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Ethanol and (–)-α-Pinene: Attractant Kairomones for Some Large Wood-Boring Beetles in Southeastern USA

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Abstract Ethanol and α-pinene were tested as attractants for large wood-boring pine beetles in Alabama, Florida, Georgia, North Carolina, and South Carolina in 2002–2004. Multiple-funnel traps baited with (−)-α-pinene (released at about 2 g/d at 25–28°C) were attractive to the following Cerambycidae: *Acanthocinus nodosus*, *A. obsoletus*, *Arhopalus rusticus nubilus*, *Asemum striatum*, *Monochamus titillator*, *Prionus pocularis*, *Xylotrechus integer*, and *X. sagittatus sagittatus*. *Buprestis lineata* (Buprestidae), *Alaus myops* (Elateridae), and *Hylobius pales* and *Pachylobius picivorus* (Curculionidae) were also attracted to traps baited with (−)-α-pinene. In many locations, ethanol synergized attraction of the cerambycids *Acanthocinus nodosus*, *A. obsoletus*, *Arhopalus r. nubilus*, *Monochamus titillator*, and *Xylotrechus s. sagittatus* (but not *Asemum striatum*, *Prionus pocularis*, or *Xylotrechus integer*) to traps baited with (−)-α-pinene. Similarly, attraction of *Alaus myops*, *Hylobius pales*, and *Pachylobius picivorus* (but not *Buprestis lineata*) to traps baited with (−)-α-pinene was synergized by ethanol. These results provide support for the use of traps baited with ethanol and (−)-α-pinene to detect and monitor common large wood-boring beetles from the southeastern region of the USA at ports-of-entry in other countries, as well as forested areas in the USA.

Keywords Cerambycidae · *Xylotrechus* · *Monochamus* · *Acanthocinus* Curculionidae · *Hylobius* · *Pachylobius* · Elateridae · *Alaus* · Ethanol α-Pinene · Kairomone · Exotics

Introduction

Introductions of bark and wood-boring beetles via the movement of solid wood packing materials used in crating and securing cargo for shipping are common (Hoebeke, 1994; Haack and Cavey, 2000; Haack, 2001). From 1996 to 1998, most

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interceptions of beetles at ports-of-entry in the USA were associated with solid wood packing material (USDA APHIS and Forest Service, 2000). Coleoptera accounted for 94% of all pest interceptions with the Cerambycidae accounting for 37% of all beetle interceptions. The risk of invasive species of Cerambycidae moving between continents and countries is particularly high because of the cryptic nature of adults and larvae (Allison et al., 2004).

The impacts of Cerambycidae can be varied, ranging from beneficial as primary agents of nutrient recycling within forested stands (Hanks, 1999; Allison et al., 2004) to damaging in terms of social, economic, and environmental values (Liebhold et al., 1995). The mining activities of larvae result in large-diameter holes and tunnels in wood that can translate into significant levels of degrading damage to forestry products (Safranyik and Raske, 1970; Cerezke, 1977). Several species of long-horned beetles (*Monochamus* spp.) are known vectors of a wilting disease caused by the pine wood nematode *Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickel (Tylenchida: Aphenlenchoididae) (Wingfield et al., 1982; Linit, 1988). Introduction of the pine wood nematode into Japan in the early 1900s resulted in numerous epidemics of pine wilt on 28% of the pine forests by 2000 (Mamiya, 2003). Since 1996, the Asian long-horned beetle *Anoplophora glabripennis* (Motschulsky) has killed thousands of high-value urban trees in Illinois, New York, New Jersey, and Ontario with the cost of eradication and tree restoration expected to exceed US$300 million by 2009 (USDA Forest Service, 2005). Similarly, the brown spruce borer *Tetropium fuscum* (Fabricius) has become established in Nova Scotia, killing significant numbers of red spruce *Picea rubens* Sargent in park lands near Halifax (Natural Resources Canada, 2005). It is likely that even more introductions will occur because of increases in the movement of solid wood packing material associated with expected increases in international trade (USDA APHIS and Forest Service, 2000).

One common trapping protocol used for wood borers at ports-of-entry and forest monitoring sites in the USA employs multiple funnel or intercept traps baited with devices releasing ethanol and (−)-α-pinene at fairly high rates (1–2 g/d at 20–25°C; USDA Forest Service, 2001). In Ontario, traps baited with ethanol and (±)-α-pinene were attractive to various species of Cerambycidae, including *Monochamus scutellatus* (Say) and *Xylotrechus undulatus* (Say) (Chénier and Philogène, 1989). In British Columbia, *Xylotrechus longitarsis* Casey was attracted to traps baited with ethanol and (−)-α-pinene (Morewood et al., 2002), whereas *Monochamus notatus* (Drury) and *M. scutellatus* were attracted to traps baited with ethanol and a blend of seven monoterpenes that included (−)-α-pinene (Allison et al., 2001).

My objective was to assess the efficacy of standard commercially available ethanol and (−)-α-pinene lures used with multiple-funnel traps in capturing the following common large (>8 mm in length) Cerambycidae in the southeastern USA: *Monochamus titillator* (Fabricius), *Xylotrechus sagittatus sagittatus* (Germar), *X. integer* (Haldeman), *Acanthocinus nodosus* (Fabricius), *A. obsoletus* (Olivier), *Arophalus rusticus nubilus* (LeConte), *Asemum striatum* (L.), and *Prionus pocularis* Dalman. The goal was to verify that traps baited with the combination of the two lures were as effective as, if not better than, traps baited solely with one lure over a broad range in the South: eight National Forests in five Southern states. Previous studies on the attractiveness of ethanol and monoterpenes to Cerambycidae in the USA have largely been restricted to Florida with some recent tests in South Dakota.

In Florida, Fatzinger (1985), Fatzinger et al. (1987), and Phillips et al. (1988) found that the combination of ethanol and turpentine was attractive to various species of

pine Cerambycidae; however, these studies did not incorporate blank controls. Moreover, the use of turpentine in these studies is a concern because the monoterpene composition of turpentine can vary widely depending on the species and location of pines used in producing turpentine (Mirov, 1961; Smith, 2000). The main monoterpene in one of the Florida studies (and likely the other two as well) was α-pinene (Phillips et al., 1988). In South Dakota, Costello (2005) found that traps baited with ethanol and α-pinene were attractive to the cerambycids *Acanthocinus obliquus* (LeConte), *A. spectabilis* (LeConte), *Acmaeops proteus* (Kirby), and *Monochamus clamator* (LeConte); however, traps baited solely with α-pinene were not tested.

I also monitored the responses of the following species of saproxylic beetles commonly found in southern pine stands: *Buprestis lineata* Fabricius (Buprestidae), *Alaus myops* (Fabricius) (Elateridae), and the root weevils (Curculionidae) *Hylobius pales* Herbst and *Pachylobius picivorus* LeConte. Larval *Alaus myops* prey upon the larvae of pine woodborers, whereas larvae of the weevils *Hylobius pales* and *Pachylobius picivorus* feed in the roots and stumps of stressed or dying pines, often feeding on seedlings after removal of mature trees in plantations (USDA Forest Service, 1985). Ethanol synergized attraction of *Pachylobius picivorus* to turpentine in Wisconsin (Hunt and Raffa, 1989), whereas in Florida, ethanol synergized attraction of *Hylobius pales* but not *Pachylobius picivorus* to turpentine (Phillips et al., 1988). Erbilgin et al. (2001) found that *Hylobius pales* and *Pachylobius picivorus* were attracted to flight traps baited with α-pinene and ethanol in Louisiana and Wisconsin, although neither compound was tested alone.

Methods and Materials

Chemicals and Release Devices

Phero Tech Inc. (Delta, British Columbia, Canada) supplied sealed ultrahigh-release (UHR) plastic pouches containing either ethanol (150 ml) or α-pinene (200 ml; chemical purities >95%). The enantiomeric purity of α-pinene was >95% (–). The release rates of ethanol and α-pinene from UHR pouches were approximately 1 and 2 g/d, respectively, at 25–28°C (determined by weight loss).

Experimental Design

Eight experiments were conducted in 2002–2004 to evaluate the attractiveness of ethanol and (–)-α-pinene to large bark- and wood-boring beetles in the southeastern region of the USA. All eight experiments used the same design with one experiment conducted in mature pine stands on each of seven National Forests (NF) and one Experimental Forest (EF) in the South (Table 1). Disturbances occurred in stands used in experiments 1–3 and 6–8 during the 6-mo period preceding trap deployment but not in stands used in experiments 4–5. Prescribed fire was the disturbance agent in experiments 1–3 and 8, whereas salvage logging was used to remove a spot infestation of *Dendroctonus frontalis* Zimmerman in stands used in experiment 6; stands in experiment 7 were thinned with removal of woody material.

I employed a behavioral choice type of design in all experiments with treatments within a block grouped within the same area and traps spaced 10–15 m apart. My expectation was that the plumes of volatiles from each treatment would blend

Table 1 National forest (NF) and experimental forest (EF) locations, forest types, and trapping dates for experiments (2002–2004)

Experiment	Location	Tree species	Trapping dates
1	Ocala NF near Salt Springs FL	*Pinus palustris* Miller	26 February–26 May 2002
2	Osceola NF near Lake City FL	*Pinus palustris* and *P. elliottii* Engelmann	25 February–25 May 2002
3	Oconee NF near Juliette GA	*P. taeda* L.	12 June–8 August 2002
4	Blue Valley EF near Highlands NC	*P. strobus* L.	20 June–20 August 2002
5	Bankhead NF near Grayson AL	*P. taeda* and *Tsuga canadensis* (L.)	28 April–10 July 2003
6	Nantahala NF near Murphy NC	*P. strobus* and *P. echinata* Miller	1 May–14 August 2003
7	Sumter NF near Union SC	*P. taeda*	15 April–16 July 2003
8	Apalachicola NF near Tallahassee FL	*Pinus palustris* and *P. elliottii*	30 March–16 June 2004

together and spread over a single catchment area. In all experiments, 16 8-unit multiple-funnel traps (Phero Tech Inc.) were set in four linear blocks of four traps per block at each of the two sites. Blocks within site, and traps within blocks, were spaced 10–15 m apart, whereas sites were spaced 50–500 m apart. Each trap was suspended between trees by rope such that the bottom of each was 0.2–0.5 m above ground level. No trap was within 2 m of any tree. Collection cups contained 150–200 ml of pink propylene glycol solution (Peak RV and Marine Antifreeze, Old World Industries Inc., Northbrook, IL, USA) as a killing and preservation agent. Voucher specimens were deposited in the Entomology Collection, Museum of Natural History, University of Georgia (Athens, GA, USA). In each of the eight experiments, four treatments were randomly assigned to traps within each of eight replicate blocks as follows: (1) blank control; (2) ethanol alone; (3) α-pinene alone; and (4) ethanol + α-pinene. In all experiments, lures were replaced at intervals of 50–60 d.

Statistical Analyses

Data were analyzed only for locations where sufficient numbers of the following species were captured: *Acanthocinus nodosus*, *A. obsoletus*, *Arhopalus rusticus nubilus*, *Asemum striatum*, *Monochamus titillator*, *Prionus pocularis*, *Xylotrechus integer*, *X. s. sagittatus*, *Buprestis lineata*, *Alaus myops*, *Hylobius pales*, and *Pachylobius picivorus*. The data were analyzed with the SYSTAT (ver. 11.00.01) and the SigmaStat (ver. 3.01) statistical packages (SYSTAT Software Inc., Point Richmond, CA, USA). Trap catch data were transformed by $\ln(Y + 1)$ to remove heteroscedasticity (Pepper et al., 1997). Where possible, trap catch data in all experiments were subjected to two-way analysis of variance (ANOVA) using the following model components: (1) replicate, (2) ethanol, (3) α-pinene, and (4) ethanol × α-pinene. In a number of locations, mean trap catches of some species to one or two treatments (control and traps baited with ethanol alone) were zero with zero variance and a clear violation of the assumption of homoscedasticity (Cobb, 1998). In such

instances, data were subjected to one-sided t tests (using a Bonferroni correction for multiple comparisons), testing that individual treatment means were greater than zero (Reeve and Strom, 2004). Trap catch data where variances were homoscedastic for all treatments at all locations were subjected to two-way ANOVA using the following model components: (1) replicate nested within location, (2) location, (3) treatment, and (4) locations × treatment.

In all experiments, the Holm–Sidak multiple comparison procedure was used to compare means within a location for each species when treatment effect was significant at $P = 0.05$. When two treatments had means of zero with zero variance, then the two remaining means were compared by two-sided t test at $P = 0.05$.

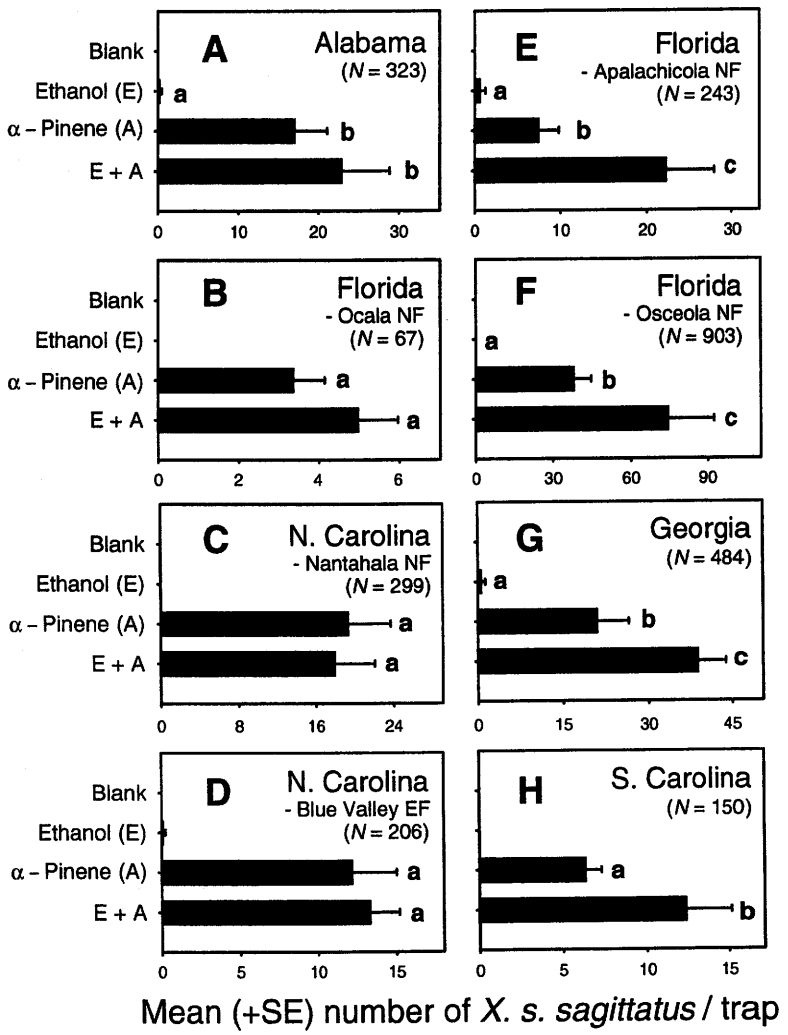

Fig. 1 Effects of ethanol and (−)-α-pinene on trap catches of *Xylotrechus s. sagittatus* (Cerambycidae) in southeastern USA. Means followed by the same letter are not significantly different at $P = 0.05$ [Holm–Sidak multiple comparison test for three treatments (A, E, F, and G) or t test for two treatments (B, C, D, and H)]. Treatments without a letter had zero catches of beetles

Synergism between ethanol and (−)-α-pinene in attracting beetles was indicated by satisfying two statistical conditions. First, ethanol and/or (−)-α-pinene had to be benign alone in attracting beetles to traps. Second, the combination of ethanol and (−)-α-pinene had to result in higher trap catches than ethanol or (−)-α-pinene alone.

Results

A total of 2675 *Xylotrechus s. sagittatus* (about 66% of all Cerambycidae caught) were captured from all eight locations (Fig. 1). The data for *X. s. sagittatus* could not

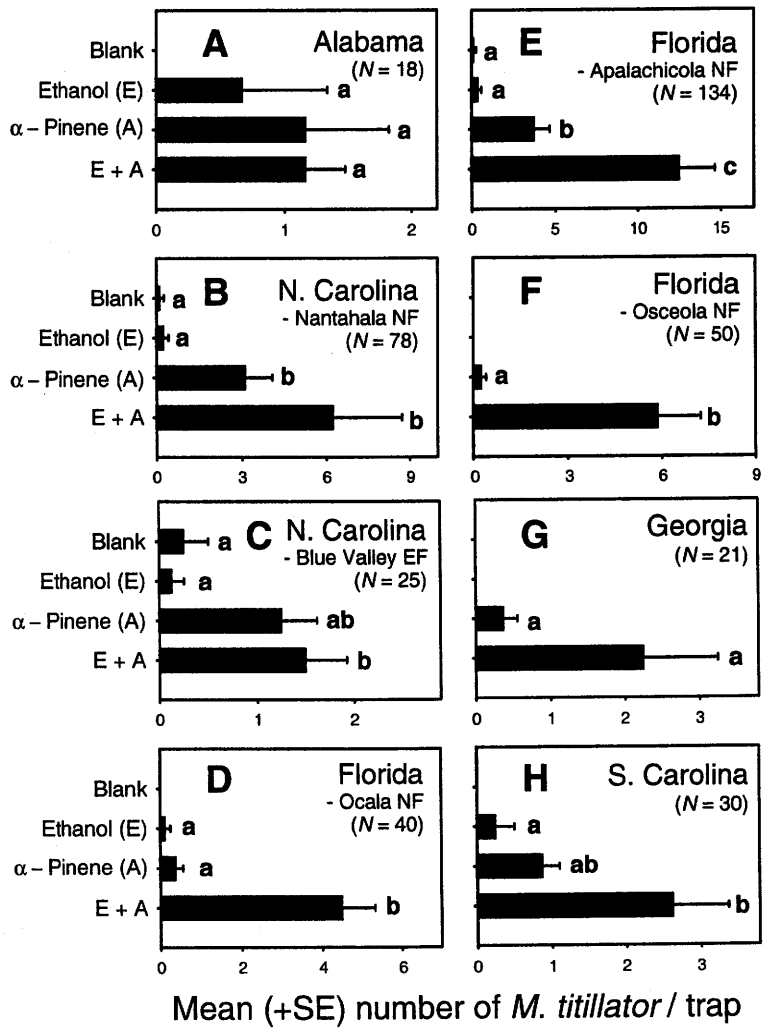

Fig. 2 Effects of ethanol and (−)-α-pinene on trap catches of *Monochamus titillator* (Cerambycidae) in southeastern USA. Means followed by the same letter are not significantly different at $P = 0.05$ [Holm–Sidak multiple comparison test for three to four treatments (A–E and H) or t test for two treatments (F and G)]. Treatments without a letter had zero catches of beetles

be analyzed by two-way ANOVA because no beetles were caught in control traps at any location. Catches of *X. s. sagittatus* in traps baited with (−)-α-pinene (with or without ethanol) were greater than zero at all locations (*t* tests, all $df = 7$, all $P < 0.01$). At some locations, ethanol seemed to affect trap catches of *X. s. sagittatus* as a synergist (Fig. 1). There were no beetles caught in traps baited solely with ethanol at four locations (Fig. 1), whereas catches in ethanol-baited traps at other four locations were not different from zero (*t* tests, all $df = 7$, all $P > 0.50$). However, when ethanol was added to traps baited with (−)-α-pinene, catches of *X. s. sagittatus* were significantly greater than those in traps baited with (−)-α-pinene in four locations: Georgia, South Carolina, and the Apalachicola and Osceola NF in Florida (Fig. 1E–H). At no location, was attraction of beetles to traps baited with (−)-α-pinene interrupted by ethanol.

Monochamus titillator was caught at all eight localities with a total capture of 396 beetles (about 10% of total Cerambycidae catch; Fig. 2). Trap catches of *M. titillator* were significantly affected by (−)-α-pinene but not ethanol in the Nantahala NF and Blue Valley EF in North Carolina, whereas both (−)-α-pinene and ethanol affected catches in the Apalachicola NF in Florida (Table 2). Two-way ANOVA could not be employed for *M. titillator* at the remaining five locations because no beetles were caught in control traps. Catches of *M. titillator* in traps baited solely with (−)-α-pinene were different from zero in South Carolina (*t* test, $df = 7$, $P = 0.006$) but not the remaining four locations (*t* tests, all $df = 7$, all $P > 0.10$). Ethanol had a synergistic effect on catches to traps baited with (−)-α-pinene at six of the eight locations (Fig. 2). Catches of *M. titillator* in traps baited with ethanol and (−)-α-pinene were significantly greater than those baited solely with (−)-α-pinene or ethanol alone at all three locations in Florida (Fig. 2D–F). In Alabama, Georgia, and South Carolina, catches of beetles in traps baited with ethanol and (−)-α-pinene were different from zero (*t* tests, all $df = 7$, all $P < 0.04$), whereas catches in traps

Table 2 Significant levels for ANOVA on effects of ethanol and (−)-α-pinene on beetle trap catches in southeastern USA

Species	Location	Rep	Ethanol (E)	α-Pinene (A)	E × A
Acanthocinus obsoletus	FL Osceola NF	0.592	0.003	<0.001	0.001
Alaus myops	FL Apalachicola NF	0.267	0.074	<0.001	0.117
	FL Ocala NF	0.818	0.922	<0.001	0.425
	FL Osceola NF	0.085	0.186	<0.001	0.345
	SC Sumter NF	0.003	0.441	<0.001	0.978
Arophalus r. nubilus	FL Osceola NF	0.001	0.074	<0.001	0.023
Asemum striatum	SC Sumter NF	0.045	0.666	<0.001	0.894
Buprestis lineata	FL Ocala NF	0.313	0.930	<0.001	0.621
	SC Sumter NF	0.141	0.268	0.001	0.565
Hylobius pales	FL Apalachicola NF	0.615	0.005	<0.001	<0.001
	FL Ocala NF	0.391	0.545	<0.001	0.545
	FL Osceola NF	0.610	<0.001	<0.001	0.001
Monochamus titillator	FL Apalachicola NF	0.778	0.001	<0.001	0.010
	NC Nantahala NF	0.291	0.470	<0.001	0.709
	NC Blue Valley EF	0.480	0.909	0.001	0.665
Pachylobius picivorus	FL Apalachicola NF	0.652	0.004	<0.001	0.005
	FL Ocala NF	0.688	0.009	<0.001	0.355
	FL Osceola NF	0.658	0.039	<0.001	0.187

baited with ethanol alone were not greater than zero (t tests, all $df = 7$, all $P > 0.50$). At no location, were catches in traps baited with (−)-α-pinene interrupted by ethanol (Fig. 2).

We caught a total of 187 *Acanthocinus obsoletus* at four locations (Fig. 3A–D). (−)-α-Pinene had a significant effect on *A. obsoletus* in the Osceola NF (Table 2) with catches in traps baited solely with (−)-α-pinene greater than those in blank

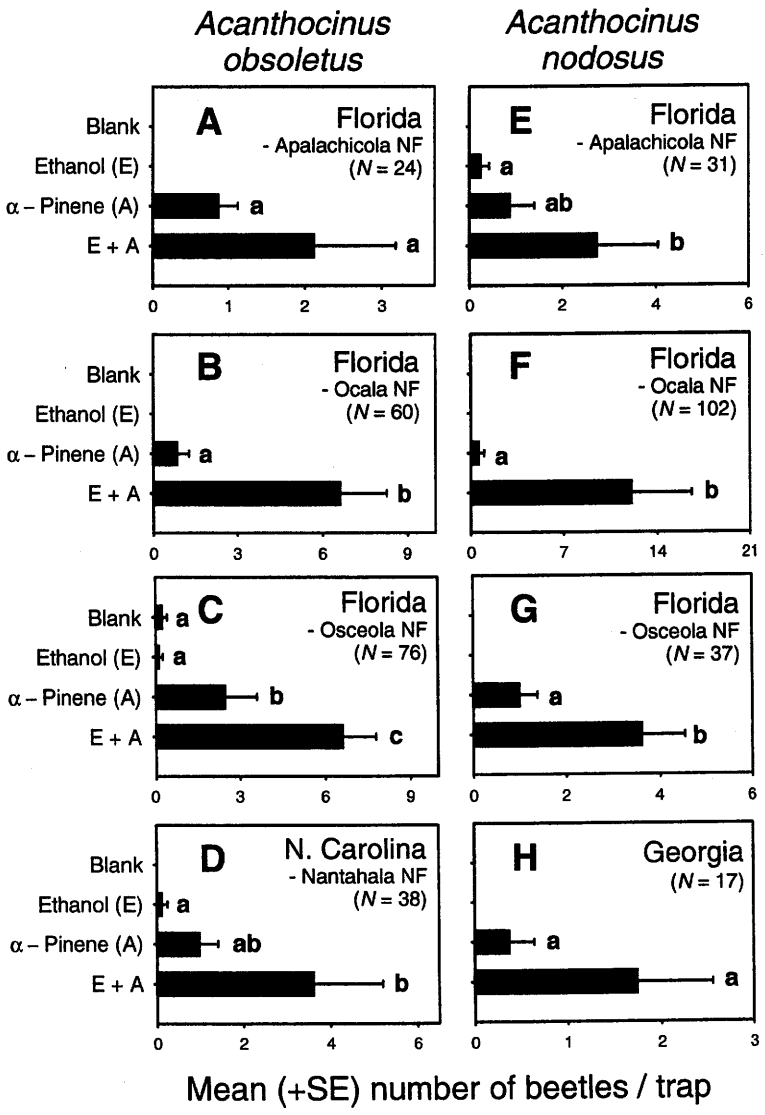

Fig. 3 Effects of ethanol and (−)-α-pinene on trap catches of *Acanthocinus obsoletus* (A–D) and *A. nodosus* (E–H) (Cerambycidae) in southeastern USA. Means followed by the same letter are not significantly different at $P = 0.05$ [Holm–Sidak multiple comparison test for three to four treatments (C–E) or t test for two treatments (A, B, and F–H)]. Treatments without a letter had zero catches of beetles

control traps (Fig. 3C). *Acanthocinus obsoletus* was not captured in control traps at the remaining three locations. Catches of *A. obsoletus* in traps baited with (−)-α-pinene were greater than zero in the Apalachicola NF (*t* test, $df = 7$, $P = 0.03$) but not in the Ocala and Nantahala NF (*t* tests, $df = 7$, $P = 0.068$ and 0.060, respectively). In contrast, catches of beetles in traps baited with ethanol and (−)-α-pinene were greater than zero in all three locations (*t* tests, all $df = 7$, all $P < 0.04$; Fig. 3A, B, D). Catches in traps baited solely with ethanol were not greater than zero in the Nantahala NF (*t* test, $df = 7$, $P = 0.526$); none were caught in ethanol-baited traps in the Apalachicola and Ocala NF (Fig. 3A, B). Catches of *A. obsoletus* in traps baited with (−)-α-pinene were synergized by adding ethanol lures at two of the three Florida locations (Fig. 3B, C).

We caught a total of 198 *Acanthocinus nodosus* at four locations (Fig. 3E–H). No beetles were captured in control traps at all four locations. Catches of *A. nodosus* in traps baited solely with (−)-α-pinene were greater than zero in the Osceola NF (*t* test, $df = 7$, $P = 0.028$) but not at the other three locations (*t* tests, all $df = 7$, all $P > 0.15$). As with *A. obsoletus*, ethanol had a synergistic effect on trap catches of *A. nodosus*. Catches of *A. nodosus* in traps baited with both ethanol and (−)-α-pinene were greater than zero at all four locations (*t* tests, all $df = 7$, all $P < 0.02$). Catches in traps baited solely with ethanol were not greater than zero in the Apalachicola NF (*t* test, $df = 7$, $P = 0.2566$); none were caught in ethanol-baited traps in the Ocala, Osceola, and Nantahala NF (Fig. 3F–H). Catches of *A. nodosus* in traps baited with (−)-α-pinene were increased by adding ethanol lures at two of the three Florida locations (Fig. 3F, G).

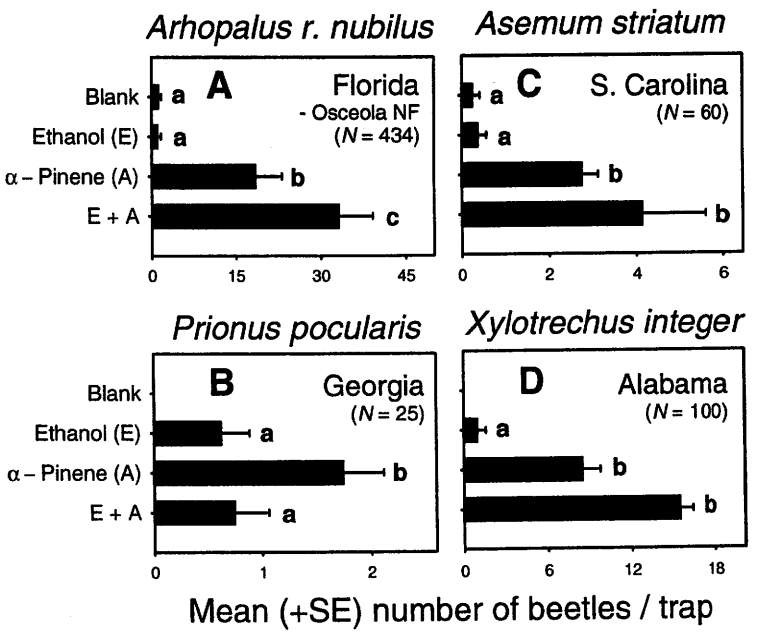

Fig. 4 Effects of ethanol and (−)-α-pinene on trap catches of *Arhopalus r. nubilus* (A), *Prionus pocularis* (B), *Asemum striatum* (C), and *Xylotrechus integer* (D) (Cerambycidae) in southeastern USA. Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak multiple comparison test). Treatments without a letter had zero catches of beetles

Catches of *Arhopalus r. nubilus* and *Asemum striatum* were significantly affected by (−)-α-pinene in two separate locations (Table 2). For both species, catches of beetles in traps baited with (−)-α-pinene alone caught more beetles than control traps (Fig. 4A, C). Ethanol had a synergistic effect on *A. r. nubilus* with catches in traps baited with both ethanol and (−)-α-pinene greater than those in traps baited solely with (−)-α-pinene; traps baited with ethanol alone were not attractive (Fig. 4A). Catches of *Xylotrechus integer* in traps baited with (−)-α-pinene (with or without ethanol) were greater than zero (*t* tests, all $df = 3$, all $P < 0.002$), whereas catches in traps baited solely with ethanol were not greater than zero (*t* test, $df = 3$, $P = 0.273$). Catches of *Prionus pocularis* in traps baited with (−)-α-pinene were greater than zero (*t* test, $df = 7$, $P < 0.001$), whereas catches in traps with the remaining treatments were not greater than zero (*t* tests, all $df = 7$, all $P > 0.059$), both of which were significantly less than catches in traps baited solely with (−)-α-pinene (Fig. 4B).

Buprestids were not common with only one species captured in numbers sufficient for analyses. *Buprestis lineata* were represented in trap catches from six locations with a total capture of 348 beetles (Fig. 5). In South Carolina and the Ocala NF in Florida, catches of *B. lineata* were significantly affected by (−)-α-pinene, but not

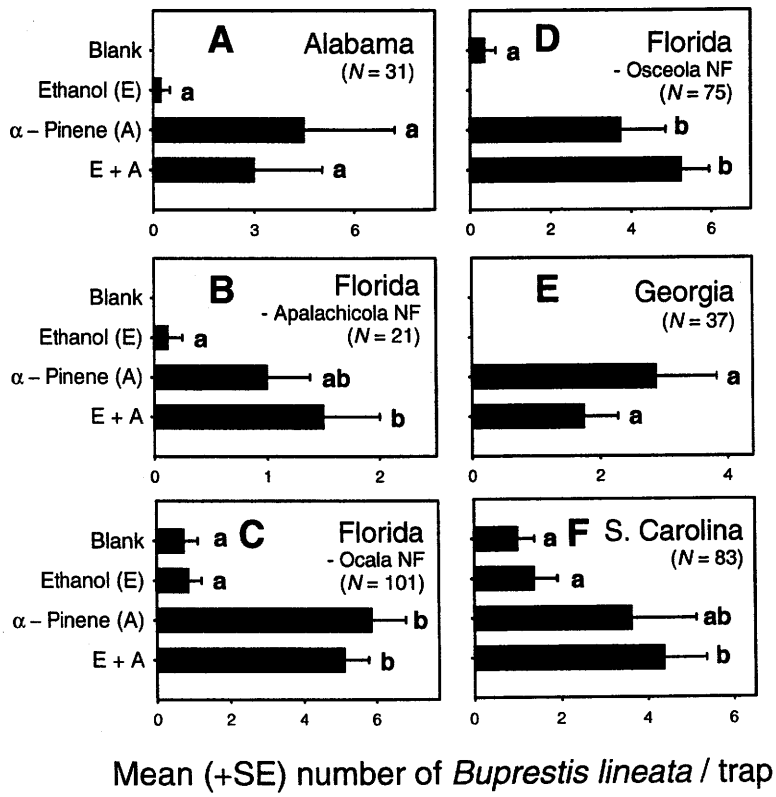

Fig. 5 Effects of ethanol and (−)-α-pinene on trap catches of *Buprestis lineata* (Buprestidae) in southeastern USA. Means followed by the same letter are not significantly different at $P = 0.05$ [Holm–Sidak multiple comparison test for three to four treatments (A–D, and F) or *t* test for two treatments (E)]. Treatments without a letter had zero catches of beetles

ethanol, with no significant interaction between ethanol and (−)-α-pinene (Table 2). In both locations, catches of beetles in traps baited with ethanol and (−)-α-pinene were greater than those in control traps (Fig. 5C, F). In the Apalachicola NF, catches of *B. lineata* in traps baited with ethanol and (−)-α-pinene were greater than zero (*t* test, $df = 7$, $P = 0.038$); the opposite was not true for catches in the remaining two treatments (*t* tests, all $df = 7$, all $P > 0.056$). In the Osceola NF (Florida), catches of *B. lineata* in traps baited with (−)-α-pinene (with or without ethanol) were greater than those in control traps (Fig. 5D). Catches of beetles in traps baited with (−)-α-pinene (with or without ethanol) were greater than zero in Georgia (*t* test, all $df = 7$, all $P < 0.01$) but not Alabama (*t* tests, all $df = 3$, all $P > 0.17$). At no location, was there a difference between catches of *B. lineata* in traps baited solely with (−)-α-pinene and those baited with both (−)-α-pinene and ethanol.

A total of 672 *Alaus myops* were captured in four locations (Fig. 6). Trap catches of *A. myops* in South Carolina and the three locations in Florida were affected by (−)-α-pinene (Table 2). At all four locations, traps baited with (−)-α-pinene (with or without ethanol) caught more beetles than control traps or traps baited solely with ethanol (Fig. 6). There was no significant interaction between location and treatment on catches of *A. myops* ($F = 0.912$, $df = 9,84$, $P = 0.519$). Traps baited with ethanol were not attractive to *A. myops*, although attraction of beetles to (−)-α-pinene was increased by ethanol at two of the Florida locations (Fig. 6A and C).

Two common pine root weevils *Hylobius pales* and *Pachylobius picivorus* were caught in sufficient numbers in Florida for analyses (total of 257 and 1616 beetles, respectively; Fig. 7). (−)-α-Pinene had a significant effect on catches of both species at all three locations in Florida (Table 2). Catches of *Pachylobius picivorus* in traps baited with (−)-α-pinene (with or without ethanol) were significantly greater than those in control traps at all three locations (Fig. 7A–C). The same was true for catches of *Hylobius pales* in the Osceola NF and the Ocala NF but not at the

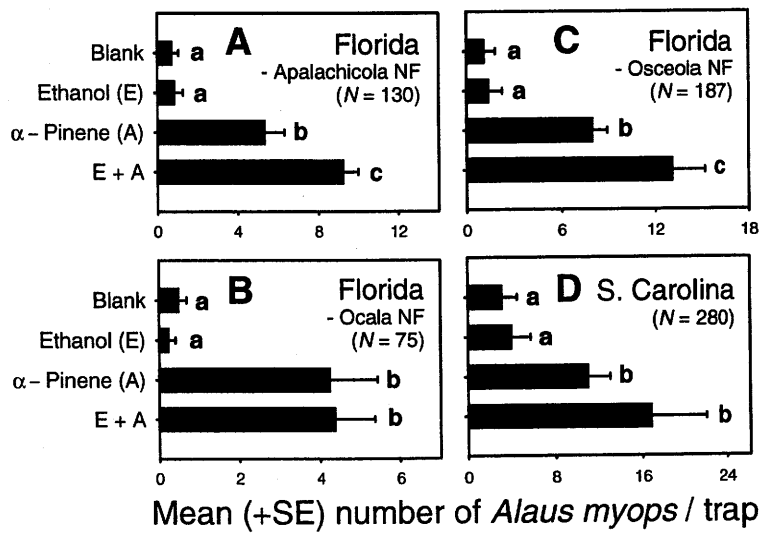

Fig. 6 Effects of ethanol and (−)-α-pinene on trap catches of *Alaus myops* (Elateridae) in South Carolina and northern Florida. Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak multiple comparison test)

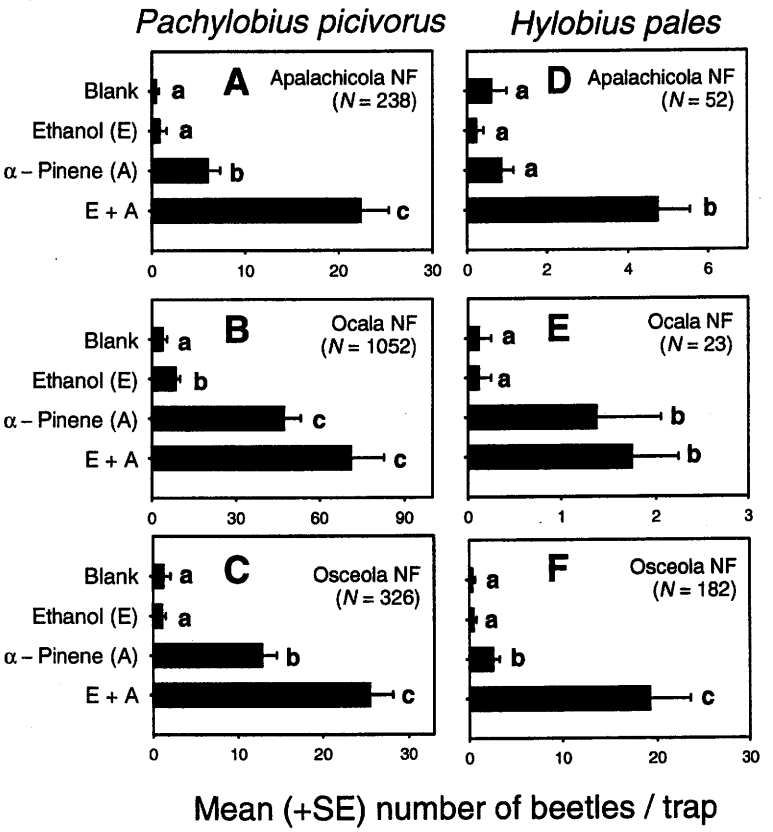

Fig. 7 Effects of ethanol and (−)-α-pinene on trap catches of *Pachylobius picivorus* (A–C) and *Hylobius pales* (D–F) (Curculionidae) in northern Florida. Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak multiple comparison test)

Apalachicola NF (Fig. 7E and F). There was an interaction between treatments and location on catches of *Hylobius pales* in Florida ($F = 6.830$, $df = 6,21$, $P < 0.001$) but not on catches of *Pachylobius picivorus* ($F = 1.704$, $df = 6,21$, $P = 0.135$). At all locations, catches of both species in traps baited with ethanol and (−)-α-pinene were greater than those in control traps. However, the effect of ethanol on attraction of both weevils to (−)-α-pinene was synergistic in the Apalachicola and Osceola NF but not in the Ocala NF (Fig. 7A–F).

Discussion

Almost all of the wood-boring beetle species caught in this study breed in recently cut, wind-thrown, fire-killed, insect-killed, or dying pines as well as pine logs and stumps (USDA Forest Service, 1985; Yanega, 1996). One commonality to these situations is the release of resin by pines that thwarts further damage or invasions by insects or pathogens (Raffa, 1992; Trapp and Croteau, 2001). α-Pinene is a common and predominant monoterpene in the resin of most southern pines (Smith, 2000).

Xylotrechus integer breeds in stands of balsam fir *Abies balsamea* (L.) and eastern hemlock (Yanega, 1996); one of the sites used in Alabama contained a large component of mature eastern hemlock. However, α-pinene is a common monoterpene in eastern hemlock as well (Broeckling and Salom, 2003). Therefore, it is not surprising that traps baited with (−)-α-pinene were attractive to several species of pine-inhabiting wood borers throughout the southeastern USA. Selection should favor those individuals that capitalize on any cues that facilitate the quick invasion of suitable yet ephemeral and patchy resources (Atkins, 1966).

In many locations, attraction of four species of Cerambycids as well as the weevils *Hylobius pales* and *Pachylobius picivorus* and the wood-borer predator *Alaus myops* to traps baited with (−)-α-pinene was increased by the addition of ethanol (Figs. 1E–H, 2D–F, H, and 3B, C, F, G). The exceptions were *Prionus pocularis* (Fig. 4B), *Asemum striatum* (Fig. 4C), and *Xylotrechus integer* (Fig. 4D). Ethanol concentrations of woody tissues can rise dramatically in stressed or damaged trees because of anaerobic respiration (Moeck, 1970; Kelsey, 1996; Kelsey and Joseph, 2001). In cases such as those arising from fire damage, such cues are likely short lived and may be important for species that invade trees soon after injury (Kelsey and Joseph, 2003).

The synergistic effect of ethanol on the attraction of many of the species to traps baited with (−)-α-pinene was evident in many but not all locations. The apparent lack of synergy at some locations may be random events because of low numbers of beetles captured at these locations. Alternatively, it may represent geographical variation in the use of host attractants for these species, reflecting some variation in host preferences. Our studies were conducted in forests that varied widely in species composition (Table 1), and there is considerable variation in chemical and enantiomeric composition of resin among pine species in North America (Smith, 2000). The addition of other components, such as β-pinene or 3-carene, may be important in some locations. Enantiomeric composition of α-pinene may also be important (Allison et al., 2004). Erbilgin et al. (2001) found that *Pachylobius picivorus* were attracted equally to traps baited with ethanol and (+)-α-pinene as to traps baited with ethanol and (−)-α-pinene in Louisiana. However, they also found that catches of *H. pales* were lower in traps baited with ethanol and (+)-α-pinene than in traps baited with ethanol and (−)-α-pinene.

Managers of agencies responsible for interceptions of exotic species at ports-of-entry face a dilemma in choosing between general lures that attract a broad array of bark and wood-boring beetles and species-specific lures for a trapping program. Traps baited with commercial lures releasing ethanol and (−)-α-pinene at high rates are attractive to many common large wood-boring beetles from the southeastern USA (Figs. 1, 2, 3, 4, 5, 6, and 7) and other regions of North America (Phillips et al., 1988; Chénier and Philogène, 1989; Hunt and Raffa, 1989; Erbilgin et al., 2001; Allison et al., 2001; Morewood et al., 2002; Costello, 2005). Ethanol does not seem to interrupt attraction of these species to traps baited with (−)-α-pinene.

Species-specific attractants, such as pheromones, may be much more attractive than ethanol and (−)-α-pinene albeit to a smaller number of species (Billings and Cameron, 1984; Allison et al., 2003). The bark beetle pheromones ipsenol and ipsdienol are attractive to bark beetles as well as various species of sawyer beetles (*Monochamus* spp.) in North America, but few other cerambycids (Billings and Cameron, 1984; Billings, 1985; Miller and Borden, 1990; Allison et al., 2001, 2003; De Groot and Nott, 2004; Miller and Asaro, 2005). However, as the absolute

efficiency of such lures in trapping populations of any species of bark- and wood-boring beetles is largely unknown, the relative increase in attraction to species-specific lures may not be that significant in forested areas. The relative increase in efficiency may be more important at ports-of-entry than in forested areas simply because of the lack of competing sources of attractants on average. Therefore, adding bark beetle pheromone lures to the combination of ethanol and (−)-α-pinene may provide an optimal solution by maintaining a low level of attraction to broad range of wood borers while maintaining a high level of attraction to some key species, such as bark beetles and sawyer beetles.

The issue of trap efficacy is an important one for risk assessments of exotic invasive species. We need to determine the proportion of a population caught by baited funnel traps to predict the real risk at that moment. We also need to know the variation in trapping efficacy caused by various environmental parameters, such as population levels, competing sources of attractants, and the lack of vertical silhouettes. Resolution of all these issues should lead to an increased ability in assessing risk and directing containment operations in an efficacious and timely manner.

The knowledge obtained by our work provides quarantine officials and forest managers in other countries with support for using traps baited with ethanol and (−)-α-pinene for capturing Cerambycidae native to the southeastern USA that may be inadvertently transported to other countries. In addition, such knowledge can be used at processing plants and ports-of-departure within the USA to ensure certification of products free of wood borers. Finally, such knowledge supports the use of traps baited with ethanol and (−)-α-pinene in monitoring the ecological impacts of wildfire and silvicultural treatments in southern forests (Hanula et al., 2002).

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