Agricultural and Forest Entomology

Agricultural and Forest Entomology (2015), **17**, 258–269 DOI: 10.1111/afe.12101

Species characterization and responses of subcortical insects to trap-logs and ethanol in a hardwood biomass plantation

David R. Coyle, Courtney L. Brissey and Kamal J. K. Gandhi

D. B. Warnell School of Forestry and Natural Resources, University of Georgia, 180 E. Green Street, Athens, GA 30602, U.S.A.

Abstract

1 We characterized subcortical insect assemblages in economically important eastern cottonwood (*Populus deltoides* Bartr.), sycamore (*Platanus occidentalis* L.) and sweetgum (*Liquidambar styraciflua* L.) plantations in the southeastern U.S.A. Furthermore, we compared insect responses between freshly-cut plant material by placing traps directly over cut hardwood logs (trap-logs), traps baited with ethanol lures and unbaited (control) traps.

2 We captured a total of 15 506 insects representing 127 species in four families in 2011 and 2013. Approximately 9% and 62% of total species and individuals, respectively, and 23% and 79% of total Scolytinae species and individuals, respectively, were non-native to North America.

3 We captured more Scolytinae using cottonwood trap-logs compared with control traps in both years, although this was the case with sycamore and sweetgum only in 2013. More woodborers were captured using cottonwood and sweetgum trap-logs compared with control traps in both years, although only with sycamore in 2013.

4 Ethanol was an effective lure for capturing non-native Scolytinae; however, not all non-native species were captured using ethanol lures. *Ambrosiophilus atratus* (Eichhoff) and *Hypothenemus crudiae* (Panzer) were captured with both trap-logs and control traps, whereas *Coccotrypes distinctus* (Motschulsky) and *Xyleborus glabratus* Eichhoff were only captured on trap-logs.

5 Indicator species analysis revealed that certain scolytines [e.g. *Cnestus mutilatus* (Blandford) and *Xylosandrus crassiusculus* (Motschulsky)] showed significant associations with trap-logs or ethanol baits in poplar or sweetgum trap-logs. In general, the species composition of subcortical insects, especially woodboring insects, was distinct among the three tree species and between those associated with trap-logs and control traps.

Keywords Buprestidae, Cerambycidae, Curculionidae, non-natives, Scolytinae, Siricidae.

Introduction

The southeastern U.S.A. is one of the largest timber producing regions in North America (Howard, 2007), and has over 77 billion ha of natural and plantation-grown forestland (USDA Forest Service, 2011). Recent research has shown that hardwood trees such as eastern cottonwood (*Populus deltoides* Bartr.), American sycamore (*Platanus occidentalis* L.) and sweetgum (*Liquidambar styraciflua* L.) may attain economically profitable productivity levels in the southeastern region (Wright & Cunningham, 2008; Merkle & Cunningham, 2011; Coyle *et al.*, 2013). In addition to forests, an additional 2 million ha of farmland can be potentially developed for biomass production (Munsell & Fox, 2010). If poplar, sycamore, sweetgum and other hardwood species are to be potential candidates for intensive forestry operations for wood and/or biofuels production (Kline & Coleman, 2010), then a comprehensive examination of the ecological ramifications of hardwood monocultures may be necessary for long-term sustainable fibre production.

Subcortical insects [i.e. bark, ambrosia, and woodboring beetles (Coleoptera: Buprestidae, Cerambycidae, and Curculionidae) and woodwasps (Hymenoptera: Siricidae)] are

Correspondence: David R. Coyle. Tel.: +1 706 542 2686; fax: +1 706 542 8356; e-mail: drcoyle@uga.edu

critical components of forest ecosystems and, via tree colonization, they contribute to tree dieback and mortality, as well as the breakdown of coarse-woody debris. Communities of ecologically and economically important native and non-native subcortical insects colonizing southern pine species are well known (Miller, 2006; Miller & Rabaglia, 2009; Miller *et al.*, 2011). By contrast, little is known about the communities of subcortical insects that utilize hardwood trees (Oliver & Mannion, 2001; Coyle *et al.*, 2005; Gandhi & Herms, 2010). Subcortical insects in several genera (e.g. *Agrilus*, *Corthylus*, *Platypus* and *Xylosandrus*) are known to attack living and stressed hardwood trees (Kühnholz *et al.*, 2001), sometimes contributing to tree mortality and economic damage (Fierke *et al.*, 2005; Chong *et al.*, 2009; Kovacs *et al.*, 2010; Coleman *et al.*, 2012). Similarly, piles of recently cut timber are not immune to insect damage (Allen & Rudinsky, 1959; Wilson, 1960, 1962; Mathew, 1987). Any increase in poplar, sycamore or sweetgum production for wood products, biomass and/or bioenergy would result in large quantities of logged material/wood, either at the processing plant or in the field, which may further lead to increased subcortical insect populations. Hence, a thorough understanding of the insect communities associated with these tree species may be necessary if hardwood biomass plantations are to be economically and ecologically viable over the long-term.

Monitoring populations and communities of non-native and native pestiferous subcortical insects requires effective trapping methods. Traditionally, these trapping methods have included various trap-types (e.g. funnel and intercept panel traps) and attached chemical attractants (e.g. monoterpenes and ethanol) (Borden, 1989; Flechtmann *et al.*, 2000; Allison *et al.*, 2004; Gandhi *et al.*, 2010) and/or bringing back logs infested with beetles from the field to capture emerging adults (Ferro *et al.*, 2009; Lu *et al.*, 2012). Freshly cut logs are known to attract subcortical insects that use hardwood and conifer hosts (Flechtmann *et al.*, 1999; Maier, 2008; Domingue *et al.*, 2011; Lee *et al.*, 2011). Using direct host material to attract subcortical insects may be considered optimal compared with using refined baits that may be missing minor but important host attractants (Barnes *et al.*, 2014). However, few studies have used cut hardwood trees as baits to monitor subcortical insects (Švihra & Koehler, 1981; Mayfield & Hanula, 2012). To our knowledge, no similar studies have been conducted in poplar, sycamore or sweetgum plantations, and none have assessed whether subcortical insects would be better sampled using host material, ethanol baits or unbaited traps placed in the stand.

The present study aimed to: (i) determine the differences in subcortical insect assemblages among poplar, sycamore, and sweetgum plantations and (ii) test the suitability of trap-logs and ethanol as monitoring tools for the detection of native and non-native subcortical insect species.

Materials and methods

Study location and experimental design

The present study took place at the Savannah River Site, a National Environmental Research Park, located near Aiken, South Carolina, U.S.A. (33°23′N, 81°40′E). This area is part of the Carolina Sandhills Ecoregion, and is characterized by warm, humid summers and mild winters, with highly variable precipitation.

The study was conducted in an experimental forest (planted in spring 2000) containing eastern cottonwood clones ST66 and S7C15, sycamore, sweetgum and loblolly pine (*Pinus taeda* L.) (Coleman *et al.*, 2004). Within each of three replicated blocks, four plots per tree genotype were arranged in a randomized complete block design. Trees were planted in 0.22-ha plots at a spacing of $2.5 \times 3.0\,m^2$. During 2000–2008, the four plots in each block received one of four treatments: fertilization, irrigation, fertilization + irrigation, or no treatment (control). Treatments were applied equally each week from 1 April to 30 September annually.

We conducted experiments in 2011 and 2013 in eastern cottonwood S7C15, sycamore and sweetgum plots that received the fertilization + irrigation treatment. We chose the fertilization + irrigation treatment because these trees were approximately 33% larger than the other treatments (Coyle & Coleman, 2005; Coyle *et al.*, 2008) and we assumed that they would be more attractive to insects as a result of increased amounts of volatiles being emitted from wood and foliage.

We established four traps in each plot, arranged in a square. For the first experiment, we monitored beetle captures over cut trees or an untreated control. Three trees were felled in each of the fertilization + irrigation plots ($n = 9$ trees per species) on 19 April 2011. Apparently healthy trees with no dieback were chosen based on similar size [mean ± SE diameter to breast height (DBH): cottonwood, 16.9 ± 1.0 cm; sycamore, 16.1 ± 0.6 cm; sweetgum, 18.2 ± 0.7 cm; tree DBH was not significantly different from each other: $P = 0.19$, PROC ANOVA in SAS; SAS Inc., version 9.2, Cary, North Carolina]. Trees were separated by ≥ 25 m and logs were cut into approximately 2-m sections. Branches and leaves were left on the stem sections to add to the volatile plume from the trap-logs. Unbaited 12-unit Lindgren funnel traps were installed next to each tree's stump, with the cut bolts and foliage stacked in a log cabin formation under the trap and surrounding the stump, thereby using the volatiles produced by logs as insect attractants. One Lindgren funnel control trap, devoid of any cut plant material, was installed in each plot ($n = 3$ traps per tree species), approximately 25 m away from trap-logs.

We conducted the second experiment in the same plots, monitoring beetle captures over cut trees, ethanol lures or an untreated control over bare ground. We chose trees in the same manner (mean ± SE DBH: cottonwood, 21.4 ± 0.3 cm; sycamore, 20.7 ± 0.4 cm; sweetgum, 19.6 ± 0.8 cm; tree DBH was not significantly different from each other: $P = 0.08$, PROC ANOVA in SAS, version 9.2] and felled two trees per plot on 25 April 2013. Each plot also contained a funnel trap baited with one UHR ethanol lure (changed every 4 weeks in accordance with the manufacturer instructions; Contech Enterprises, Inc., Canada) and a control trap away from any cut plant material.

Insect trapping

Trap collection cups were filled with a 50 : 50 blend of propylene glycol (Prestone Products Corp., Danbury, Connecticut) and water, and checked every 2 weeks. In 2011, traps were open from 19 April to 23 August (nine trapping periods) and, in 2013, traps were open from 25 April to 12 September (10 trapping periods).

Coleoptera (Buprestidae, Cerambycidae and Curculionidae: Scolytinae) and Hymenoptera (Siricidae) were identified using published keys (Franklin & Lund, 1956; Wood, 1982; Lingafelter, 2007; Schiff *et al.*, 2012). We used the nomenclature from Wood (1982) and Wood and Bright (1992), with updates from Alonso-Zarazaga and Lyal (2009) and Bright (2014), for all Scolytinae identifications. Voucher specimens have been deposited in the Georgia Museum of Natural History, University of Georgia, Athens, Georgia.

Statistical analysis

Traditional data transformations failed to achieve normality required for a classic analysis of variance. Hence, nonparametric analyses (PROC NPAR1WAY in SAS, version 9.2) were used to test for the main effect of tree species (Kruskal–Wallis test) or trap-type (trap-log versus control in 2011, trap-log versus ethanol, trap-log versus control or ethanol versus control in 2013) within tree species (Wilcoxon rank-sum test). We tested all species of Scolytinae together as a single group (referred to as total Scolytinae) and all woodboring insects (Coleoptera: Buprestidae, Cerambycidae, and Hymenoptera: Siricidae) together (referred to as total woodborers), as well as the most common individual species (i.e. those that comprised ≥ 4% of total catches in a given year). Tests were conducted separately for each sampling year and $\alpha = 0.05$ was considered statistically significant.

Indicator species analyses (PC-ORD, version 5.1; MjM Software Design, Gleneden Beach, Oregon) were used to determine whether particular subcortical insect species (≥ 4% of total captures in a given year) were associated with any tree species or trapping method (Dufrêne & Legendre, 1997; McCune & Mefford, 1999; McCune & Grace, 2002). Analyses were conducted separately for scolytine beetles and woodborers. Monte Carlo tests using 1000 runs were used to generate randomized indicator values for each species. These randomized indicator values were then compared with the observed indicator values to assess statistical significance of the strength of species affinity for combinations of tree species and trap-types.

We used non-metric multidimensional scaling (NMS) (PC-ORD, version 5.1, MjM Software Design) to determine differences in Scolytinae and woodborer assemblages attracted to trap logs, ethanol baits and control traps for each tree species. Bray–Curtis dissimilarities were used on square root +1 (in 2011) or log +1 (in 2013) transformed data. We based NMS on 50 runs with real data with a 0.0001 stability criterion, 15 runs to evaluate stability, 250 maximum iterations, with a step-down in dimensionality and an initial step length of 0.20 (McCune & Grace, 2002). After checking the scree plot for optimal dimensions and model stability, the final NMS was run using three dimensions with a 0.00001 stability criterion, and one run without a step-down in dimensionality. Two-dimensional ordination graphs with mean ± SE distance were created using the two axes (x, y or z) that explained the most variation (r^2) in each of the data sets.

Results

We caught a total of 15 506 subcortical insects represented by 115 native and 12 non-native species (see Supporting information, Table S1). Overall, 12 non-native species of Scolytinae comprised > 72% of all woodborers and scolytines caught in traps (Table 1). The non-native species *Cnestus mutilatus* (Blandford), *Dryoxylon onoharaensis* (Murayama), *Xyleborinus saxesenii* (Ratzeburg) and *Xylosandrus crassiusculus* (Motschulsky) dominated our catches, and accounted for > 61% of all subcortical insects. Other non-native species included *Ambrosiodmus rubricollis* (Eichhoff), *Ambrosiophilus atratus* (Eichhoff), *Coccotrypes distinctus* (Motschulsky), *Cyclorhipidion bodoanum* (Reitter), *Euwallacea interjectus* (Blandford), *Hypothenemus californicus* Hopkins, *Hypothenemus crudiae* (Panzer) and *Xyleborus glabratus* Eichhoff. A native weevil species, *Dryophthorus americanus* Bedel, comprised over half of our total insect catches in 2011. Catches of all nonscolytine weevils were low in 2013, as were woodborer catches in both years.

Table 1 Native and non-native woodborer and scolytine captures during summer 2011 and 2013 at the Savannah River Site near Aiken, South Carolina, U.S.A.

Group	Family	Origin	Number of species	Total captures
Woodborers	Buprestidae	Native	8	120
		Non-native	0	0
	Cerambycidae	Native	41	936
		Non-native	0	0
	Siricidae	Native	1	30
		Non-native	0	0
	Total		50	1086
Scolytinae	Scolytinae	Native	40	2582
		Non-native	12	9646
	Total		52	12 228
Weevils*	Various	Native	25	2192
		Non-native	0	0
	Total		25	2192

For a complete species list and abundance, see Supporting information, Table S1.
*excluding Scolytinae.

Tree species had a significant effect on insect catches for several insect groups (Table 2). Catches of total Scolytinae were almost equal on poplar and sweetgum, which were > 80% and > 64% greater than sycamore, respectively, in both years. *Xyleborinus saxesenii* catches in poplar were 60% greater than sweetgum and 84% greater than sycamore in 2011, and > 69% greater than either sweetgum or sycamore in 2013. *Xylosandrus crassiusculus* was caught most often on sweetgum in 2011, and relatively equally among tree species in 2013. *Pityophthorus liquidambarus* Blackman, as its name suggests, was caught almost exclusively in sweetgum plots each year. *Cnestus mutilatus* was caught over four times as often in sweetgum than poplar or sycamore in 2013. Catches of total woodboring insects did not differ among tree species (Table 2).

There were generally greater insect catches in traps placed over trap-logs compared with control traps in 2011, although captures were dependent upon tree species and insect taxa (Fig. 1 and Table 3). In 2013, the most insects were caught on either trap-logs or ethanol lures (Fig. 2 and Table 4). Total Scolytinae catches in 2011 were greater with poplar trap-logs than control traps but not in sycamore or sweetgum plots.

Table 2 Mean ± SE insects per trap captured and Kruskal–Wallis analyses for subcortical insect groups and individual species comprising > 4% of total captures during the 2011 and 2013 study periods

Taxa	Year	Poplar	Sycamore	Sweetgum	χ^2	*P*
Total Scolytinae	2011	2.94 ± 0.32	1.56 ± 0.18	2.56 ± 0.33	14.05	**0.001**
	2013	39.16 ± 2.42	21.43 ± 1.34	35.39 ± 2.70	36.95	**< 0.001**
Non-native Scolytinae	2011	1.88 ± 0.27	0.49 ± 0.08	1.25 ± 0.21	11.18	**< 0.001**
	2013	37.22 ± 2.39	17.60 ± 1.10	22.35 ± 1.74	54.62	**< 0.001**
Total Woodborers	2011	1.27 ± 0.24	1.06 ± 0.13	1.25 ± 0.15	1.54	0.463
	2013	1.83 ± 0.29	1.64 ± 0.17	1.48 ± 0.16	1.05	0.591
Cnestus mutilatus	2011	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	na	na
	2013	1.28 ± 0.24	1.23 ± 0.24	5.85 ± 1.23	42.92	**< 0.001**
Dryoxylon onoharaensis	2011	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	na	na
	2013	6.33 ± 0.68	1.73 ± 0.24	1.91 ± 0.22	41.59	**< 0.001**
Elaphidion mucronatum	2011	0.23 ± 0.05	0.70 ± 0.12	0.45 ± 0.08	9.24	**0.010**
	2013	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	na	na
Euderces pini	2011	0.55 ± 0.20	0.03 ± 0.02	0.13 ± 0.07	20.43	**< 0.001**
	2013	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	na	na
Hypothenemus rotundicollis	2011	0.39 ± 0.08	0.15 ± 0.04	0.05 ± 0.02	20.59	**< 0.001**
	2013	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	na	na
Hypothenemus seriatus	2011	0.17 ± 0.04	0.23 ± 0.05	0.19 ± 0.06	2.25	0.324
	2013	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	na	na
Monarthrum mali	2011	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	na	na
	2013	0.33 ± 0.09	0.87 ± 0.22	3.45 ± 0.57	53.52	**< 0.001**
Pityophthorus liquidambarus	2011	0.01 ± 0.01	0.04 ± 0.02	0.48 ± 0.12	35.93	**< 0.001**
	2013	0.03 ± 0.01	0.10 ± 0.03	7.10 ± 1.20	180.69	**< 0.001**
Xyleborinus saxesenii	2011	1.60 ± 0.25	0.26 ± 0.05	0.65 ± 0.15	40.81	**< 0.001**
	2013	20.88 ± 2.15	6.37 ± 0.64	5.94 ± 0.54	60.01	**< 0.001**
Xylosandrus crassiusculus	2011	0.08 ± 0.03	0.12 ± 0.04	0.33 ± 0.08	8.42	**0.015**
	2013	8.52 ± 1.13	7.95 ± 0.82	8.14 ± 1.00	1.31	0.520

Insects were captured in intensively-managed stands of three tree species in South Carolina, U.S.A. In 2011, each tree species plot contained three traps baited with cut trees and a control trap; in 2013, each plot contained two cut tree-baited traps, a trap baited with an ethanol lure and a control trap.
Significant *P*-values are indicated with boldface type.
na not applicable.

In 2013, the highest numbers of Scolytinae were caught in trap-logs for sycamore and sweetgum, and ethanol lures for poplar. Catches of non-native Scolytinae mirrored those of total Scolytinae. Total woodboring insect catches were greater on trap-logs of each tree species compared with control traps in 2011, although they did not differ in sycamore traps in 2013. *Xyleborinus saxesenii* and *Euderces pini* (Olivier) were the only individual species that responded to poplar trap-logs, whereas both *Elaphidion mucronotum* (Say) and *Hypothenemus rotundicollis* (Eichhoff) responded to sycamore trap-logs. *Cnestus mutilatus* and *D. onoharaensis* were caught in the greatest numbers in ethanol-baited traps, whereas *E. mucronotum*, *Monarthrum mali* (Fitch) and *P. liquidambarus* showed a clear preference for sweetgum trap-logs. With the exception of poplar in 2013, *X. crassiusculus* catches tended to be greater over trap-logs, although they were not statistically different from controls.

Indicator species analysis revealed that four species of scolytine beetles caught only with poplar and sweetgum trap-logs in 2011 had significant indicator values (Table 5). *Hypothenemus rotundicollis* and *X. saxesenii* were primarily associated with poplar trap-logs, whereas *P. liquidambarus* and *X. crassiusculus* were associated with sweetgum trap-logs. Among woodborers, only *E. mucronotum* was associated with unbaited funnel traps placed in sweetgum stands (Table 5). In 2013, *M. mali* and *P. liquidambarus* were associated with sweetgum trap-logs, whereas *C. mutilatus* was associated with ethanol lures in both poplar and sweetgum plots (Table 5).

The NMS ordination diagram in two dimensions for total Scolytinae in 2011 (final stress = 16.14, final instability = 0.00001) indicated that beetle assemblages in the three stand types were distinct along at least one of the hypothetical gradients (Fig. 3A). Total woodboring insect community assemblages (final stress = 12.93, final instability = 0.00007) captured over trap-logs were distinct among the three host types, although assemblages captured in control traps were quite similar (Fig. 3B). Assemblages of total Scolytinae were somewhat distinct on all three tree species in 2013 (final stress = 13.61, final instability = 0.00047) (Fig. 4A), whereas total woodboring insect community assemblages were less distinct (final stress = 14.77, final instability = 0.0045) (Fig. 4B). Insect community assemblages captured with the ethanol lure tended to have the characteristics of assemblages captured on both trap-logs and control traps.

Discussion

Non-native Scolytinae clearly dominated trap catches in these biomass plantations. Although only a small proportion of scolytine species were non-native, most individuals caught were non-native to North America (Table 1). The probable reason why non-native species comprised such a large proportion of

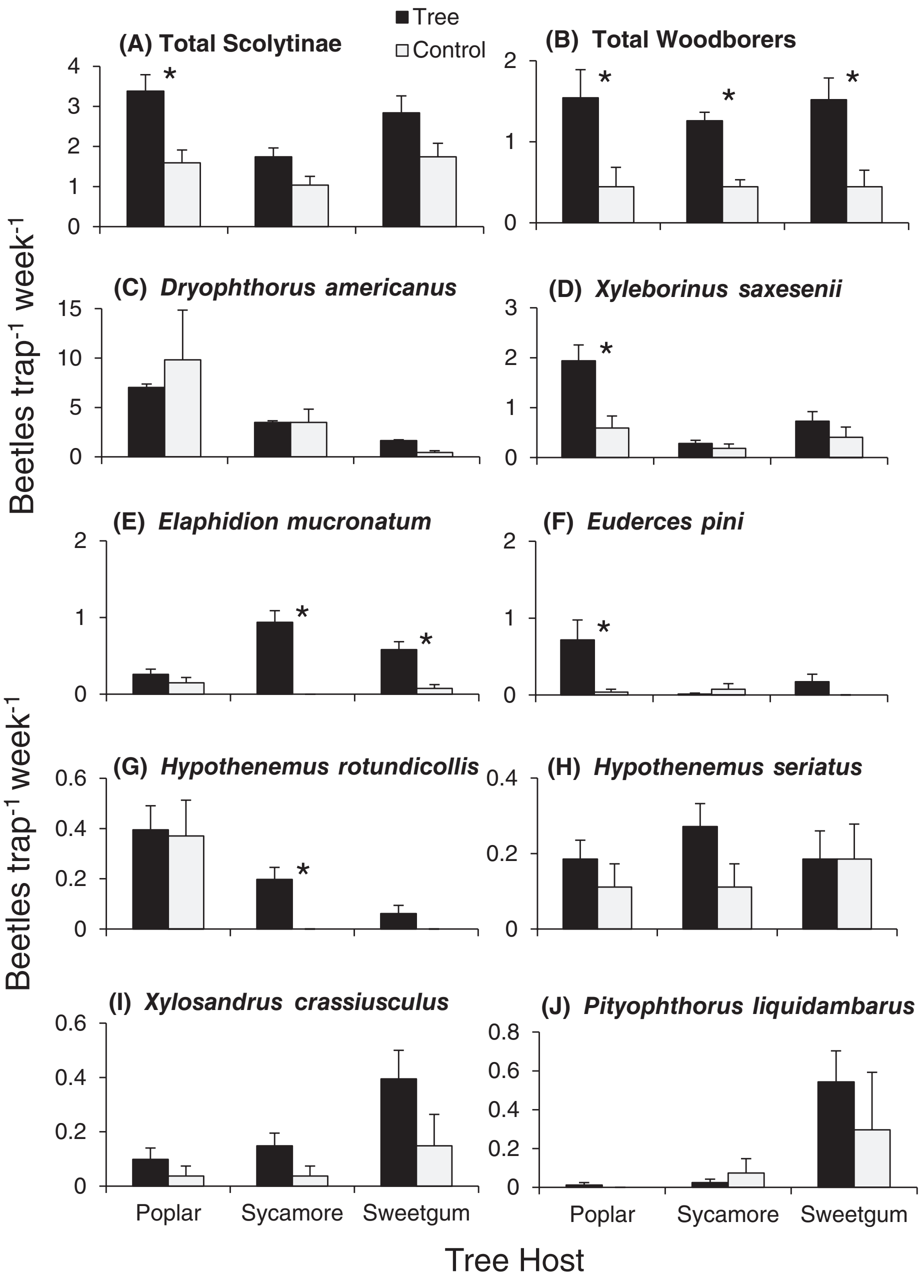

Figure 1 Effect of trap trees on captures (mean ± SE) of (A) total Scolytinae, (B) total woodborers, (C) *Dryophthorus americanus*, (D) *Xyleborinus saxesenii*, (E) *Elaphidion mucronatum*, (F) *Euderces pini*, (G) *Hypothenemus rotundicollis*, (H) *Hypothenemus seriatus*, (I) *Xylosandrus crassiusculus* and (J) *Pityophthorus liquidambarus* during summer 2011 in an intensively-managed hardwood plantation in South Carolina, U.S.A. Within an insect group × tree host, an asterisk indicates significant differences between traps over cut trees and controls (Wilcoxon rank sum test, $\alpha = 0.05$).

total captures is because these species posess characteristics (e.g. life-history traits, behavioural plasticity) common to invasive species that enhance their ability to colonize and establish in new environments (Sakai *et al.*, 2001). Several species, such as *X. saxesenii*, *X. crassiusculus*, *C. mutilatus* and *D. onoharaensis*, have established breeding populations, as indicated by the high numbers of individuals captured in this and other studies (Coyle *et al.*, 2005; Ulyshen & Hanula, 2009). *Cnestus mutilatus* appears to be in the process of a rapid range expansion across the southeastern U.S.A. It was first collected in South Carolina in 2010 (Chong *et al.*, 2012) and the escalation of our capture rates from 2011 to 2013 from few individuals to hundreds of beetles (see Supporting information, Table S1) further supports this notion. Although these three species are among some of the most common ambrosia beetles in the southeastern U.S.A. (Turnbow & Franklin, 1980; Atkinson *et al.*, 1988; Miller & Rabaglia, 2009), several less-common non-native scolytines such as *A. atratus* and *H. crudiae* were also captured in very low

Table 3 Wilcoxon rank-sum test of the effect of trap-trees on captures of the most common subcortical insects in intensively-managed stands of three hardwood tree species during 2011 in South Carolina, U.S.A.

	Poplar		**Sycamore**		**Sweetgum**	
Taxa	χ^2	*P*	χ^2	*P*	χ^2	*P*
Total Scolytinae	7.42	**0.007**	1.86	0.173	0.40	0.525
Non-native Scolytinae	10.47	**0.001**	1.76	0.185	1.60	0.207
Total Woodborers	6.00	**0.014**	9.53	**0.002**	11.51	**0.001**
Dryophthorus americanus	0.11	0.743	0.02	0.893	3.02	0.082
Xyleborinus saxesenii	11.64	**0.001**	0.39	0.530	0.04	0.850
Elaphidion mucronatum	0.29	0.588	16.99	**< 0.001**	8.77	**0.003**
Euderces pini	4.89	**0.027**	0.70	0.403	1.73	0.188
Hypothenemus rotundicollis	0.01	0.922	5.75	**0.017**	1.37	0.242
Hypothenemus seriatus	0.43	0.512	1.73	0.189	0.25	0.615
Xylosandrus crassiusculus	0.48	0.490	1.67	0.194	2.78	0.096
Pityophthorus liquidambarus	0.33	0.564	1.37	0.242	0.02	0.891

See also Fig. 1 for a graphical comparison of these data.
Significant *P*-values are indicated with boldface type.

numbers. It remains to be determined whether these species will increase in numbers with time or continue to persist at low levels.

Much greater numbers of Scolytinae were caught with trap-logs than unbaited traps. Similarly, in Norway, traps baited with either Scots pine (*Pinus sylvestris* L.) or downy birch (*Betula pubescens* Ehrh.) caught up to 420-fold more Scolytinae than unbaited controls (Brattli *et al.*, 1998). Konara oak (*Quercus serrata* Murray) trap logs were successfully used to describe a guild of Scolytinae and Platypodidae in Japan (Sanguansub *et al.*, 2012) and loblolly pine and sweetgum trap-logs were used to describe saproxylic beetle assemblages in South Carolina, U.S.A. (Ulyshen & Hanula, 2009). The responses of insects varied among tree species, as reported in other studies (Maier, 2008; Ulyshen & Hanula, 2009). Trap catches of total Scolytinae, *X. saxesenii*, *E. pini*, *D. onoharaensis* and *H. rotundicollis* were greater on poplar, whereas those of *C. mutilatus*, *M. mali* and *P. liquidambarus* were greater on sweetgum. Catches of *X. crassiusculus* were greatest on sweetgum in 2011, although they were even among the three host types in 2013. *Xyleborinus saxesenii* is attracted to and utilizes many hosts, including chestnut (*Castanea* spp.), plum (*Prunus* spp.) and pear (*Pyrus* spp.) trees (Deyrup & Atkinson, 1987; Batt, 2000; Oliver & Mannion, 2001). The lack of response to sweetgum trap-trees in 2011 was particularly unexpected, considering the high levels of adult emergence recorded by Ulyshen and Hanula (2009) from sweetgum in the same area. This difference could be the result of inter-annual variation, or possibly climatic factors. By contrast, catches of *H. rotundicollis* were greater in sycamore trap-logs, and this species is also known to utilize several hardwood hosts, such as hickory (*Carya* spp.), oak (*Quercus* spp.) and beech (*Fagus* spp.) trees (Salsbury, 2004). Catches of total woodboring insects appeared to be particularly responsive to trap-logs of every tree species in 2011 but not 2013, and catches of *E. pini* and *E. mucronatum* appeared to vary based on tree species (poplar, as well as sycamore and sweetgum, respectively). Both of these cerambycids are polyphagous, utilizing several hardwood species (and a conifer species in the case of *E. mucronotum*) as hosts (Turnbow & Hovore, 1979; Linsley & Chemsak, 1997; Morris, 2002).

Similarly, indicator species analysis revealed that *X. saxesenii* and *H. rotundicollis* were associated primarily with poplar trap-logs, and *M. mali*, *X. crassiusculus* and *P. liquidambarus* were associated with sweetgum trap-logs. These trends are likely the result of a different volatile profile emitted by phloem and xylem layers, as well as the leaves of the three host species, because all aboveground host material was used in the present study (Geron *et al.*, 2001). Although certain insect species were caught in these hardwood stands, and showed an association with particular tree species, they may or may not be using these trees as viable hosts. For example, *Ips avulsus* (Eichhoff), *Ips calligraphus* (Germar) and *Ips grandicollis* (Eichhoff) were caught in relatively low numbers (35 individuals) in our traps. *Ips* species are known only to infest conifers (Wood, 1982), and it is likely that they were either flying in the general area to find a host or were attracted to decaying coarse-woody debris. Furthermore, the native weevil *D. americanus* was the most commonly caught subcortical beetle in 2011 and this species has previously been associated with pine trees (Downie & Arnett, 1996; Aukema & Raffa, 2005; Ulyshen & Hanula, 2010). Future studies should be conducted aiming to determine log colonization rates, which would indicate actual host usage in addition to attraction.

Ethanol is a widely used attractant for various species of Scolytinae, and is considered the standard lure type (Montgomery & Wargo, 1983; Miller & Rabaglia, 2009; Ranger *et al.*, 2011; Reding *et al.*, 2011; Kelsey *et al.*, 2013). Nationwide exotic pest detection efforts regularly use ethanol to detect non-native bark and ambrosia beetles (Rabaglia *et al.*, 2008). Ethanol is also emitted from cut logs as part of the decomposition process (Kelsey, 1994), which supports our use of cut logs as baits for subcortical insects. The inclusion of ethanol-baited traps led to increases in the overall numbers of insects caught in traps, especially of *C. mutilatus* and *D. onoharaensis*. Although no Scolytinae species were caught solely in traps baited with ethanol, certain Cerambycidae [e.g. *Methia necydalia* (F.), *Monochamus notatus* (Drury) and *Xylotrechus saggitatus* Germar] were caught only with ethanol-baited traps (Table 1). In addition, we identified six new state records (Table 1) in traps baited with trap-logs or ethanol

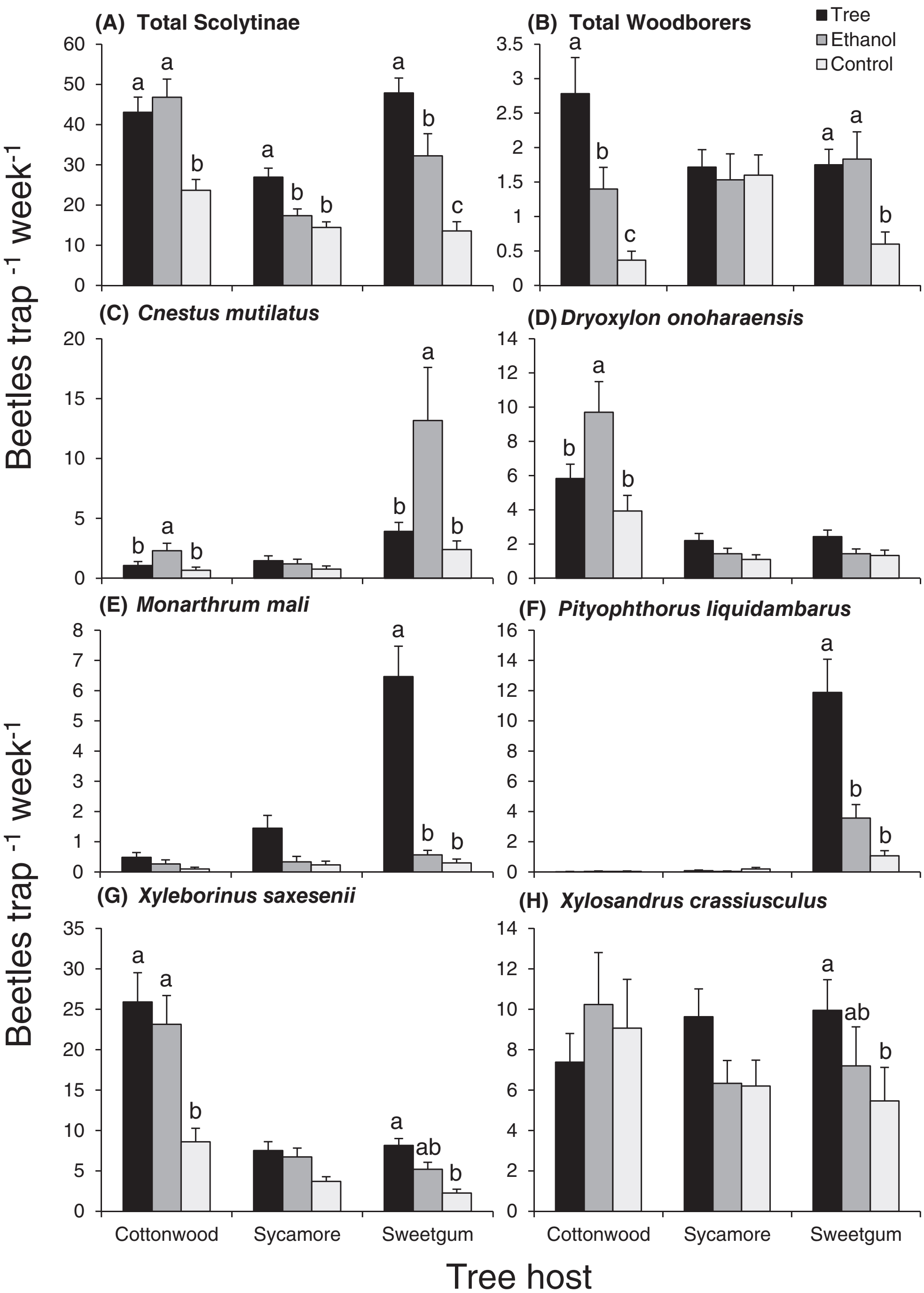

Figure 2 Effect of trap trees and ethanol lures on captures (mean ± SE) of (A) total Scolytinae, (B) total woodborers, (C) *Cnestus mutilatus*, (D) *Dryoxylon onoharaensis*, (E) *Monarthrum mali*, (F) *Pityophthorus liquidambarus*, (G) *Xyleborinus saxesenii* and (H) *Xylosandrus crassiusculus* during summer 2013 in an intensively-managed hardwood plantation in South Carolina, U.S.A. Within an insect group × tree host, letters indicate significant differences in captures among traps over cut trees, ethanol lures, and controls (Wilcoxon rank sum test, $\alpha = 0.05$).

lures, as well as the northernmost capture of *C. distinctus* in North America.

By creating a 'hot-spot' of downed woody debris, we were able to determine whether certain subcortical insect species may cue to the debris instead of flying randomly throughout a forest searching for hosts; unbaited traps in the present study were used to assess the flying activity of subcortical insects in these hardwood plantations and/or the effect of visual attraction to a bole-shaped structure by tree-infesting insects. For example, indicator species analyses found that at least five scolytine beetle species (*H. rotundicollis*, *M. mali*, *X. saxesenii*, *P. liquidambarus* and *X. crassiusculus*) were associated primarily with trap-logs

Table 4 Wilcoxon rank-sum test of the effect of trap-trees and ethanol lures on captures of the most common subcortical insects in intensively-managed stands of three hardwood tree species during 2013 in South Carolina, U.S.A.

	Poplar		**Sycamore**		**Sweetgum**	
Taxa	χ^2	*P*	χ^2	*P*	χ^2	*P*
Total Scolytinae	19.06	**< 0.001**	15.98	**< 0.001**	44.15	**< 0.001**
Non-native Scolytinae	19.53	**< 0.001**	12.12	**0.002**	24.71	**< 0.001**
Total woodborers	19.37	**< 0.001**	1.29	0.525	11.95	**0.003**
Cnestus mutilatus	10.16	**0.006**	0.90	0.637	14.46	**< 0.001**
Dryoxylon onoharaensis	6.78	**0.034**	2.17	0.338	3.12	0.210
Monarthrum mali	4.22	0.121	5.49	0.064	50.53	**< 0.001**
Pityophthorus liquidambarus	0.34	0.844	2.38	0.304	27.49	**< 0.001**
Xyleborinus saxesenii	16.63	**< 0.001**	3.95	0.138	26.39	**< 0.001**
Xylosandrus crassiusculus	2.05	0.359	2.43	0.296	7.82	**0.020**

See also Fig. 2 for a graphical comparison of these data.
Significant *P*-values are indicated with boldface type.

Table 5 Significant indicator values for subcortical insect species that comprised > 4% of total captures in a given year on three tree species and two (2011) or three (2013) trap-types in an intensively-managed hardwood plantation in South Carolina, U.S.A.

Year	Tree species	Trap-type	Insect species	Observed indicator value (IV)	IV from randomized groups[a] Mean ± SD	*P*-value[b]
2011	Poplar	Trap-log	*Hypothenemus rotundicollis*	38.6	24.0 ± 6.65	**0.027**
			Xyleborinus saxesenii	46.9	27.9 ± 5.28	**0.002**
	Sweetgum	Trap-log	*Pityophthorus liquidambarus*	57.1	24.5 ± 9.29	**0.004**
			Xylosandrus crassiusculus	40.6	25.9 ± 6.52	**0.028**
		Unbaited trap	*Elaphidion mucronatum*	35.8	24.7 ± 4.40	**0.015**
2013	Poplar	Ethanol	*Dryoxylon onoharaensis*	33.0	20.3 ± 3.26	**0.001**
	Sweetgum	Trap-log	*Monarthrum mali*	63.4	30.1 ± 8.04	**< 0.001**
			Pityophthorus liquidambarus	70.2	27.1 ± 9.26	**< 0.001**
		Ethanol	*Cnestus mutilatus*	48.9	27.6 ± 5.33	**< 0.001**

[a] A Monte Carlo test at 1000 runs was used to generate randomized indicator values.
[b] Pairwise comparisons were performed between the observed and randomized indicator values for each species.
Significant *P*-values are indicated with boldface type.

of poplar and sweetgum, and not with the unbaited traps placed in stands. Three non-native species (*H. crudiae*, *H. californicus* and *X. glabratus*) were also captured primarily with trap-logs suggesting the importance of cut plant material. More than three times as many woodborer or scolytine species were captured with trap-logs compared with ethanol-baited or unbaited control traps, including two non-native species (Table 6), highlighting the importance of using trap-logs or other natural baits for monitoring insect communities.

NMS ordination revealed that Scolytinae assemblages were largely influenced by tree species rather than trap-type (Figs 3 and 4). The subcortical insect assemblage associated with poplar trees was distinct from those of sweetgum or sycamore trees. In evidence, a total of 94 species were associated with poplar trees with 26 unique species such as *Xyleborus celsus* Eichhoff, *Trischidias atomas* Hopkins and *Hyperplatys maculata* Haldeman (Table S1). A total of 83 species were captured in sycamore and 79 in sweetgum-dominated stands, with only 16 and 14 unique species, respectively. Hence, poplar-dominated stands may have a more species-rich and unique subcortical beetle assemblage compared with sweetgum and sycamore in the study sites. These data suggest that, even with our relatively small plots (0.22 ha), these highly mobile insects are greatly influenced by plot composition.

Differences in species composition of subcortical insects among trapping methods were particularly evident for total woodboring insects. In 2011, the woodboring insect assemblage around trap-logs differed markedly among the three hosts; however, all control traps caught almost identical woodboring insects (Fig. 3). This trend suggests that the ambient or background woodboring insect assemblage was ubiquitous among the three tree species tested, although different species were attracted to trap-logs. In 2013, although the patterns were less distinct, woodboring insect assemblages were still more influenced by tree species than by the trapping method (Fig. 4). Hence, the use of trap-logs is a better method than unbaited traps for monitoring woodboring beetle assemblages in these plantation stands, although annual variation in community composition must be considered. Our woodborer capture rates (approximately 15 individuals per trap per year) were similar to other studies examining woodborers in the eastern U.S.A. (capture rates ranged from < 1 to ~55 individuals per trap per year; Miller & Duerr, 2008; Dodds, 2011; Miller *et al.*, 2011). Although trap-logs are effective for monitoring populations of bark and woodboring insects, ethanol-baited traps appear to be more effective than trap-logs or unbaited control traps for monitoring non-native Scolytinae, although care must be taken to account for species-specific attraction to different trapping methodologies.

In conclusion, both trap-logs and ethanol lures hold value as attractants compared with unbaited traps for subcortical insects, especially for non-native species detection and monitoring.

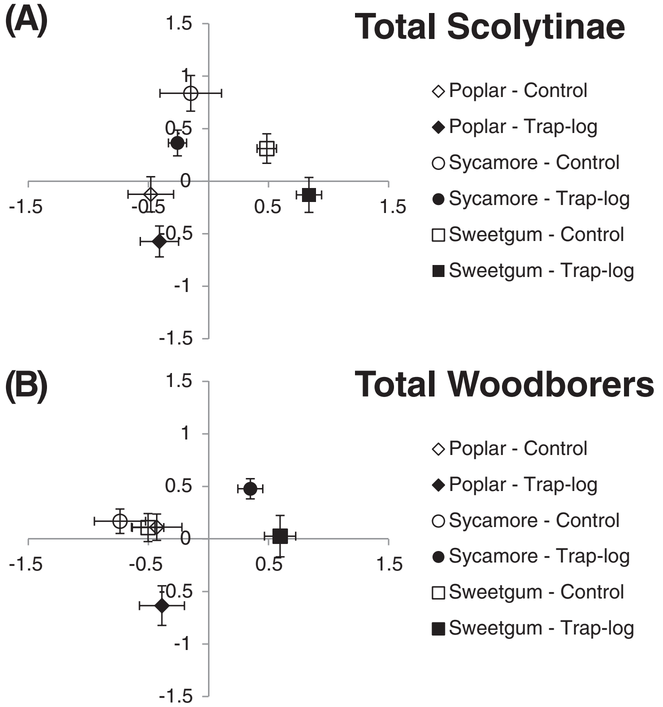

Figure 3 Total Scolytinae (A) and total woodborer (B) assemblages during summer 2011 in an intensively-managed hardwood plantation in South Carolina, U.S.A. The beetle assemblage captured in traps baited with cut poplar, sycamore, and sweetgum trap trees and control traps is compared for each group. The two graphed axes represented 58.9% of the variation for Scolytinae and 67.4% of the variation for woodborers.

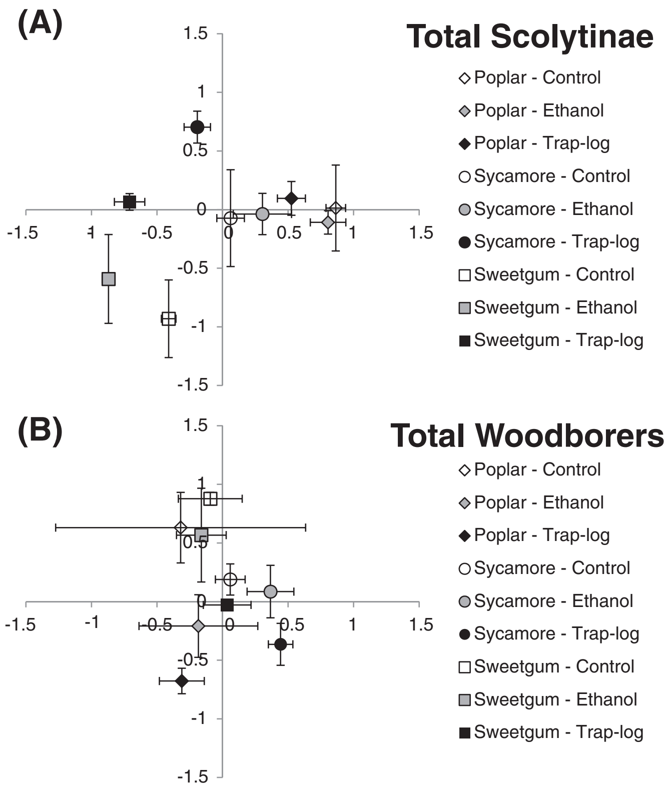

Figure 4 Total Scolytinae (A) and total woodborer (B) assemblages during summer 2013 in an intensively-managed hardwood plantation in South Carolina, U.S.A. The beetle assemblage captured around traps baited with cut poplar, sycamore, and sweetgum trap trees, ethanol lures, and control traps is compared for each group. The two graphed axes represented 57.4% of the variation for Scolytinae and 60.1% of the variation for woodborers.

Although some non-native scolytinae will attack and injure live trees, few native Scolytinae species will do so (Kühnholz *et al.*, 2001; Coyle *et al.*, 2005). At present, it is unclear whether the non-native species captured in the present study are causing any economic or ecological damage or whether they are just utilizing empty niches in these ecosystems (Stone *et al.*, 2007; Ranger *et al.*, 2010). Subcortical insect assemblages and populations differed based on the tree species and trapping methods. Additional key relevant questions for sustainable forest management include whether certain subcortical insect species may become

Table 6 Woodborers and Scolytinae captured only with a single trap type

Trap type Control	Ethanol	Trap-log
Dicerca obscura (F.)[a]	*Methia necydalia* (F.)[b]	*Buprestis apricans* Herbst[a]
Bellamira scalaris Say[b]	*Xylotrechus saggitatus* (Germar)[b]	*Buprestis rufipes* Olivier[a]
Stenelytrana emarginata (F.)[b]	*Cyrtinus pygmaeus* (Haldeman)[b]	*Chalcophora virginiensis* (Drury)[a]
Hylastes porculus Erichson[c]	*Monochamus notatus* (Drury)[b]	*Anelaphus pumilis* (Newman)[b]
Hylocurus langstoni Blackman[c]		*Knuliana cincta spinifera* (F.)[b]
Ips calligraphus (Germar)[c]		*Neoclytus mucronotus* (F.)[b]
		Acanthocinus pusillus Kirby[b]
		Lepturges angulatus (LeConte)[b]
		Sternidius variegatus (Haldeman)[b]
		Prionus imbricornis (L.)[b]
		Arhopalus rusticus (LeConte)[b]
		Coccotrypes distinctus (Motschulsky)[c, d]
		Xyleborus glabratus Eichhoff[c, d]
		Crypturgus alutaceus Schwart[c]
		Phleotribus frontalis (Oliver)[c]
		Pseudopityophthorus minutissimus (Zimmermann)[c]
		Pseudopityophthorus pruinosus (Eichhoff)[c]
		Trischidias atomus (Hopkins)[c]
		Xyleborus celsus Eichhoff[c]

[a]Buprestidae.
[b]Cerambycidae.
[c]Scolytinae.
[d]Non-native species.

either rare or abundant under different management scenarios; would the proportion of native versus non-native species change; and would certain insect species become pestilent in a monocultural environment.

Acknowledgements

We thank John Blake (USDA Forest Service – Savannah River) for project support. Andy Blake and Blake Morris (USDA Forest Service – Savannah River) and Brittany Barnes and Kris Smoot (University of Georgia – Athens) provided excellent field assistance. We thank Dan Miller (USDA Forest Service) for his thoughtful comments on an earlier version of this manuscript. We are immensely grateful to Tom Atkinson (University of Texas – Austin) for identifying *Hypothenemus* and *Pityophthorus* spp., and Charles O'Brien (Florida A&M, retired) for identifying all nonscolytine Curculionidae. Rick Hoebeke (University of Georgia – Athens) verified the identity of many specimens. This research was supported by the Daniel B. Warnell School of Forestry and Natural Resources, University of Georgia, and the USDA Forest Service, Southern Research Station.

Supporting information

Additional Supporting information may be found in the online version of this article under the DOI reference:
10.1111/afe.12101

Table S1. Total subcortical insect captures during summer 2011 and 2013 at the Savannah River Site near Aiken, South Carolina, U.S.A.

References

Allen, D.G. & Rudinsky, J.A. (1959) Effectiveness of thiodan, sevin, and lindane on insects attacking freshly cut Douglas-fir logs. *Journal of Economic Entomology*, **52**, 482–484.

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

Alonso-Zarazaga, M.A. & Lyal, C.H.C. (2009) A catalogue of family and genus group names in Scolytinae and Platypodinae with nomenclatural remarks (Coleoptera: Curculionidae). *Zootaxa*, **2258**, 1–134.

Atkinson, T.H., Foltz, J.L. & Connor, M.D. (1988) Seasonal and vertical flight patterns of phloem- and wood-boring Coleoptera (Scolytidae, Platypodidae, Buprestidae, Cerambycidae, Curculionidae) in a slash pine plantation in northern Florida. *Environmental Entomology*, **17**, 259–265.

Aukema, B.H. & Raffa, K.F. (2005) Selective manipulation of predators using pheromones: responses to frontalin and ipsdienol pheromone components of bark beetles in the Great Lakes region. *Agricultural and Forest Entomology*, **7**, 193–200.

Barnes, B.F., Meeker, J.R., Johnson, W. *et al.* (2014) Trapping techniques for siricids and their parasitoids (Hymenoptera: Siricidae and Ibaliidae) in the southeastern U.S. *Annals of the Entomological Society of America*, **107**, 119–127.

Batt, A.M. (2000) Preliminary observations on the pear root beetle, *Xyleborinus saxeseni* (Ratz) (Coleoptera: Scolytidae). *Egyptian Journal of Agricultural Research*, **78**, 587–593.

Borden, J.H. (1989) Semiochemicals and bark beetle populations: exploitation of natural phenomena by pest management strategists. *Ecography*, **12**, 501–510.

Brattli, J.G., Andersen, J. & Nilssen, A.C. (1998) Primary attraction and host tree selection in deciduous and conifer living Coleoptera: Scolytidae, Curculionidae, Cerambycidae, and Lymexylidae. *Journal of Applied Entomology*, **122**, 345–352.

Bright, D.E. (2014) A catalog of Scolytidae and Platypodidae (Coleoptera), Supplement 3 (2000–2010), with notes on subfamily and tribal reclassifications. *Insecta Mundi*, **0356**, 1–336.

Chong, J.H., Reid, L. & Williamson, M. (2009) Distribution, host plants, and damage of the black twig borer, *Xylosandrus compactus* (Eichhoff), in South Carolina. *Journal of Agricultural and Urban Entomology*, **26**, 199–208.

Chong, J.H., Weaver, J.S. & Reid, L.S. (2012) New records of bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) from South Carolina, U.S.A. *The Coleopterists Bulletin*, **66**, 250–252.

Coleman, M.D., Coyle, D.R., Blake, J. *et al.* (2004) *Production of Short Rotation Woody Crops Grown with a Range of Nutrient and Water Availability: Establishment Report and First-Year Responses*. Report No SRS-GTR-072. USDA-Forest Service, Southern Research Station, Asheville, North Carolina.

Coleman, T.W., Graves, A.D., Hoddle, M. *et al.* (2012) Forest stand composition and impacts associated with *Agrilus auroguttatus* Schaeffer (Coleoptera: Buprestidae) and *Agrilus coxalis* waterhouse in oak woodlands. *Forest Ecology and Management*, **276**, 104–117.

Coyle, D.R. & Coleman, M.D. (2005) Forest production responses to irrigation and fertilization are not explained by shifts in allocation. *Forest Ecology and Management*, **208**, 137–152.

Coyle, D.R., Booth, D.C. & Wallace, M.S. (2005) Ambrosia beetle (Coleoptera: Scolytidae) species, flight, and attack on living eastern cottonwood trees. *Journal of Economic Entomology*, **98**, 2049–2057.

Coyle, D.R., Coleman, M.D. & Aubrey, D.P. (2008) Above and below-ground biomass accumulation, production, and distribution of sweetgum and loblolly pine grown with irrigation and fertilization. *Canadian Journal of Forest Research*, **38**, 1335–1348.

Coyle, D.R., Aubrey, D.P., Siry, J.C., Volfovicz-Leon, R.R. & Coleman, M.D. (2013) Optimal nitrogen application rates for three intensively-managed hardwood tree species in the southeastern USA. *Forest Ecology and Management*, **303**, 131–142.

Deyrup, M. & Atkinson, T.H. (1987) Comparative biology of temperate and subtropical bark and ambrosia beetles (Coleoptera: Scolytidae, Platypodidae) in Indiana and Florida. *Great Lakes Entomologist*, **20**, 59–66.

Dodds, K.J. (2011) Effects of habitat type and trap placement on captures of bark (Coleoptera: Scolytidae) and longhorned (Coleoptera: Cerambycidae) beetles in semiochemical-baited traps. *Journal of Economic Entomology*, **104**, 879–888.

Domingue, M.J., Csóka, G., Tóth, M. *et al.* (2011) Field observations of visual attraction of three European oak buprestid beetles toward conspecific and heterospecific models. *Entomologia Experimentalis et Applicata*, **141**, 112–121.

Downie, N.M. & Arnett, R.H. Jr. (1996) *The Beetles of Northeastern North America*, Vols. I & II. The Sandhill Crane Press, Gainseville, Florida.

Dufrêne, M. & Legendre, P. (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs*, **67**, 345–366.

Ferro, M.L., Gimmel, M.L., Harms, K.E. & Carlton, C.E. (2009) The beetle community of small oak twigs in Louisiana, with a literature review of Coleoptera from fine woody debris. *The Coleopterists Bulletin*, **63**, 239–263.

Fierke, M.K., Kinney, D.L., Salisbury, V.B., Crook, D.J. & Stephen, F.M. (2005) Development and comparison of intensive and extensive sampling methods and preliminary within-tree population estimates of red oak borer (Coleoptera: Cerambycidae) in the Ozark Mountains of Arkansas. *Environmental Entomology*, **34**, 184–192.

Flechtmann, C.A.H., Dalusky, M.J. & Berisford, C.W. (1999) Bark and ambrosia beetle (Coleoptera: Scolytidae) responses to volatiles from aging loblolly pine billets. *Environmental Entomology*, **28**, 638–648.

Flechtmann, C.A.H., Ottati, A.L.T. & Berisford, C.W. (2000) Comparison of four trap types for ambrosia beetles (Coleoptera, Scolytidae) in Brazilian *Eucalyptus* stands. *Journal of Economic Entomology*, **93**, 1701–1707.

Franklin, R.T. & Lund, H.O. (1956) The Buprestidae (Coleoptera) of Georgia. *Georgia Agricultural Experiment Bulletin*, **3**, 1–48.

Gandhi, K.J.K. & Herms, D.A. (2010) North American arthropods at risk due to widespread *Fraxinus* mortality caused by the alien emerald ash borer. *Biological Invasions*, **12**, 1839–1846.

Gandhi, K.J.K., Cognato, A.I., Lightle, D.M. *et al.* (2010) Species composition, seasonal activity, and semiochemical response of native and exotic bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) in northeastern Ohio. *Journal of Economic Entomology*, **103**, 1187–1195.

Geron, C., Harley, P. & Guenther, A. (2001) Isoprene emission capacity for US tree species. *Atmospheric Environment*, **35**, 3341–3352.

Howard, J.L. (2007) *U.S. Timber Production, Trade, Consumption, and Price Statistics 1965 to 2005*. Research Paper FPL-RP-637. USDA-Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Kelsey, R.G. (1994) Ethanol synthesis in Douglas-fir logs felled in November, January, and March and its relationship to ambrosia beetle attack. *Canadian Journal of Forest Research*, **24**, 2096–2104.

Kelsey, R.G., Beh, M.M., Shaw, D.C. & Manter, D.K. (2013) Ethanol attracts scolytid beetles to *Phytophthora ramorum* cankers on coast live oak. *Journal of Chemical Ecology*, **39**, 494–506.

Kline, K.L. & Coleman, M.D. (2010) Woody energy crops in the southeastern United States: two centuries of practitioner experience. *Biomass and Bioenergy*, **34**, 1655–1666.

Kovacs, K.F., Haight, R.G., McCullough, D.G. *et al.* (2010) Cost of potential emerald ash borer damage in US communities, 2009–2019. *Ecological Economics*, **69**, 569–578.

Kühnholz, S., Borden, J.H. & Uzunovic, A. (2001) Secondary ambrosia beetles in apparently healthy trees; Adaptations, potential causes and suggested research. *Integrated Pest Management Reviews*, **6**, 209–219.

Lee, J.C., Negrón, J.F., McElwey, S.J. *et al.* (2011) Biology of the invasive banded elm bark beetle (Coleoptera: Scolytidae) in the western United States. *Annals of the Entomological Society of America*, **104**, 705–717.

Lingafelter, S.W. (2007) *Illustrated Key to the Longhorned Woodboring Beetles of the Eastern United States*. Special Publication No. 3. Coleopterists Society Miscellaneous Publication, Nevada City, California.

Linsley, E.G. & Chemsak, J.A. (1997) The Cerambycidae of North America, Part VIII: Bibliography, Index, and Host Plant Index. *University of California Publications in Entomology*, **117**, 534.

Lu, R.C., Wang, H.B., Zhang, Z. *et al.* (2012) Attraction of *Tomicus yunnanensis* (Coleoptera: Scolytidae) to Yunnan pine logs with and without periderm or phloem: an effective monitoring bait. *Psyche*, **2012**, 5 p., Article ID 794683.

Maier, C.T. (2008) Emergence, trapping, and seasonal abundance of adult Cerambycidae (Coleoptera) associated with Cupressaceae in Connecticut. *Journal of Economic Entomology*, **101**, 430–437.

Mathew, G. (1987) Insect borers of commercially important stored timber in the state of Kerala, India. *Journal of Stored Products Research*, **23**, 185–190.

Mayfield, A.E. & Hanula, J.L. (2012) Effect of tree species and end seal on attractiveness and utility of cut bolts to the redbay ambrosia beetle and granulate ambrosia beetle (Coleoptera: Curculionidae: Scolytinae). *Journal of Economic Entomology*, **105**, 461–470.

McCune, B. & Grace, J. (2002) *Analysis of Ecological Assemblages*. MjM Software Design, Gleneden Beach, Oregon.

McCune, B. & Mefford, M.J. (1999) *PC-ORD: Multivariate Analysis of Ecological Data, Version 4.0*. MjM Software, Gleneden Beach, Oregon.

Merkle, S. & Cunningham, M. (2011) Southern hardwood varietal forestry: a new approach to short-rotation woody crops for biomass energy. *Journal of Forestry*, **109**, 7–14.

Miller, D.R. (2006) Ethanol and (−)-α-pinene: attractant kairomones for some large wood-boring beetles in southeastern USA. *Journal of Chemical Ecology*, **32**, 779–794.

Miller, D.R. & Duerr, D.A. (2008) Comparison of arboreal beetle catches in wet and dry collection cups with Lindgren multiple funnel traps. *Journal of Economic Entomology*, **101**, 107–113.

Miller, D.R. & Rabaglia, R.J. (2009) Ethanol and (−)-α-pinene: attractant kairomones for bark and ambrosia beetles in the southern US. *Journal of Chemical Ecology*, **35**, 435–448.

Miller, D.R., Asaro, C., Crowe, C.M. & Duerr, D.A. (2011) Bark beetle pheromones and pine volatiles: attractant kairomone lure blend for longhorn beetles (Cerambycidae) in pine stands of the southeastern United States. *Journal of Economic Entomology*, **104**, 1245–1257.

Montgomery, M.E. & Wargo, P.M. (1983) Ethanol and other host-derived volatiles as attractants to beetles that bore into hardwood. *Journal of Chemical Ecology*, **9**, 181–190.

Morris, R.F. II (2002) Distribution and biological notes for some Cerambycidae (Coleoptera) occurring in the southeastern United States. *Insecta Mundi*, **16**, 209–213.

Munsell, J.F. & Fox, T.R. (2010) An analysis of the feasibility for increasing woody biomass production from pine plantations in the southern United States. *Biomass and Bioenergy*, **34**, 1631–1642.

Oliver, J.B. & Mannion, C.M. (2001) Ambrosia beetle (Coleoptera: Scolytidae) species attacking chestnut and captured in ethanol-baited traps in Middle Tennessee. *Environmental Entomology*, **30**, 909–918.

Rabaglia, R., Duerr, D., Acciavatti, R.E. & Ragenovich, I. (2008) *Early Detection and Rapid Response for Non-native Bark and Ambrosia Beetles*. U.S. Department of Agriculture Forest Service, Forest Health Protection, Washington, District of Columbia.

Ranger, C.M., Reding, M.E., Persad, A.B. & Herms, D.A. (2010) Ability of stress-related volatiles to attract and induce attacks by *Xylosandrus germanus* and other ambrosia beetles. *Agricultural and Forest Entomology*, **12**, 177–185.

Ranger, C.M., Reding, M.E., Gandhi, K.J.K. *et al.* (2011) Species dependent influence of (−)-α-pinene on attraction of ambrosia beetles to ethanol-baited traps in nursery agroecosystems. *Journal of Economic Entomology*, **104**, 574–579.

Reding, M.E., Schultz, P.B., Ranger, C.M. & Oliver, J.B. (2011) Optimizing ethanol-baited traps for monitoring damaging ambrosia beetles (Coleoptera: Curculionidae, Scolytinae) in ornamental nurseries. *Journal of Economic Entomology*, **104**, 2017–2024.

Sakai, A.K., Allendorf, F.W., Holt, J.S. *et al.* (2001) The population biology of invasive species. *Annual Review of Ecology and Systematics*, **32**, 305–332.

Salsbury, G.A. (2004) *Guide to the Bark and Ambrosia Beetles of Kansas*. Kansas Department of Agriculture's Plant Protection and Weed Control Program, Topeka, Kansas.

Sanguansub, S., Goto, H. & Kamata, N. (2012) Guild structure of ambrosia beetles attacking a deciduous oak tree *Quercus serrata* in relation to wood oldness and seasonality in three locations in the Central Japan. *Journal of Entomological Science*, **15**, 42–55.

Schiff, N.M., Goulet, H., Smith, D.R., Boudreault, C., Wilson, A.D. & Scheffler, B.E. (2012) Siricidae (Hymenoptera: Symphyta: Siricoidea) of the Western Hemisphere. *Canadian Journal of Arthropod Identification*, **21**, 1–305. (PDF version). Published on 6 July 2012 [WWW document]. URL http://www.biology.ualberta.ca/bsc/ejournal/sgsbws_21/sgsbws_21.html [accessed on 5 January 2014].

Stone, W.D., Nebeker, T.E. & Gerard, P.D. (2007) Host plants of *Xylosandrus mutilatus* in Mississippi. *Florida Entomologist*, **90**, 191–195.

Švihra, P. & Koehler, C.S. (1981) Attraction of flying *Scolytus multistriatus* to cut wood of three elm species in California. *Environmental Entomology*, **10**, 565–566.

Turnbow, R.H. & Franklin, R.T. (1980) Flight activity by Scolytidae in the northeast Georgia Piedmont (Coleoptera). *Journal of the Georgia Entomological Society*, **15**, 26–37.

Turnbow, R.H. & Hovore, F.T. (1979) Notes on Cerambycidae from the southeastern U.S. (Coleoptera). *Entomological News*, **90**, 219–229.

Ulyshen, M.D. & Hanula, J.L. (2009) Habitat associations of saproxylic beetles in the southeastern United States: a comparison of forest types, tree species and wood postures. *Forest Ecology and Management*, **257**, 653–664.

Ulyshen, M.D. & Hanula, J.L. (2010) Patterns of saproxylic beetle succession in loblolly pine. *Agricultural and Forest Entomology*, **12**, 187–194.

USDA Forest Service (2011) *SRS – Forest Inventory and Analysis*. [WWW document]. URL http://srsfia2.fs.fed.us/states/state_information.shtml [accessed on 24 August 2014].

Wilson, L.F. (1960) *Reducing Pulpwood Losses from Borer Attacks by Shading Conventional Pulp Piles*. Lake States Forest Experiment Station Technical Note No. 583. 2 pp.

Wilson, L.F. (1962) Insect damage to field-piled pulpwood in northern Minnesota. *Journal of Economic Entomology*, **55**, 510–516.

Wood, S.L. (1982) *The Bark and Ambrosia Beetles of North and Central America (Coleoptera: Scolytidae), a Taxonomic Monograph*. Great Basin Naturalist Memoirs No. 6. Brigham Young University, Provo, Utah.

Wood, S.L. & Bright, D.E. (1992) A catalog of the Scolytidae and Platypodidae (Coleoptera), Part 1: taxonomic index. *Great Basin Naturalist Memoirs*, **13**(A): 1-834; (B): 835-1553.

Wright, J. & Cunningham, M. (2008) Sweetgum plantations for sawtimber, energy, pulp, and other uses. *Forest Landowner Journal*, 5/6, 26-28.

Accepted 23 November 2014
First published online 2 January 2015