.04$, d.f. $= 3, 57$; $P = 0.009$), *O. caelatus* ($F = 6.80$, d.f. $= 3, 57$; $P = 0.0005$), *P. rufipennis* ($F = 18.05$, d.f. $= 3, 57$; $P < 0.0001$), *T. piniperda* ($F = 19.05$, d.f. $= 3, 57$; $P < 0.0001$), and *X. germanus* ($F = 7.90$, d.f. $= 3, 57$; $P = 0.0002$).

Cerambycidae. In total, 1,280 cerambycids from 54 species were captured at trap trees throughout the course of sampling. Six species, *Clytus ruricola* (Olivier), *Tetropium* sp., *Acanthocinus pusillus* Kirby, *Monochamus scutellatus scutellatus* (Say), *Monochamus carolinensis* (Olivier), and *Astylopsis sexguttata* (Say) accounted for 63% of total cerambycids captured. Thirty-five species were captured 10 times or less, with thirteen species captured only once. Only one exotic cerambycid [*Phymatodes testaceus* (L.)] was captured and it was found on *P. sylvestris*. On *P. resinosa*, 643 cerambycids from 42 species were captured, whereas traps on *P. sylvestris* collected 639 cerambycids from 43 species. Of the 54 species captured, 53% are known to inhabit conifers.

On average, significantly more cerambycids were captured in traps on *P. sylvestris* compared with *P. resinosa* ($F = 6.8$, d.f. $= 1$, 18; $P = 0.0178$; Table 2). However, there were no significant differences in total catches of conifer-inhabiting cerambycid species on either tree species ($F = 1.23$, d.f. $= 1$, 18; $P = 0.2826$). Of the 54 total species captured, 31 were found on both *P. resinosa* and *P. sylvestris*, whereas 11 were unique to *P. resinosa* and 12 only were found on *P. sylvestris*. Slightly less than half (45%) of the unique species on *P. resinosa* were singlets, with 66% of unique species on *P. sylvestris* only captured once. Of the conifer-inhabiting species, significantly more *A. pusillus* ($F = 11.92$, d.f. $= 1$, 18; $P = 0.0028$) and *Tetropium* sp. ($F = 5.05$, d.f. $= 1$, 18; $P = 0.0375$) were found on *P. resinosa* (Table 2). There was no significant difference in the average number of *M. scutellatus* found on the two pine species ($F = 0.00$, d.f. $= 0.97$; $P = 0.9706$;

Table 3. Mean (± SE) number of Scolytinae and Cerambycidae captured arriving at *S. noctilio* control and treatment trees

Species	Control	April	June	July	P value
Total Scolytinae	185.3 ± 52.1b	348.0 ± 97.8ab	611.2 ± 171.7.9a	87.9 ± 24.8c	<0.0001
Conifer Scolytinae	25.3 ± 8.9c	208.9 ± 73.3a	556.1 ± 195.0a	73.0 ± 25.6b	<0.0001
Anisandrus sayi	129.9 ± 24.5a	102.0 ± 19.3a	28.5 ± 5.5b	8.1 ± 1.7c	<0.0001
Dendroctonus valens	0.4 ± 0.2b	4.3 ± 1.3a	4.5 ± 1.4a	0.40 ± 0.2b	<0.0001
Dryocoetes affaber	0.6 ± 0.2b	49.7 ± 26.3ab	171.2 ± 86.0a	8.5 ± 5.9b	0.0255
Gnathotrichus materiarius	0.9 ± 0.4b	3.8 ± 1.3a	5.5 ± 1.8a	1.5 ± 0.6b	0.0004
Ips grandicollis	1.9 ± 0.8c	27.6 ± 10.0a	9.5 ± 3.5b	5.8 ± 2.2b	<0.0001
Ips pini	1.3 ± 0.9c	100.0 ± 65.2ab	392.6 ± 256.0a	40.5 ± 26.4b	<0.0001
Monarthrum mali	2.8 ± 1.1a	3.4 ± 1.3a	4.3 ± 1.6a	1.2 ± 0.5b	0.009
Orthotomicus caelatus	0.2 ± 0.1b	1.8 ± 0.8a	2.6 ± 1.1a	0.05 ± 0.05b	0.0005
Polygraphus rufipennis	1.9 ± 0.7b	9.9 ± 3.3a	1.6 ± 0.6b	0.5 ± 0.2c	<0.0001
Tomicus piniperda	1.7 ± 0.7b	7.2 ± 2.9a	0.8 ± 0.4b	0.02 ± 0.02c	<0.0001
Xylosandrus germanus	3.0 ± 1.1a	3.0 ± 1.1a	1.1 ± 0.5b	0.7 ± 0.3b	0.0002
Total Cerambycidae	15.7 ± 1.8c	32.8 ± 3.4a	25.7 ± 2.7b	8.9 ± 1.1d	<0.0001
Conifer Cerambycidae	5.1 ± 0.8c	17.7 ± 2.4a	9.8 ± 1.4b	3.0 ± 0.5d	<0.0001
Acanthocinus pusillus	0.0 ± 0.0b	3.4 ± 0.9a	2.3 ± 0.6a	0.3 ± 0.2b	<0.0001
Clytus ruricola	3.4 ± 0.7a	3.2 ± 0.6a	3.7 ± 0.7a	0.3 ± 0.1b	<0.0001
Monochamus scutellatus	0.1 ± 0.07b	3.2 ± 1.0a	0.3 ± 0.1b	0.1 ± 0.07b	<0.0001
Tetropium sp.	1.1 ± 0.3b	4.1 ± 1.0a	1.1 ± 0.3b	0.3 ± 0.1c	<0.0001

Means followed by the same letter within a row are not significantly different (Tukey's HSD, $P > 0.05$).

Table 4. Species richness, Chao1 estimates, Simpson's diversity index, and Berger–Parker dominance estimates for total and conifer-inhabiting insects on *P. resinosa* and *P. sylvestris* trap trees

Estimate	P. resinosa	P. sylvestris	P value
Species richness	86	91	0.99
Conifer spp. species richness	56	57	0.99
Chao1	107 ± 12.6	123.5 ± 17.2	–
Conifer spp. Chao1	71.2 ± 10.9	97.0 ± 28.7	–
Simpson's index (1-D)	0.7965	0.7319	0.001
Conifer spp. Simpson's index	0.7236	0.5983	0.001
Berger–Parker	0.3073	0.4219	0.001
Conifer spp. Berger–Parker	0.4448	0.562	0.001

Table 2). The hardwood species, *C. ruricola* ($F = 0.69$, d.f. $= 1, 18$; $P = 0.4173$) was found at equal numbers on each pine species (Table 2).

There were significant differences in the total numbers of cerambycids ($F = 36.33$, d.f. $= 3, 57$; $P < 0.0001$) and conifer-inhabiting species ($F = 31.13$, d.f. $= 3, 57$; $P < 0.0001$) captured in the five collections after girdling date (Table 3). There were also significant differences in the response of all individual species of cerambycids tested to the girdling times, including *M. scutellatus* ($F = 21.66$, d.f. $= 3, 57$; $P < 0.0001$), *A. pusillus* ($F = 9.85$, d.f. $= 3, 57$; $P < 0.0001$), *C. ruricola* ($F = 11.32$, d.f. $= 3.57$; $P < 0.0001$), and *Tetropium* sp. ($F = 15.52$, d.f. $= 3, 57$; $P < 0.0001$).

Siricidae. In total, 448 Siricidae from six species were captured in traps throughout the course of sampling. *Sirex noctilio* accounted for 85% of total siricid catches. A hardwood species, *Tremex columba* (L.), was the next most abundant species accounting for 10.7% of siricid captures. *Sirex nigricornis* F. (2.4%), *Sirex edwardsii* Brullé (0.7%), *Urocerus albicornis* (F.) (0.4%), and *Urocerus cressoni* Norton (0.7%) were the only other siricids collected in traps. The response of *S. noctilio* to tree girdle treatments and tree species were reported previously in Zylstra et al. (2010). Unfortunately, low numbers of native siricid captures made statistical analysis of these species impossible.

Species Richness and Biodiversity Estimates. Total species richness on *P. resinosa* (86) and *P. sylvestris* (91) were not significantly different (Table 4). Species richness of conifer-inhabiting species on *P. resinosa* (56) and *P. sylvestris* (57) were also not significantly different. However, Chao1 estimated total species richness and conifer-inhabiting species richness were higher for *P. sylvestris* trap trees. Simpson's Index (1-D) diversity estimate of arboreal insects in traps on *P. resinosa* was significantly higher than for traps on *P. sylvestris* ($P = 0.001$, Table 4). Simpson's Index diversity estimate of conifer-inhabiting species was also higher on *P. resinosa* compared with *P. sylvestris*. Conversely, Berger–Parker estimates of dominance for both total species and conifer-inhabiting species were significantly higher on *P. sylvestris* compared with *P. resinosa* ($P = 0.001$, Table 4). *Ips pini* was
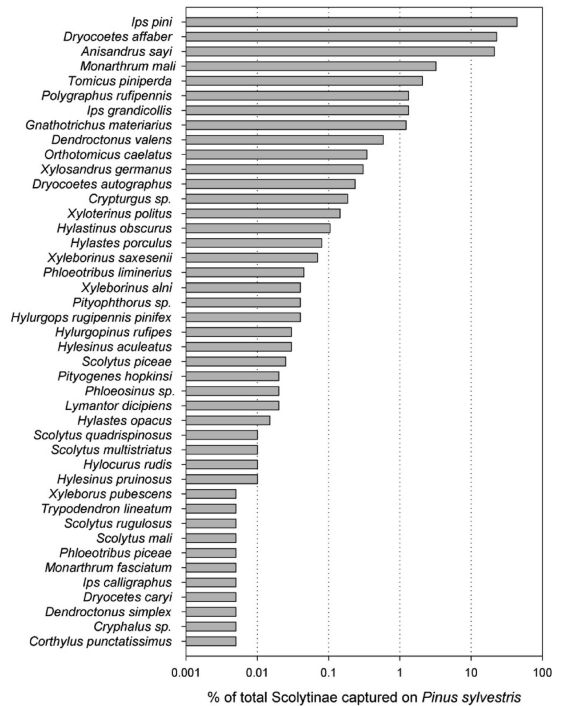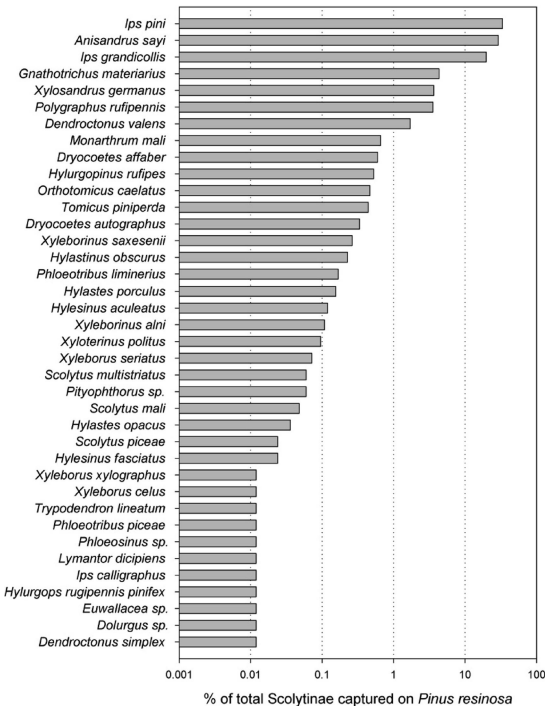

Fig. 1. Abundance of Scolytinae captured on *P. resinosa* and *P. sylvestris* trap trees. Individual bars represent the proportion of total beetle abundance captured from all trap trees and controls of each tree species.
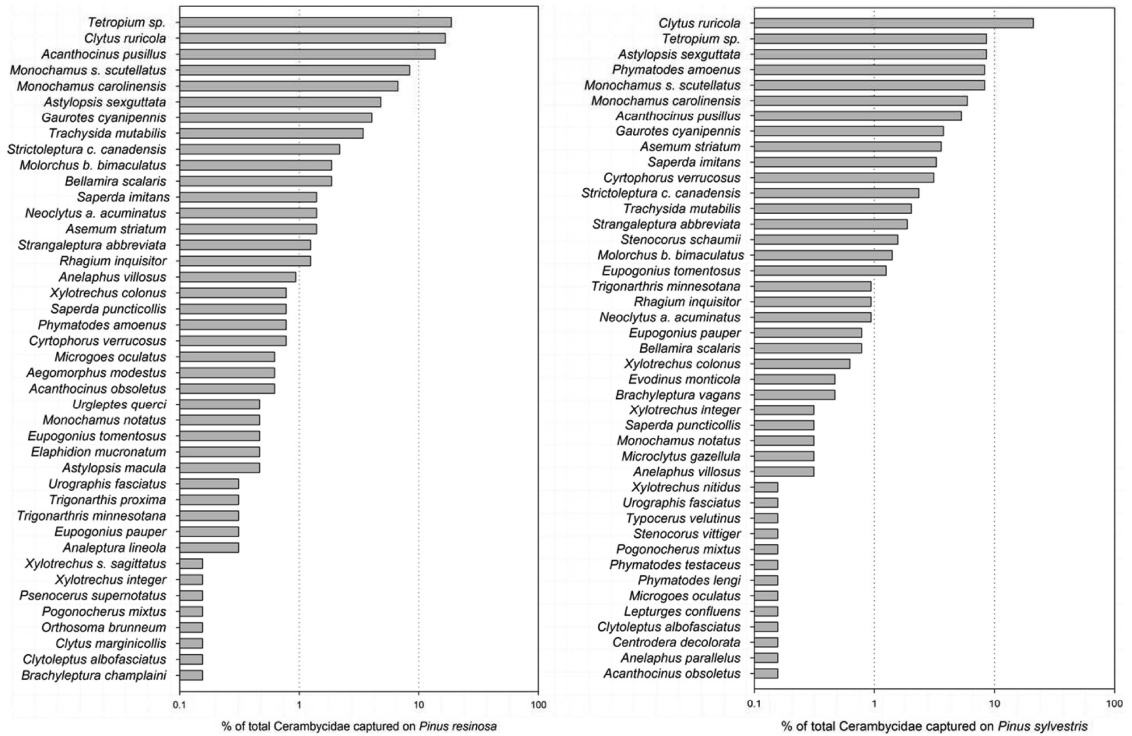
Fig. 2. Abundance of Cerambycidae captured on *P. resinosa* and *P. sylvestris* trap trees. Individual bars represent the proportion of total beetle abundance captured from all trap trees and controls of each tree species.

the dominant scolytine collected on both tree species (Fig. 1). The hardwood species *Anisandrus sayi* was also a prevalent scolytine species on both pine trees, whereas conifer inhabiting *I. grandicollis* and *D. affaber* were abundant species on *P. resinosa* and *P. sylvestris*, respectively (Fig. 1). Only three cerambycid species (*Tetropium* sp., *C. ruricola*, and *A. pusillus*) accounted for >10% of the total catch on *P. resinosa* (Fig. 2). *Clytus ruricola*, a hardwood species, was the only cerambycid species in *P. sylvestris* traps that accounted for >10% of the total catches (Fig. 2).

Individual-based rarefaction curves of conifer-inhabiting species for the three girdle treatments and control trees for *P. resinosa* and *P. sylvestris* followed similar patterns (Fig. 3). None of the treatments or control trees reached an asymptote. Rarefaction curves for both tree species suggest that control trees, followed by April girdled trees likely had higher species richness than June or July girdled trees. For both tree species, trees girdled in June had the lowest species richness.

Pinus resinosa controls and *P. sylvestris* trees girdled in April captured the highest species richness for the two trap-tree species (Table 5). On both tree species, the lowest species richness and species abundance occurred on trees girdled in July at *S. noctilio* flight. Chao1 estimates suggested that for all treatments and control trees, observed species richness was substantially lower than estimated richness (Table 5). Highest species diversity was found on April girdled trees for

both *P. resinosa* and *P. sylvestris* (Table 5). Control trees for both pine species had the highest dominance estimates, with *A. sayi* dominating trap catches (Table 5; Fig. 4).

For conifer-inhabiting species, *P. resinosa* controls and *P. sylvestris* trees girdled in April captured the highest species richness for the two trap-tree species. The lowest species richness of conifer-inhabiting arboreal species occurred on trees girdled in July for each tree species. Like total species estimates, Chao1 estimates for conifer-inhabiting insects suggested that for all treatments and control trees, observed species richness was lower than estimated species richness (Table 5). Control trees had the highest species diversity estimates of conifer-inhabiting species, with April girdled diversity estimates also relatively high. June (*P. resinosa*) and July (*P. sylvestris*) girdled trees had the highest dominance estimates for conifer-inhabiting species.

Anisandrus sayi and *C. ruricola*, both hardwood colonizers, were the most abundant scolytine and cerambycid species captured on control trees of both pine species (Fig. 4). With the exception of *A. sayi*, phloem-feeding insects dominated April girdled trees, with *Ips* spp., *P. rufipennis*, *D. affaber*, and *T. piniperda* as important species (Fig. 5). *Tetropium* sp., *A. pusillus*, and *M. scutellatus* were the most abundant cerambycids captured on April girdled *P. resinosa* and *P. sylvestris*. *Ips pini* was the most common insect trapped on trees girdled in June for both pine species (Fig. 6).
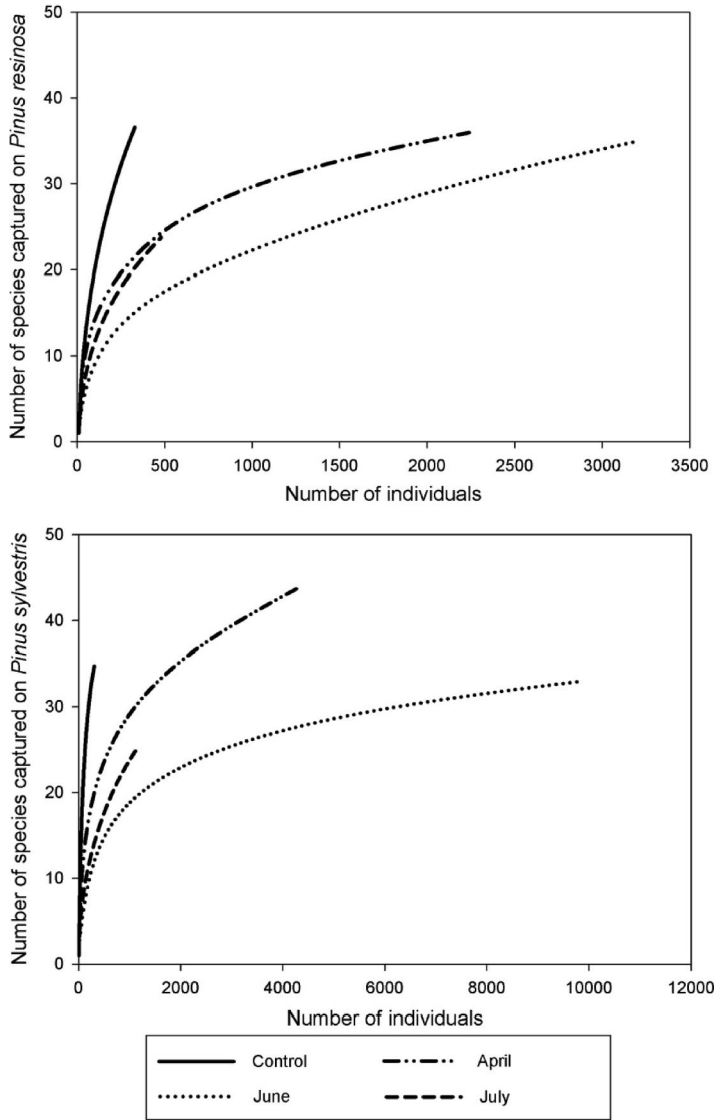
Fig. 3.   Individual based rarefaction curves for control and tree girdling treatments for conifer-inhabiting arboreal insects captured on *P. resinosa* and *P. sylvestris*.

Ips grandicollis accounted for over 10% of all insects collected on *P. resinosa* girdled in June, but this species was collected at much lower numbers on *P. sylvestris*. *Acanthocinus pusillus* and *C. ruricola* were the most abundant cerambycids captured on *P. resinosa* and *P. sylvestris*, respectively, girdled in June. *Ips* species also dominated *P. resinosa* and *P. sylvestris* girdled at *S. noctilio* flight in July, with *A. sayi* also an important species (Fig. 7). *Sirex noctilio* generally was found at the same levels in each girdling treatment for both tree species, with the exception of trees girdled in July.

Discussion

Understanding the arboreal insect community that arrives at and potentially colonizes *S. noctilio* trap trees

soon after their creation is an important step toward determining potential influences on population dynamics of an invasive woodwasp. Successional studies of insects associated with economically important scolytines have led to a better understanding of mortality factors that may play an important role as population regulation mechanisms (Dahlsten and Stephen 1974, Dixon and Payne 1979, Goyer and Finger 1980). Within-tree interactions occurring among members of various guilds have been documented for some scolytines and cerambycids (Schroeder and Weslien 1994, Dodds et al. 2001) and some interactions in *S. noctilio* infested trees have been described (Ryan et al. 2011a,b).

Our data describes a subset of arboreal insects (Cerambycidae, Scolytinae, and Siricidae) arriving at two

Table 5. Observed and estimated species richness, abundance, Simpson's index, and Berger–Parker dominance estimates for total and conifer-inhabiting insects on *P. resinosa* and *P. sylvestris* trap tree treatments

Treatment	Species richness		Chao1 (± SE)		Number of individuals		Simpsons 1-D		Berger–Parker dominance	
	Pinus resinosa	*Pinus sylvestris*	*Pinus resinosa*	*Pinus sylvestris*	*Pinus resinosa*	*Pinus sylvestris*	*Pinus resinosa*	*Pinus sylvestris*	*Pinus resinosa*	*Pinus sylvestris*
Control all	63	60	86 (12.5)	75.5 (9.4)	1,763	2,269	0.46	0.39	0.73	0.78
Conifer spp.	37	35	52 (10.0)	39.5 (4.1)	330	310	0.83	0.84	0.28	0.35
April all	61	67	99 (23.9)	102 (21.2)	3,191	6,478	0.83	0.77	0.27	0.34
Conifer spp.	36	44	54.0 (16.2)	89.5 (34.7)	2,243	4,355	0.80	0.68	0.38	0.51
June all	52	52	65.6 (8.7)	87 (25.6)	3,509	10,874	0.52	0.61	0.68	0.54
Conifer spp.	35	33	50.2 (10.9)	40 (7.1)	3,207	9,877	0.43	0.53	0.74	0.59
July all	38	41	63 (16.4)	61 (13.5)	636	1,309	0.70	0.63	0.52	0.59
Conifer spp.	24	25	35.3 (9.6)	36.3 (9.6)	484	1,123	0.52	0.51	0.68	0.67

species of trap trees that were chemically girdled at different times of the year; however, it does not document direct host use by these insects. We saw direct evidence of use by some species, primarily phloem-inhabiting Coleoptera, including *Ips* spp., *P. rufipennis*, *Dryocoetes* spp., and several cerambycid species, but for the majority of species we have no evidence that trap trees were used as a resource. Only 58% of the total scolytines, cerambycids, and siricids captured are known conifer-inhabiting species leaving a large portion of captured insects that are associated with other

trees or plants. Sites used for this study existed in a hardwood dominated landscape, and on average deciduous trees represented 11% of total basal area (K.J.D., unpublished data) in stands. Consequently, the presence of hardwood species in traps was not unexpected, but the abundance was surprising compared with other regional trapping studies (Dodds 2011). Host monoterpenes are attractants to arboreal insects (Allison et al. 2004, Miller 2006, Seybold et al. 2006) and explain attraction of conifer-colonizing insects to dying or dead trap trees. Attraction to volatiles
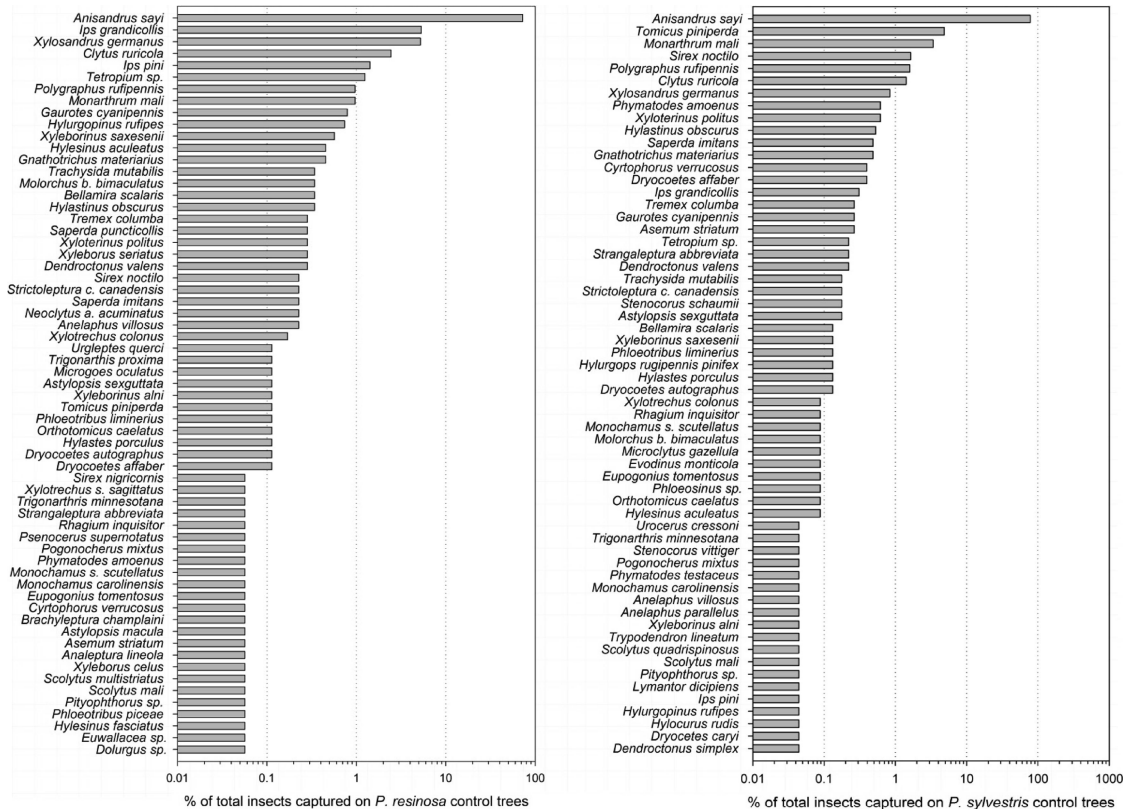

Fig. 4. Abundance of Scolytinae, Cerambycidae, and Siricidae captured on *P. resinosa* and *P. sylvestris* control trap trees. Individual bars represent the proportion of total insect abundance captured from all trap trees and controls of each tree species.
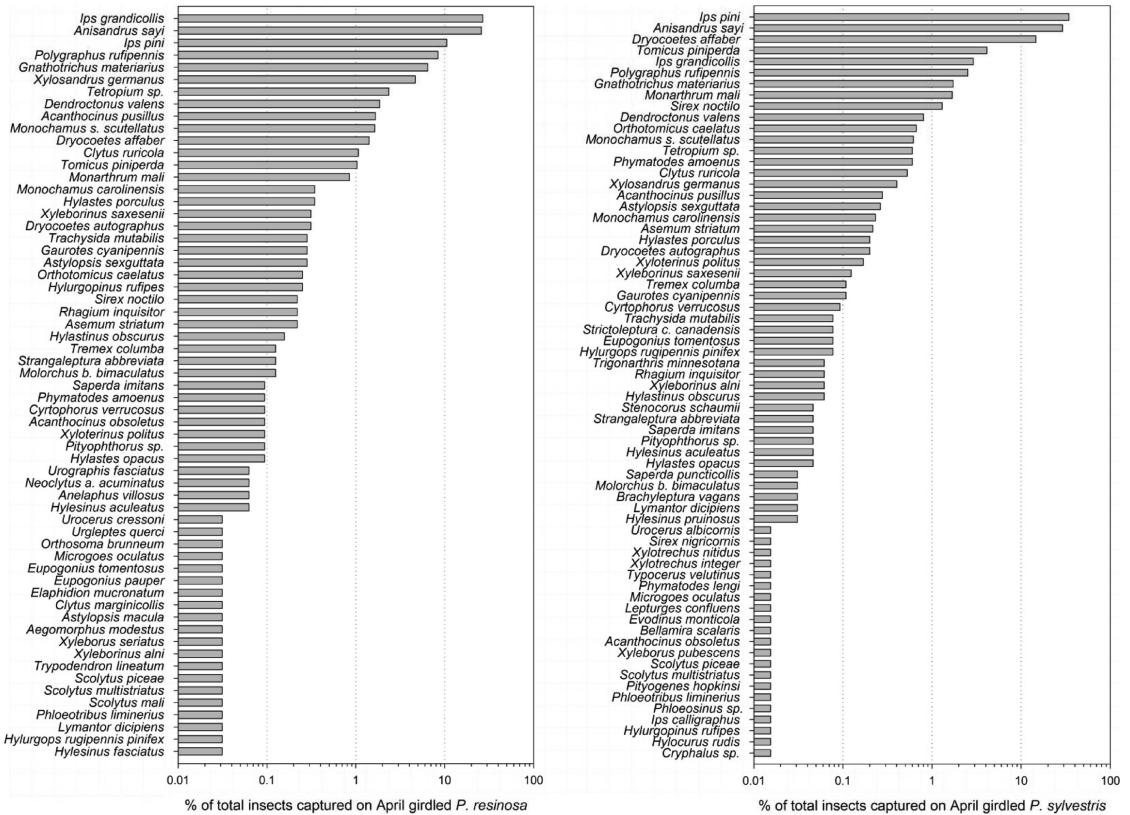
Fig. 5. Abundance of Scolytinae, Cerambycidae, and Siricidae captured on *P. resinosa* and *P. sylvestris* April girdled trap trees. Individual bars represent the proportion of total insect abundance captured from all trap trees and controls of each tree species.

shared by conifers, particularly ethanol (Elliott et al. 1983, Montgomery and Wargo 1983, Coyle et al. 2005) or random landing behavior (Witanachchi and Morgan 1981, Saint-Germain et al. 2007) could be possible explanations for the presence of insects on nonhosts.

Although total scolytine and conifer-inhabiting scolytine abundance were higher on *P. sylvestris* than *P. resinosa*, clear preference for this tree was not common in species where statistical analysis could be conducted. Of the 11 scolytine species captured over 100 times, three species (*D. affaber*, *M. mali*, and *T. piniperda*) were found more often in traps on *P. sylvestris.* Only one of these species was exotic, the Eurasian *T. piniperda*, and this species was clearly more strongly attracted to its native host. *Tomicus piniperda* has been documented previously to colonize *P. sylvestris* at a higher rate than *P. resinosa* (Siegert and McCullough 2003) and we found it attracted to its ancestral host at higher rates. Although *M. mali* uses hardwoods for reproduction, *Dryocoetes affaber* inhabits pine (Baker 1972). However, it is unknown why large numbers of *D. affaber* were attracted to *P. sylvestris* over native *P. resinosa. Ips grandicollis* and *X. germanus* were captured more frequently on *P. resinosa* than *P. sylvestris.* Ten exotic species were captured on *P. resinosa* and nine were found on *P. sylvestris.* Exotic species represented only 3.3% of the total scolytine captured from

all trees and this is much lower than estimates from other parts of North America (Coyle et al. 2005, Miller and Rabaglia 2009, Gandhi et al. 2010). *Xyleborus seriatus* Blandford, an Asian species only collected previously from Massachusetts and Maine, was the only new detection for New York State and was captured at two sites in traps on *P. resinosa.*

Because of their habit of colonizing stressed or recently dead trees, *Ips* species were a concern as competitors for trap tree resources. *Ips grandicollis* has colonized trap trees in Australia (Carnegie and Bashford 2012) and been documented cohabiting trees with *S. noctilio* in North America (Ryan et al. 2011a). This species, and its congener *I. pini*, were present in large numbers at trap trees. *Ips pini* was more common than *I. grandicollis* in trap catches, accounting for 63% of total *Ips* catches on *P. resinosa* and 97% on *P. sylvestris.* The overall lower catches of *I. grandicollis* compared with *I. pini* may be a result of colonization behavior and trap placement. *Ips grandicollis* colonizes lower portions of tree boles than *I. pini* (Ayres et al. 2001) and our traps were placed high on trees closer to the base of the live crown, perhaps biasing trap catches toward *I. pini.* Although this may explain the difference in total abundance between the two *Ips* species, it would not explain the discrepancy in abundance from the two tree species. Other factors, such
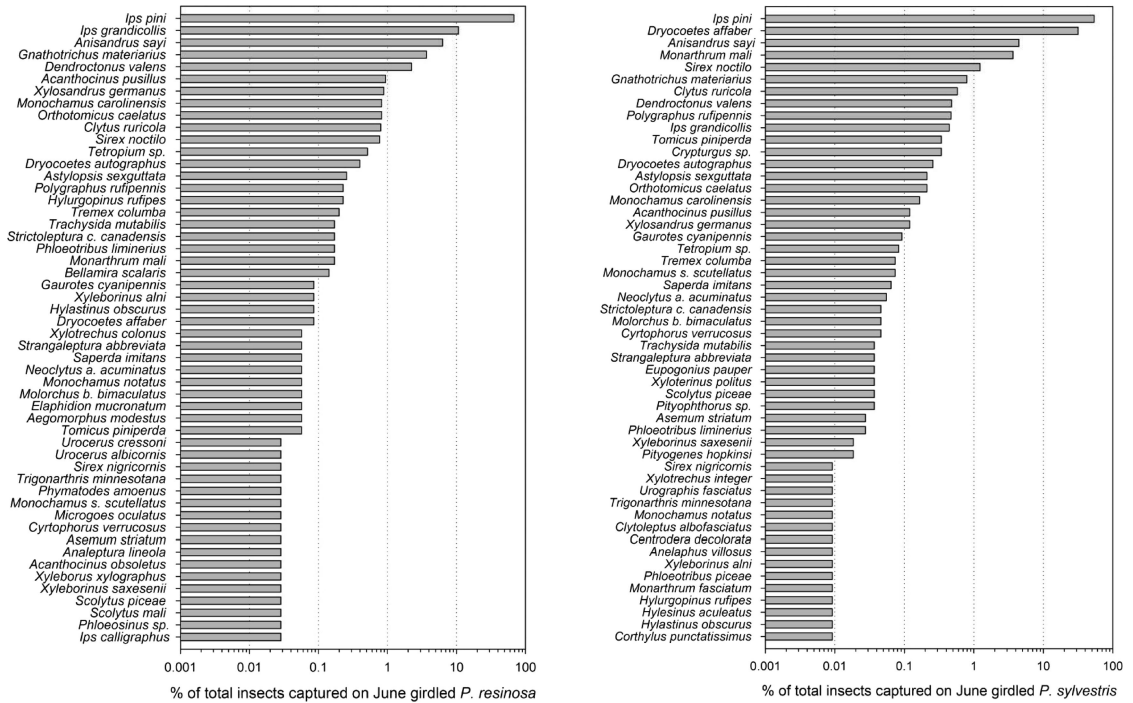
Fig. 6. Abundance of Scolytinae, Cerambycidae, and Siricidae captured on *P. resinosa* and *P. sylvestris* June girdled trap trees. Individual bars represent the proportion of total insect abundance captured from all trap trees and controls of each tree species.

as local population levels of the *Ips* species, differences in stand condition between *P. resinosa* and *P. sylvestris*, pheromone competition, or all of these, could factor into trap discrepancies. Although *I. pini* was common on both pine species, *I. grandicollis* was more abundant on *P. resinosa* and was a dominant species on all girdling treatment on this tree species.

Scolytine response to the treatments varied, but in general most species statistically tested responded more strongly to trap trees girdled in April or June. Trees girdled in April represent a resource that was dying at the beginning of flight for many scolytine species, providing an easily exploited resource. In addition, many scolytine species are captured in spring and early summer in the northeastern United States (Dodds et al. 2010b), so this influx of uninhabited resources may be temporally synched with beetle flight and consequently facilitated higher trap catches. In comparison, trees girdled in July may not have been physiologically compromised when the majority of insects were dispersing through forest stands. Trees girdled in July could provide a resource for early arriving arboreal beetles early during the year after girdling. Three ambrosia beetles were found at statistically higher numbers on control trees than at least one other treatment. No scolytines were captured at significantly higher abundances on the July treatment. Although controls were not chemically girdled, traps were hung between trees with rope that wrapped around the boles, mechanically damaging the bark and sapwood. Many trees also were delimbed while climb-

ing to set traps. Consequently, it is likely that for at least some portion of the trapping period, control trees also were emanating stress volatiles and attracting insects.

Only 4.2% of total trap catches on trap trees were cerambycids, and significantly more total cerambycids were captured on *P. sylvestris* than *P. resinosa*. However, conifer-inhabiting cerambycids were found in equal numbers on each trap tree species. Very few cerambycid species were captured in large enough numbers to statistically analyze. Two of the three conifer-inhabiting species common enough for statistical comparisons (*A. pusillus*, *Tetropium* sp.) were more abundant on *P. resinosa* than *P. sylvestris*. *Monochamus scutellatus*, *A. pusillus*, and *Tetropium* sp. were most abundant in traps hanging from April girdled trees. These trees were stressed for the longest period of time and represent a resource commonly exploited by cerambycid beetles. No cerambycids were found at higher numbers on July girdled trees, suggesting decline of vigor in these trees was not to a point appropriate for beetle attraction, or seasonal abundance of these insects was not synchronized with this resource. *Clytus ruricola* was found at very low numbers on July girdled trees, but that may have been because of seasonal flight patterns (K.J.D., unpublished data).

Previously published results from this study found higher numbers of *S. noctilio* attracted to its native host *P. sylvestris* compared with *P. resinosa* (Zylstra et al. 2010). In addition to the 381 *S. noctilio* captured at trap trees (Zylstra et al. 2010), five native siricid species,
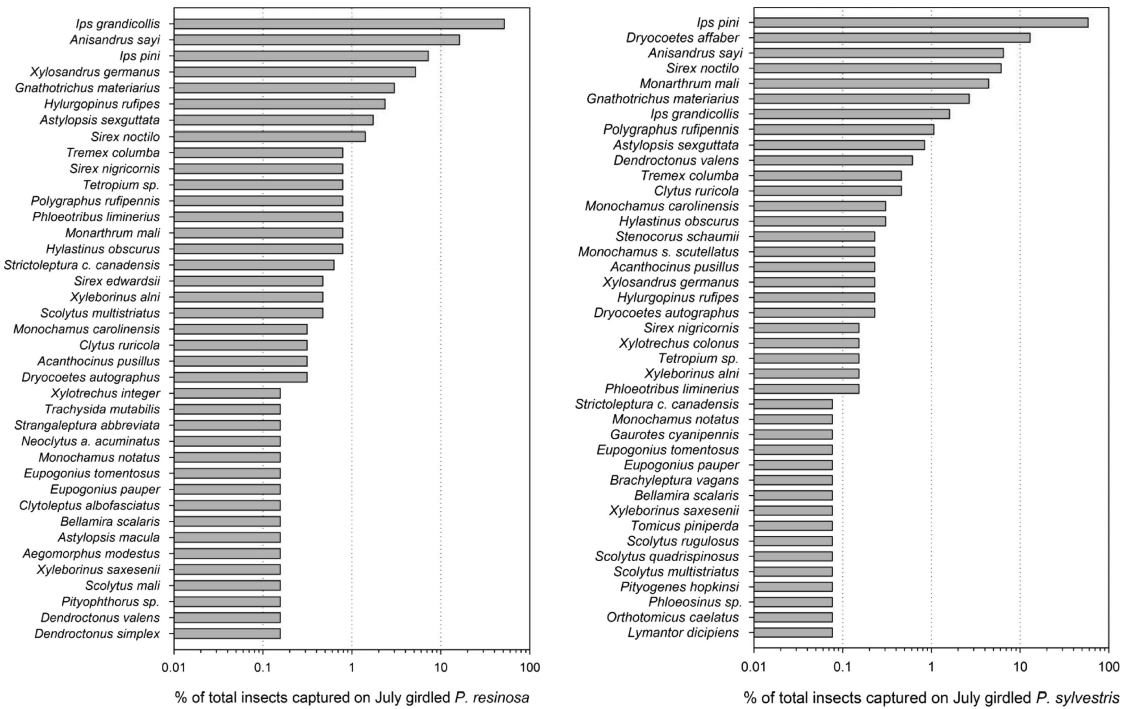
Fig. 7. Abundance of Scolytinae, Cerambycidae, and Siricidae captured on *Pinus resinosa* and *Pinus sylvestris* July girdled trap trees. Individual bars represent the proportion of total insect abundance captured from all trap trees and controls of each tree species.

including *S. nigricornis, S. edwardsii, T. columba, U. cressoni,* and *U. albicornis,* were trapped. However, only 19 specimens from the four conifer-inhabiting species were captured. The majority of native conifer-inhabiting siricids were found in *P. resinosa* (68%) and on trees girdled in July (52%). Native siricids colonize weakened or dead tree material (Smith and Schiff 2002) and more often are found active later in the summer (August–October) compared with *S. noctilio,* which flies earlier and colonizes living trees (Dodds et al. 2010a, Zylstra et al. 2010). Trap trees were created early in the spring and summer to target *S. noctilio* and consequently may have been either already colonized fully by the exotic woodwasp or other arboreal insects, their associated organisms, or both, or not biologically suitable for native species. Other studies have documented low levels of native siricids emerging from *S. noctilio* infested trees (Long et al. 2009, Ryan et al. 2011a, Standley et al. 2012), but this may be more an artifact of timing or habitat suitability than actual rarity. *Tremex columba* colonizes hardwood tree species (Stillwell 1967), so it is unknown why relatively large numbers were captured on trap trees of both *Pinus* species.

A large community of scolytine, cerambycid, and siricids were attracted to *P. resinosa* and *P. sylvestris* trees girdled throughout the season. The lack of asymptotes on rarefaction curves suggested that the entire community was not sampled and that additional sampling effort would yield more species for each treatment. Chao1 estimates also suggested that species

richness was higher for each tree species, girdling treatment, and control trees and there was a larger community of insects present that were not collected during the sampling period. Although total species richness and conifer-inhabiting species richness were not different on the two tree species, Simpson's estimates were higher on *P. resinosa* compared with *P. sylvestris.* What is apparent from the trap catches is that many native North American pine-inhabiting arboreal species were attracted to the exotic *P. sylvestris* and use this tree as a resource. Total and conifer-inhabiting species richness declined with each successive girdling treatment, and this may relate to seasonal abundance of insects declining as the summer progresses. In general, diversity estimates were slightly higher on *P. resinosa* than *P. sylvestris,* even though abundance was higher on the exotic tree for each girdle treatment. Diversity estimates for conifer-inhabiting species showed no clear pattern. Berger–Parker dominance estimates were generally similar on *P. resinosa* and *P. sylvestris* for total and conifer-infesting species, with *I. pini* and *I. grandicollis* abundant species.

The discrepancy between the observed species richness and estimated species richness was not unexpected considering only one trapping technique at one height was used. Multiple-funnel traps hung at 6 m from the base of trap trees likely missed many insects that colonize lower portions of tree boles or canopies. Vertical placement of traps has been documented to affect results from trapping surveys (Su and Woods

2001, Vance et al. 2003, Ulyshen and Hanula 2007, Wermelinger et al. 2007, Bouget et al. 2008) and trap height likely influenced results during this study. Although some lower-bole specialists [e.g., *D. valens*, *Hylastes* spp., *Hylurgops rugipennis pinifex* (Fitch), and others] were captured during the study, other species likely were missed because of the sampling height. Multiple-funnel traps are an effective survey tool for many arboreal insects and are widely used in various surveys, but other trap types have been found to catch more species (Dodds et al. 2010b). The addition of different trap types, traps at lower portions of tree boles, or both, could have increased species richness during this study.

Native and exotic insects and fungi interact with *S. noctilio* in North American pine trees (Ryan et al. 2011a,b). Of the 109 species captured during this study, 58% are known to inhabit conifers and some portion of this community likely would compete with *S. noctilio* either directly or indirectly for tree resources. *Sirex noctilio* were captured and reared at higher numbers from trees girdled in June and July (Zylstra et al. 2010). *Ips pini* and *I. grandicollis* were also abundant species captured on trap trees at this same time and represent scolytine species that could colonize trap trees in large numbers temporally and spatially concurrent with *S. noctilio*. Several ambrosia beetles were also important contributors to the early arriving arboreal community on trap trees and they or their associated fungi may interact with *S. noctilio* or its associated fungi within trees. Timing of arrival on host trees, associated organisms, and reproductive phenology likely will dictate what organisms are important factors affecting *S. noctilio* populations.

Decaying trees are a dynamic resource, attracting organisms that use this substrate for mate location, reproduction, food resources, and other purposes over the course of decline. Trap trees deployed for *S. noctilio* detection provided an attractive resource and potential habitat for diverse communities of arboreal insects. These insects and associated organisms will likely interact with *S. noctilio* in trap trees and naturally attacked trees, and could influence population dynamics (Ryan et al. 2011a) and management scenarios for the woodwasp. Ryan et al. (2011a) documented potential interactions of a portion of insects present in dying pine trees and the current study adds to the list of possible species of interest as community-level interactions are investigated further. Regardless of the timing of trap tree creation, dispersing *S. noctilio* will encounter a large community of native and exotic arboreal insects also seeking host trees.

Acknowledgments

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