Attaching Lures to Multiple-Funnel Traps Targeting Saproxylic Beetles (Coleoptera) in Pine Stands: Inside or Outside Funnels?

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ABSTRACT We conducted two field trapping experiments with multiple-funnel traps in 2008 and one experiment in 2010 to determine the effects of lure placement (inside or outside funnels) on catches of saproxylic species of beetles (Coleoptera). The experiments were conducted in southern pine (*Pinus* spp.) stands in central Georgia using combinations of ethanol, α-pinene, ipsenol, and ipsdienol lures. We report on a modification to the multiple-funnel trap that allows placement of large lures inside the confines of the funnels with minimal blockage. In general, catches of five species of common longhorn beetles (Cerambycidae), two species of regeneration weevils (Curculionidae), four species of bark beetles (Curculionidae: Scolytinae), and seven species of beetle predators and ectoparasites (Cleridae, Histeridae, Tenebrionidae, Trogossitidae, and Zopheridae) were higher in funnel traps with lures attached inside the funnels than in those with lures attached outside of the funnels. Catches of the remaining species were unaffected by lure placement. In no instance were catches of any species lower in funnel traps with lures attached inside the funnels than in those with lures attached outside of the funnels. For most species, catches in modified funnel traps with ethanol, α-pinene, ipsenol, and ipsdienol lures attached inside funnels were comparable with those in cross-vane panel traps.

KEY WORDS Cerambycidae, Cleridae, Histeridae, Scolytinae, Trogossitidae

The Lindgren multiple-funnel trap was originally designed for mass capture of ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) at wood-processing areas (Lindgren and Fraser 1994). The trap consists of black, plastic funnels arranged vertically over a collection cup (Lindgren 1983). Multiple-funnel traps are routinely used in national programs such as the Cooperative Agricultural Pest Survey (CAPS) and the Early Detection and Rapid Response (EDRR) program for the detection of exotic and invasive saproxylic beetles, particularly bark and ambrosia beetles (Rabaglia et al. 2008, Jackson et al. 2010). Two standard lures in these national programs are large plastic pouches that release ethanol and α-pinene at high rates. Typically, these lures are attached on the outside of the funnels because of the large size of the lures (40 × 7 cm and 35 × 5 cm for the α-pinene and ethanol lures, respectively). Placing such lures inside the funnels of a trap would block the inside holes (diameter = 5 cm) of the funnels thereby defeating the purpose of the trap.

However, Lindgren (1983) recommended placement of lures inside the funnels of the trap rather than outside the funnels based on smoke studies conducted in a wind tunnel. He found that smoke dispersed up through the trap, and out from each funnel when a smoke source was placed inside the lower funnels but eluted from a single point source when placed outside the funnels. Furthermore, the odor plume was not affected by wind direction when lures were placed inside the trap. The effect of lure placement (inside or outside funnels) on funnel traps on catches of ambrosia beetles was never documented.

Our objective was to determine the effect of lure placement (inside or outside of funnels) on catches of bark and wood boring beetles in multiple-funnel traps baited with various combinations of ethanol, α-pinene, ipsenol, and ipsdienol. Such blends are broadly attractive to a diverse group of saproxylic beetles in the southeastern United States (Miller 2006, Miller and Rabaglia 2009, Miller et al. 2011). In addition, we compared catches in modified funnel traps to those in cross-vane panel traps. Black, plastic cross-vane panel traps have gained popularity for trapping larger woodboring species such as longhorn beetles (Cerambycidae) and woodwasps (Hymenoptera: Siricidae) (Dodds and de Groot 2011). Generally, cross-vane panel traps of various designs outperform stan-

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Fig. 1. Cross-vane panel trap (far left), white-lidded 8-unit multiple-funnel trap (second from left), black-lidded nonmodified 10-unit multiple-funnel trap (second from right), and black-lidded modified 10-unit multiple-funnel trap (far right). (Online figure in color.)

dard multiple-funnel traps for species of large Cerambycidae such as *Monochamus obtusus* Casey, *Monochamus titillator* (F.), *Monochamus scutellatus* (Say), *Xylotrechus longitarsis* Casey, *Asemum striatum* (L.), and *Acanthocinus nodosus* (F.) (McIntosh et al. 2001, Morewood et al. 2002, Czokajlo et al. 2003, de Groot and Nott 2003, Dodds et al. 2010, Miller and Crowe 2011, Graham et al. 2012).

Materials and Methods

We conducted two trapping experiments in 2008 and one trapping experiment in 2010 using various types of traps (Fig. 1). All three experiments were conducted in mature stands of loblolly pine, *Pinus taeda* L. and shortleaf pine, *P. echinata* Miller on the Oconee National Forest. Experiments 1 and 2 were conducted 24 July through 29 August 2008 and 29 August through 7 October 2008, respectively, at the same site (33.3796° N; 83.4107° W; 153 m ASL) near Eatonton, GA, whereas experiment 3 was conducted 15 June through 2 September 2010 at a site (33.2433° N, 83.5075° W; 163 m ASL) near Stanfordville, GA. Both stands had experienced prescribed burning during the previous year.

Contech Enterprises (Victoria, BC) supplied cross-vane panel traps and white-lidded eight-unit multiple-funnel traps (Fig. 1) as well as ultra-high release (UHR) pouches containing either ethanol or α-pinene, and bubble-cap lures containing racemic ipsenol or racemic ipsdienol (chemical purities ≥95%). The enantiomeric purity of α-pinene was >90% (–). The release rates of ethanol and α-pinene from UHR pouches were ≈1 and 2 g/d, respectively, at 23°C whereas ipsenol and ipsdienol released at ≈0.2 and 0.1 mg/d, respectively, at 21°C. Rates were provided by the manufacturer. We constructed low release bottle lures of α-pinene by filling closed 15 ml low-density polyethylene screw-cap Boston round bottles (Qorpak, Bridgeville, PA) with α-pinene (enantiomeric purity >95% [–]; chemical purity >95%; Sigma–Aldrich, St. Louis, MO). Release rates of α-pinene from the 15-ml bottle lures was ≈160 mg/d at 25–27°C (determined gravimetrically).

Synergy Semiochemicals Corporation (Burnaby, BC) supplied 8- and 12-unit black-lidded multiple-funnel traps. We created 10-unit traps (Fig. 1) by transferring two funnels from each 12-unit trap to each 8-unit trap. Some 10-unit traps were modified as follows to allow placement of UHR pouches inside funnels (Fig. 1): 1) the bottom opening of each bottom funnel of each trap was enlarged to the bayonet mount for the collection cup, an increase in diameter from 5 to 7.5 cm; 2) the bottom opening of all remaining funnels was increased from 5 to 12 cm; 3) the locking nut affixing the eyebolt to each trap canopy was re-

placed with an eyelet adapter for threaded rod (eye nut style, ¼ in.; McMaster–Carr, Atlanta, GA); and 4) a portion (7 × 12 cm) of the top funnel affixed to the canopy was removed to allow direct access to the eyelet adapter for hanging UHR pouches.

Modified 10-unit traps were long enough to hang both ethanol and α-pinene lures, one above the other inside the modified funnels without impinging into the collection cup. Uppermost in the trap was the α-pinene UHR pouch with the ethanol UHR pouch hung on the bottom of the α-pinene lure. In nonmodified 10- and 8-unit funnel traps, both pouches were hung on the funnel fourth from the top on separate legs of the funnel. In panel traps, the two pouches were hung together at the attachment center in the middle of the trap, hanging in the open space within the panels. Ipsenol and ipsdienol lures were hung on the third and fourth funnel from the bottom in all funnel traps, respectively, and at the same attachment position as the ethanol and α-pinene lures in the panel traps.

We used a behavioral choice type of experiment in a randomized, complete block design for all three experiments. In each experiment, ten replicate blocks of traps were set in pine stands with one of each treatment type per block. Traps were set 8–12 m apart within a block whereas blocks were set 12–25 m apart. Each trap was suspended between trees by rope such that the collection cup was 0.2–0.5 m above ground level and no trap was within 2 m of any tree. Collection cups contained ≈150 ml of a pink solution of propylene glycol and water (Splash RV and Marine Antifreeze, Fox Packaging Co., St. Paul, MN) as a killing and preservation medium (Miller and Duerr 2008).

In experiment 1, we compared catches of beetles in black-lidded nonmodified 10-unit traps to those in modified 10-unit traps. All traps in experiment 1 were baited with ethanol and α-pinene UHR pouches as well as ipsenol and ipsdienol bubble-cap lures. Lures were attached to the outside of the funnels in nonmodified traps and inside the funnels in modified traps. In experiment 2, we compared catches in white-lidded eight-unit funnel traps with lures placed on the outside of the funnels to those in traps with lures placed inside the funnel. All traps in experiment 2 were baited with ipsenol and ipsdienol bubble-cap lures as well as α-pinene bottle lures. The latter was hung on the fifth funnel from the bottom.

In experiment 3, we used the following three treatments: 1) modified 10-unit traps with lures placed outside of the funnels; 2) modified 10-unit traps with lures placed inside the funnels; and 3) panel traps with lures placed centrally. All traps in experiment 3 were baited with ethanol and α-pinene UHR pouches as well as ipsenol and ipsdienol bubble-cap lures (same lure combination used in experiment 1).

Data for species with sufficient total numbers of captured beetles ($N > 35$) were analyzed with the SigmaStat (ver. 3.01) statistical package (SYSTAT Software Inc., Point Richmond, CA). In experiments 1 and 2, trap catches for each species were analyzed with a paired *t*-test using blocks to denote pairs. In experiment 3, data were subject to analysis of variance (ANOVA) using the following model components: 1) replicate block and 2) treatment. When a treatment effect was significant at $P \leq 0.05$, the Holm–Sidak multiple comparison procedure was used to compare means of each species among trap types (Glantz 2005). Normality and homogeneity of variances were verified as part of the statistical procedure. We determined the species of all Cerambycidae captured in experiment 3 to better evaluate the suitability of treatments for Cerambycidae in general.

Species identifications of Cerambycidae were determined using Lingafelter (2007). We found separation of *Monochamus carolinensis* (Olivier) from *M. titillator* to be difficult and inconsistent using characters noted by Lindsey and Chemsak (1984) and Lingafelter (2007). Therefore, we designated *M. titillator*, *M. carolinensis* and any possible hybrids, as *M. titillator* complex. The two species are broadly sympatric in pine stands throughout eastern North America (Lindsey and Chemsak 1984). Previously, Hopping (1921) noted that "In long series every variation in size, maculation and reduction of the spine into a blunt form may be found" and had placed *M. carolinensis* as a synonym of *M. titillator*. Species names and authors for all species were verified with the Integrated Taxonomic Information System on-line database (ITIS 2011). Voucher specimens were deposited in the Entomology Collection, Museum of Natural History, University of Georgia (Athens, GA).

Results

Experiment 1. Modified 10-unit traps baited with ethanol, α-pinene, ipsenol, and ipsdienol lures placed inside funnels caught significantly more Cerambycidae (Coleoptera) than nonmodified traps with lures placed outside of the funnels (Table 1). Mean catches of *A. nodosus*, *Acanthocinus obsoletus* (Olivier), *Astylopsis sexguttata* (Say), *M. titillator* complex, and *Xylotrechus sagittatus* (Germar) were increased by 108–428% when lures were placed inside funnels rather than outside the funnels. Catches of *Buprestis lineata* F. (Buprestidae) were unaffected by lure placement (Table 1).

Catch enhancement in traps with lures placed inside funnels was evident with the regeneration weevils *Hylobius pales* Herbst and *Pachylobius picivorus* LeConte (Curculionidae), as well as three species of bark beetles *Dendroctonus terebrans* (Olivier), *Hylastes salebrosus* Eichhoff, and *Ips calligraphus* (Germar) (Curculionidae: Scolytinae) (Table 1). Mean catches of these species were increased by 32–100% by placing lures inside funnels. Lure placement did not affect trap catches of the bark beetles *Hylastes tenuis* Eichhoff, *Ips avulsus* (Eichhoff), and *Ips grandicollis* (Eichhoff) and the ambrosia beetles *Gnathotrichus materiarius* (Fitch) and *Xyleborus* Eichhoff spp.

Lure position affected mean trap catches of several predator and ectoparasitic species of beetles as well (Table 1). Traps with lures inside funnels caught more *Platysoma* Leach spp. (Histeridae), *Corticeus* Piller & Mitterpacher spp. (Tenebrionidae), *Temnoscheila* (=*Temnochila*) *virescens* (F.) (Trogossitidae), and *Lasconotus* Erichson spp. (Zopheridae) than traps

Table 1. Catches of saproxylic beetles in modified (lures attached inside of funnels) and nonmodified (lures attached outside of funnels) 10-unit multiple-funnel traps baited with ethanol, α-pinene, ipsenol, and ipsdienol (experiment 1)

	N	Mean (± SE) no. of beetles/trap		
		Lures outside funnels	Lures inside funnels	*P* value (paired *t*-test)
Buprestidae				
Buprestis lineata	72	2.8 ± 0.5	4.4 ± 0.8	0.153
Cerambycidae				
Acanthocinus nodosus	**44**	**0.7 ± 0.3**	**3.7 ± 1.2**	**0.036**
Acanthocinus obsoletus	**206**	**5.5 ± 1.5**	**15.1 ± 1.7**	**0.004**
Astylopsis sexguttata	**91**	**2.1 ± 0.8**	**7.0 ± 0.9**	**0.001**
***Monochamus titillator* complex**	**509**	**16.5 ± 2.0**	**34.4 ± 4.9**	**0.002**
Xylotrechus sagittatus	**111**	**3.6 ± 1.0**	**7.5 ± 1.0**	**0.018**
Cleridae				
Thanasimus dubius	303	12.2 ± 1.6	18.1 ± 3.2	0.077
Curculionidae				
Hylobius pales	**302**	**10.4 ± 0.6**	**19.8 ± 3.8**	**0.029**
Pachylobius picivorus	**225**	**8.4 ± 1.1**	**14.1 ± 2.4**	**0.004**
Curculionidae: Scolytinae				
Dendroctonus terebrans	**849**	**29.4 ± 3.0**	**55.5 ± 4.8**	**0.001**
Hylastes salebrosus	**795**	**34.2 ± 2.2**	**45.3 ± 5.1**	**0.008**
Ips calligraphus	**57**	**1.9 ± 0.5**	**3.8 ± 0.5**	**0.016**
Gnathotrichus materiarius	154	6.4 ± 1.3	9.0 ± 3.5	0.524
Hylastes tenuis	577	25.5 ± 2.0	32.2 ± 2.3	0.067
Ips avulsus	1,231	60.3 ± 5.7	62.8 ± 7.7	0.798
Ips grandicollis	2,798	143.4 ± 10.3	136.4 ± 8.9	0.637
Xyleborus spp.	243	11.4 ± 1.0	12.9 ± 2.0	0.464
Histeridae				
***Platysoma* spp.**	**1,187**	**44.1 ± 4.2**	**74.6 ± 6.3**	**0.006**
Passandridae				
Catogenus rufus	51	2.8 ± 0.6	2.3 ± 0.5	0.557
Tenebrionidae				
***Corticeus* spp.**	**156**	**4.7 ± 1.0**	**10.9 ± 1.0**	**0.003**
Trogossitidae				
Temnoscheila virescens	**2,613**	**114.6 ± 7.0**	**146.7 ± 10.1**	**0.008**
Zopheridae				
***Lasconotus* spp.**	**1,999**	**66.1 ± 6.6**	**133.8 ± 20.8**	**0.005**

Species with significant differences in mean catches between treatments are bolded. *N*, total no. of beetles captured.

with lures outside the funnels. The increase in mean catches ranged between 28 and 132% for these species. Catches of *Thanasimus dubius* (F.) (Cleridae) and *Catogenus rufus* (F.) (Passandridae) were unaffected by lure placement.

Experiment 2. The abundance and diversity of species in trap catches were lower in experiment 2 than in experiment 1, likely because of such factors as smaller traps, lower release rate of α-pinene and lack of ethanol lures. Nonetheless, placing ipsenol, ipsdienol, and α-pinene lures inside funnels increased mean trap catches of *A. obsoletus*, *T. dubius*, *D. terebrans*, *H. tenuis*, and *I. grandicollis* compared with those in traps with lures placed outside the funnels (Table 2). The increase in mean catches ranged from 46 to 144%. Catches of *B. lineata*, *M. titillator* complex, *H. pales*, *H. salebrosus*, *I. avulsus*, *I. calligraphus*, *Xyleborus* spp., *Platysoma* spp., *Corticeus* spp., and *T. virescens* were unaffected by lure placement.

Experiment 3. In experiment 3, we captured 1,629 longhorn beetles representing 17 species with sufficient numbers of four species for statistical analyses (Table 3). Mean trap catches of all four species were significantly affected by treatments (Table 4). Placing ethanol, α-pinene, ipsenol, and ipsdienol lures inside funnels significantly increased mean catches of *M. titillator* complex, *X. sagittatus*, and *A. obsoletus* by 139–216% compared with those in funnel traps with lures outside the funnels (Fig. 2A–C). Lure position had no effect on mean catches of *Astylopsis* Casey spp. [*A. sexguttata* + *Astylopsis arcuata* (LeConte)] (Fig. 2D). For all four species, mean catches in cross-vane panel traps were significantly lower than those in funnel traps with lures inside the funnels but not those in funnel traps with lures outside the funnels. A similar preference profile was found for the buprestid, *B. lineata* (Fig. 2E) whereas mean catches of the click beetle, *Alaus myops* (F.) (Elateridae) were highest in panel traps (Fig. 2 F).

There was a significant treatment effect on catches of five species of bark beetles and one species of regeneration weevils (Table 4). Panel traps caught more *D. terebrans* than funnel traps with lures placed inside or outside funnels (Fig. 3A) whereas funnel traps (regardless of lure position) outperformed panel traps in catching *I. avulsus* (Fig. 3B). Mean catches of *Orthotomicus caelatus* (Eichhoff), *H. salebrosus*, *H. tenuis*, and *H. pales* where higher in funnel traps with lures inside funnels than in funnel traps with lures outside funnels (Fig. 3C–F). Panel traps performed as well as funnel traps with lures inside funnels in catching *O. caelatus*, *H. salebrosus*, and *H. tenuis* but not *H. pales*. Catches of *H. porculus*, *I. calligraphus*, and *I. grandicollis* were unaffected by treatments (Table 4)

Table 2. Catches of saproxylic beetles in eight-unit multiple-funnel traps baited with α-pinene, ipsenol, and ipsdienol lures attached outside and inside of funnels (experiment 2)

	N	Mean (± SE) no. of beetles/trap		*P* value (paired *t*-test)
		Lures outside funnels	Lures inside funnels	
Buprestidae				
Buprestis lineata	67	2.2 ± 0.7	4.5 ± 0.9	0.057
Cerambycidae				
Acanthocinus obsoletus	196	**5.7 ± 1.2**	**13.9 ± 1.6**	**<0.001**
Monochamus titillator complex	398	16.6 ± 1.9	23.2 ± 3.3	0.105
Cleridae				
Thanasimus dubius	**545**	**21.7 ± 3.0**	**32.8 ± 3.7**	**0.048**
Curculionidae				
Hylobius pales	72	3.7 ± 1.1	3.5 ± 0.9	0.885
Curculionidae: Scolytinae				
Dendroctonus terebrans	**122**	**4.4 ± 0.6**	**7.8 ± 1.3**	**0.038**
Hylastes tenuis	**254**	**9.4 ± 0.8**	**16.0 ± 2.2**	**0.030**
Ips grandicollis	**2,720**	**110.7 ± 7.2**	**161.3 ± 14.1**	**0.003**
Hylastes salebrosus	69	2.8 ± 0.6	4.1 ± 0.8	0.375
Ips avulsus	2,536	121.9 ± 15.0	131.7 ± 13.0	0.547
Ips calligraphus	75	3.0 ± 0.7	4.5 ± 0.8	0.264
Xyleborus spp.	80	2.6 ± 5.4	5.4 ± 1.2	0.202
Histeridae				
Platysoma spp.	324	12.5 ± 1.5	19.9 ± 3.5	0.072
Tenebrionidae				
Corticeus spp.	230	9.9 ± 1.9	13.1 ± 1.4	0.220
Trogossitidae				
Temnoscheila virescens	344	18.5 ± 1.7	15.9 ± 3.0	0.369
Zopheridae				
***Lasconotus* spp.**	**943**	**32.4 ± 4.6**	**61.9 ± 6.4**	**0.002**

Species with significant differences in mean catches between treatments are bolded. *N*, total no. of beetles captured.

Table 3. Catches of Cerambycidae in cross-vane panel traps and 10-unit nonmodified multiple-funnel traps baited with α-pinene, ipsenol, and ipsdienol (lures attached outside and inside of funnels for the multiple-funnel traps) in experiment 3

	Total no. of beetles captured			
	Funnel trap with lures outside funnels	Funnel trap with lures inside funnels	Panel trap	Total
Acanthocinus nodosus (F.)	3	10	1	14
Acanthocinus obsoletus (Olivier)	25	79	26	130
Aegomorphus modestus (Gyllenhal)	1	0	0	1
Arhopalus rusticus (LeConte)	10	17	7	34
Astylopsis arcuatus (LeConte)	13	13	6	32
Astylopsis sexguttata (Say)	1	16	8	25
Curius dentatus (Newman)	1	5	1	7
Elaphidion mucronatum (Say)	2	7	2	11
Enaphalodes atomarius (Drury)	0	1	0	1
Monochamus titillator (F.) complex	239	550	193	982
Neoclytus mucronatus (F.)	0	5	1	6
Neoclytus scutellaris (Olivier)	1	3	0	4
Prionus imbricornis (L.)	6	2	1	9
Prionus pocularis (Dalman)	6	10	5	21
Typocerus lunulatus (Swederus)	1	0	0	1
Xylotrechus colonus (F.)	5	6	1	12
Xylotrechus sagittatus (Germar)	73	177	89	339
Total	387	901	341	1,629

with overall mean (±SE) trap catches of 2.7 ± 0.4, 6.6 ± 0.6, and 102.7 ± 6.2, respectively.

Mean trap catches of three species of ambrosia beetles were affected by treatments (Table 4). Funnel traps with lures inside funnels outperformed funnel traps with lures outside funnels but not panel traps for *Xylosandrus crassiusculus* (Motschulsky), *Xyleborinus saxesenii* (Ratzeburg), and *Dryoxylon onoharaensum* (Murayama) (Fig. 4A–C). Catches of *G. materiarius* were unaffected by treatments (Table 4) with an overall mean (±SE) trap catch of 1.8 ± 0.4.

Mean trap catches of five species of predators and ectoparasites were affected by treatments (Table 4). *Lasconotus* spp., *Pycnomerus sulcicollis* LeConte (Zopheridae), and *T. virescens* preferred panel traps and funnel traps with lures inside funnels equally over funnel traps with lures outside of funnels (Fig. 5A–C). Mean catches of *Tenebroides collaris* (Sturm) (Trogossitidae) were greater in funnel traps with lures inside the funnels than in panel traps and funnel traps with lures attached outside of funnels (Fig. 5D) whereas mean catches of *Coptodera aerata* Dejean (Carabidae) were greater in funnel traps with lures inside the funnels than in panel traps. Catches in funnel traps with lures outside the funnels were intermediate between the two (Fig. 5E). In contrast, *Plegaderus* Erichson spp. preferred panel traps over funnel traps, irrespective of lure placement (Fig. 5 F). There was no treatment effect on catches of *T. dubius*, *Platysoma* spp., and *Catogenus rufus* with overall mean (±SE) trap catches of 1.8 ± 0.2, 38.5 ± 3.2, and 3.5 ± 0.5, for each species, respectively.

Table 4. Significance levels for ANOVA in experiment 3

	N	Replicate		Treatment	
		$F_{(9,18)}$	*P*	$F_{(2,18)}$	*P*
Buprestidae					
Buprestis lineata	**156**	**2.327**	**0.061**	**7.548**	**0.004**
Carabidae					
Coptodera aerata	**771**	**1.873**	**0.123**	**6.025**	**0.010**
Cerambycidae					
Acanthocinus obsoletus	**130**	**2.596**	**0.041**	**7.062**	**0.005**
***Astylopsis* spp.**	**57**	**0.819**	**0.606**	**4.355**	**0.029**
***Monochamus titillator* complex**	**982**	**1.816**	**0.134**	**25.593**	**<0.001**
Xylotrechus sagittatus	**339**	**1.721**	**0.156**	**19.411**	**<0.001**
Cleridae					
Thanasimus dubius	55	0.347	0.946	2.651	0.098
Curculionidae					
Hylobius pales	**496**	**0.978**	**0.489**	**4.325**	**0.029**
Pachylobius picivorus	465	1.649	0.175	3.166	0.066
Curculionidae: Scolytinae					
Dendroctonus terebrans	**984**	**2.027**	**0.097**	**9.805**	**0.001**
Dryoxylon onoharaensis	**1,346**	**0.976**	**0.491**	**5.908**	**0.011**
Gnathotrichus materiarius	54	0.535	0.831	3.220	0.064
Hylastes porculus	80	0.269	0.975	1.047	0.371
Hylastes salebrosus	**238**	**1.955**	**0.108**	**9.679**	**0.001**
Hylastes tenuis	**382**	**2.279**	**0.065**	**9.051**	**0.002**
Ips avulsus	**1,107**	**4.846**	**0.002**	**9.012**	**0.002**
Ips calligraphus	199	0.430	0.902	0.636	0.541
Ips grandicollis	3,081	0.557	0.814	3.309	0.060
Orthotomicus caelatus	**794**	**5.126**	**0.002**	**35.002**	**<0.001**
Xyleborinus saxesenii	**393**	**0.550**	**0.820**	**14.349**	**<0.001**
Xylosandrus crassiusculus	**3,860**	**3.062**	**0.021**	**4.390**	**0.028**
Elateridae					
Alaus myops	**282**	**2.580**	**0.042**	**9.653**	**0.001**
Histeridae					
***Plegaderus* spp.**	**59**	**2.227**	**0.071**	**5.002**	**0.019**
Platysoma spp.	1,154	0.440	0.895	2.237	0.136
Passandridae					
Catogenus rufus	106	1.227	0.339	0.482	0.626
Trogossitidae					
Temnoscheila virescens	**1,947**	**1.630**	**0.181**	**5.156**	**0.017**
Tenebroides collaris	**102**	**0.930**	**0.523**	**8.319**	**0.003**
Zopheridae					
***Lasconotus* spp**	**1,846**	**1.410**	**0.255**	**4.990**	**0.019**
Pycnomerus sulcicollis	**860**	**2.307**	**0.063**	**5.359**	**0.015**

Species with significant differences in mean catches between treatments are bolded. *N*, total no. of beetles captured.

Discussion

We found that the placement of lures attached to Lindgren multiple-funnel traps (inside or outside funnels) can have a significant effect on catches of bark and wood boring beetles. In general, mean catches of *M. titillator* complex, *X. sagittatus*, *A. nodosus*, *A. obsoletus*, and *Astylopsis* spp. more than doubled by hanging ipsenol, ipsdienol, ethanol, and α-pinene lures inside the funnels of funnel traps (Tables 1 and 2; Fig. 2A–D). In no instance were trap catches of any species of Cerambycidae higher in traps with lures placed on the outside of funnels than in traps with lures hung inside the funnels.

A similar effect was found for *B. lineata* and some bark beetle species although the effect was not consistent across experiments. For example, catches of *I. calligraphus* were affected by lure position in experiment 1 but not experiment 2 whereas catches of *I. grandicollis* were affected in experiment 2 but not experiment 1 (Tables 1 and 2); neither species was affected in experiment 3. Lure position affected catches of *D. terebrans* in experiments 1 and 2 but not in experiment 3 (Fig. 3A). Lure position had no effect on catches of *I. avulsus* in any experiment whereas catches of *O. caelatus* were affected by lure position on funnel traps (Fig. 3C). Catches of *H. pales* (Fig. 3 F) and three species of ambrosia beetles were higher in traps with lures hung inside the funnels than in traps with lures attached outside the funnels (Fig. 4A–C). As with Cerambycidae, in no instance were mean catches of any species of bark or ambrosia beetles higher in traps with lures placed on the outside of funnels than in traps with lures hung inside the funnels.

Lure placement also affected catches of beetle predators and ectoparasites associated with bark and wood boring beetles (Tables 1 and 2; Fig. 5A–D). In all three experiments, mean catches of *Lasconotus* spp. were greater in traps with lures hung inside funnels than in traps with lures hung outside the funnels. As with Buprestidae, Curculionidae, and Cerambycidae, in no instance were mean catches of any species of beetle predators and ectoparasites higher in traps with lures placed on the outside of funnels than in traps with lures hung inside the funnels.

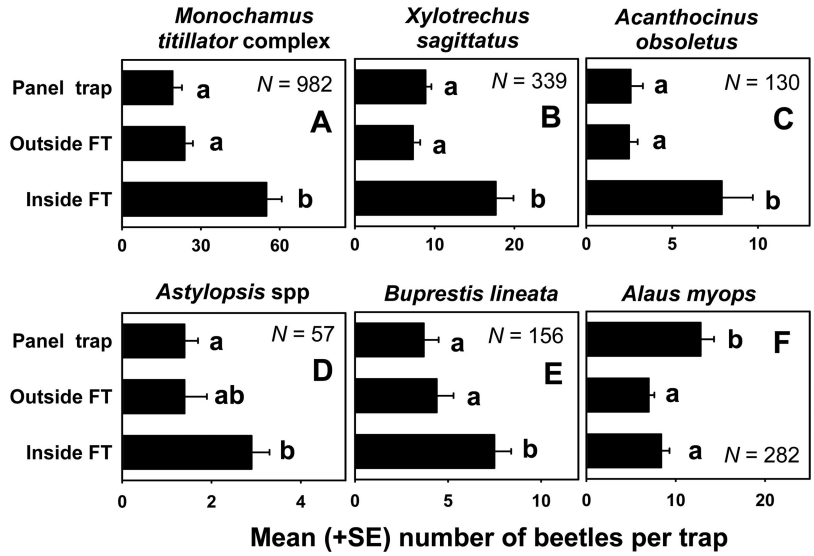

Fig. 2. Catches of *M. titillator* complex (A), *X. sagittatus* (B), *A. obsoletus* (C), *Astylopsis* spp. (D) (Cerambycidae), *B. lineata* (E) (Buprestidae), and *A. myops* (F) (Elateridae) in experiment 3 with panel traps and modified 10-unit multiple-funnel traps (lures placed inside and outside funnels). All traps were baited with ethanol, α-pinene, ipsenol, and ipsdienol lures. Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak test).

The treatment effect of lure position in our study could be attributed to modifications of trap attributes. It is possible that larger openings in the funnels facilitated greater numbers of beetles especially large Cerambycidae to fall through into the collection cups. However, we obtained a significant effect of lure position when we controlled for trap modification in experiment 3. As suggested by Lindgren (1983), placing lures inside funnels may permit odors to exit from all funnels resulting in a broader vertical plume that may increase the chance that beetles locate and follow the plume. Alternatively, beetles may have a greater tendency to go directly to the odor source and enter within the funnels of a trap when the lures are placed inside the funnels which could result in a greater likelihood of beetle captures. Some beetles, such as large Cerambycidae, may simply land on lures when they are hung on the outside of the funnels and fly away.

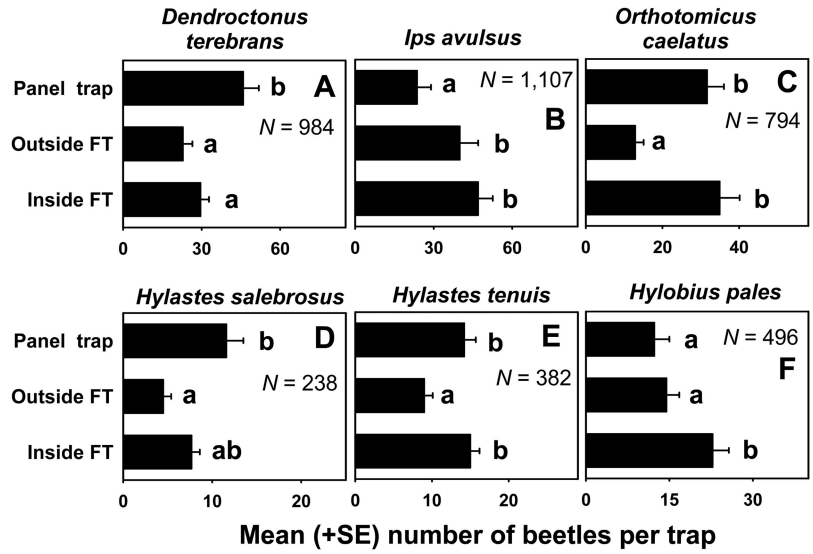

Fig. 3. Catches of *D. terebrans* (A), *I. avulsus* (B), *O. caelatus* (C), *H. salebrosus* (D), *H. tenuis* (E), and *H. pales* (F) (Curculionidae) in experiment 3 with panel traps and modified 10-unit multiple-funnel traps (lures placed inside and outside funnels). All traps were baited with ethanol, α-pinene, ipsenol, and ipsdienol lures. Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak test).

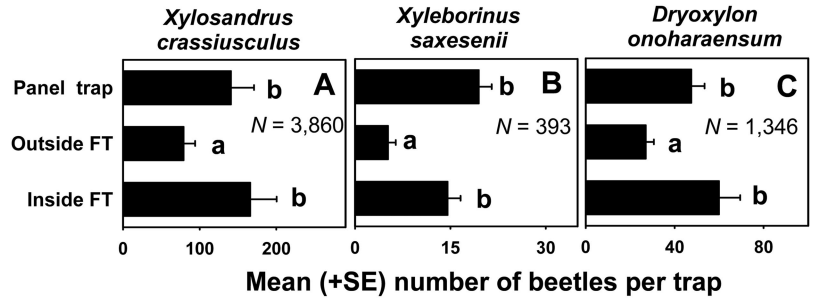

Fig. 4. Catches of *X. crassiusculus* (A), *X. saxesenii* (B), and *D. onoharaensum* (C) (Curculionidae) in experiment 3 with panel traps and modified 10-unit multiple-funnel traps (lures placed inside and outside funnels). All traps were baited with ethanol, α-pinene, ipsenol, and ipsdienol lures. Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak test).

The choice of multiple-funnel traps or cross-vane panel traps is an important consideration in trap-based programs for monitoring or detecting invasive species. Typically, cross panel traps outperform 8- and 12-unit funnel traps in catching Cerambycidae (Czokajlo et al. 2003, Dodds et al. 2010, Miller and Crowe 2011) although Costello et al. (2008) found the opposite to be true for *Acanthocinus obliquus* (LeConte), *Acmaeops proteus* (Kirby), and *Monochamus clamator* (LeConte) in South Dakota. In experiment 3, we found that modified 10-unit multiple-funnel traps with lures hung inside the funnels outperformed panel traps in trapping Cerambycidae (Table 3); modified traps with lures hung outside were comparable to panel traps. For the four most common Cerambycidae and the most common Buprestidae, more beetles were captured in modified funnel traps with lures hung inside the funnels than in panel traps (Fig. 2A–E). The same was true for *I. avulsus* (Fig. 3B), *H. pales* (Fig. 3 F), *T. collaris* (Fig. 5D), and *Coptodera aerata* (Fig. 5 F). Preferences for panel traps were shown by *A. myops* (Fig. 2 F), *D. terebrans* (Fig. 3A), and *Plegaderus* spp. (Fig. 5B). There were no significant differences in catches of all remaining species in panel traps compared with modified traps with lures hung inside the funnels.

The relative performance of panel traps can be improved by application of surfactants (Czokajlo et al. 2003, de Groot and Nott 2003, Graham et al. 2010). However, the same is also true for nonmodified multiple-funnel traps (Graham and Poland 2012) and would likely be true for modified funnel traps as well. Lure placement on panel traps needs further examination. We hung lures in the central axis of panel traps as suggested by the manufacturer. Modifications such as placement of lures on opposite sides of the panels or increasing the size of the ventilation hole in the central axis may result in better dispersal of semiochemicals and increased catches of beetles.

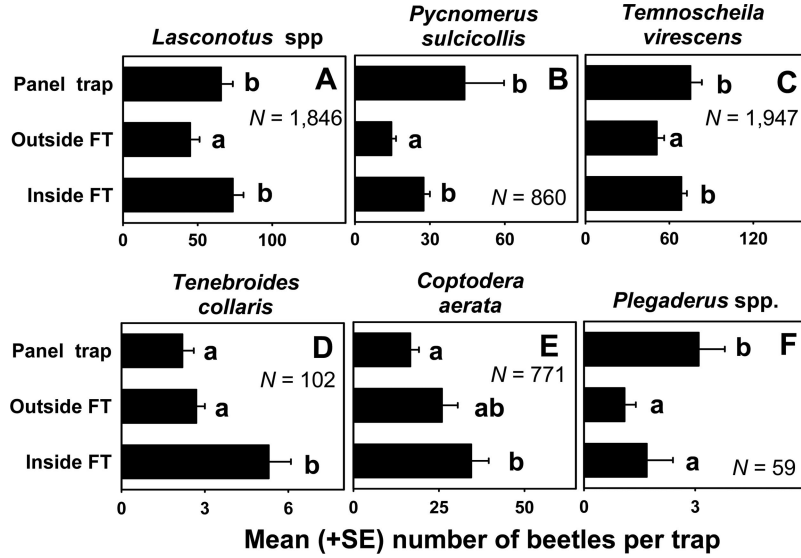

Fig. 5. Catches of *Lasconotus* spp (A), *P. sulcicollis* (B) (Zopheridae), *T. virescens* (C), *T. collaris* (D) (Trogossitidae), *C. aerata* (E) (Carabidae), and *Plegaderus* spp. (Histeridae) (F) in experiment 3 with panel traps and modified 10-unit multiple-funnel traps (lures placed inside and outside funnels). All traps were baited with ethanol, α-pinene, ipsenol, and ipsdienol lures. Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak test).

There is an important implication of our work for managers that conduct programs such as CAPS and EDRR that currently use multiple funnel traps to target bark and ambrosia beetles. If managers need to expand such detection surveys to include Cerambycidae then they can either purchase cross-vane panel traps or modify their existing multiple-funnel traps; modified traps are not commercially available at present. The modification process for funnel traps is fairly straightforward and involves disassembling traps, cutting out inner holes of funnels with tinsnips and reassembling traps. Expanding current programs for bark and ambrosia beetles to include woodborers need not be an expensive undertaking, particularly as there are thousands of multiple-funnel traps already in use that could be modified.

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References Cited

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

Czokajlo, D., J. McLaughlin, L. I. Abu Ayyash, S. Teale, J. Wickham, J. Warren, R. Hoffman, B. Aukema, K. Raffa, and P. Kirsch. 2003. Intercept panel trap effective in management of forest Coleoptera, pp. 125–126. *In* M. L. McManus and A. M. Liebhold (eds.), Proceedings: Ecology, Survey and Management of Forest Insects. USDA–Forest Service, Northeastern Research Station General Technical Report NE–311. Newton Square, PA.

Dodds, K. J., and P. de Groot. 2011. Sirex, surveys, and management: challenges of having *Sirex noctilio* in North America, pp. 265–286. *In* B. Slippers, P. de Groot, and M. J. Wingfield (eds.), The Sirex Woodwasp and its Fungal Symbiont. Research and Management of a Worldwide Invasive Pest. Springer, Dordrecht, The Netherlands.

Dodds, K. J., G. D. Dubois, and E. R. Hoebeke. 2010. Trap type, lure placement, and habitat effects on Cerambycidae and Scolytinae (Coleoptera) catches in the northeastern United States. J. Econ. Entomol. 103: 698–707.

Glantz, S. A. 2005. Primer of biostatistics. McGraw–Hill Professional, New York, NY.

Graham, E. E., and T. M. Poland. 2012. Efficacy of Fluon conditioning for capturing cerambycid beetles in different trap designs and persistence on panel traps over time. J. Econ. Entomol. 105: 395–401.

Graham, E. E., R. F. Mitchell, P. F. Reagel, J. D. Barbour, J. G. Millar, and L. M. Hanks. 2010. Treating panel traps with a fluoropolymer enhances their efficiency in capturing cerambycid beetles. J. Econ. Entomol. 103: 641–647.

Graham, E. E., T. M. Poland, D. G. McCullough, and J. G. Millar. 2012. A comparison of trap type and height for capturing cerambycid beetles (Coleoptera). J. Econ. Entomol. 105: 837–846.

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

Hopping, R. 1921. A review of the genus *Monochamus* Serv. (Cerambycidae, Coleoptera). Can. Entomol. 53: 252–258.

(ITIS) Integrated Taxonomic Information System. 2011. Integrated Taxonomic Information System. The Smithsonian Institution, Washington, DC. (www.itis.gov/index.html).

Jackson, L., T. Price, and G. Smith. 2010. Exotic wood borer/bark beetle national survey guidelines. Revised 2010 Manual. USDA–APHIS, PPQ. Raleigh, NC. (http://caps.ceris.purdue.edu/survey/manual/ewbb_guidelines).

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

Lindgren, B. S., and R. G. Fraser. 1994. Control of ambrosia beetle damage by mass trapping at a dry land log sorting area in British Columbia. For. Chron. 70: 159–163.

Lindsey, E. G., and J. A. Chemsak. 1984. The Cerambycidae of North America, Part VII, No 1: Taxonomy and classification of the subfamily Lamiinae, Tribes Parmenini through Acamthoderini. University California Press, Berkeley, CA.

Lingafelter, S. W. 2007. Illustrated key to the longhorned woodboring beetles of the eastern United States. The Colelopterists Society, Spec. Publ. No. 3, North Potomac, MD.

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

Miller, D. R. 2006. Ethanol and (–)-α-pinene: attractant kairomones for some large wood-boring beetles in southeastern USA. J. Chem. Ecol. 32: 779–794.

Miller, D. R., and C. M. Crowe. 2011. Relative performance of Lindgren multiple-funnel, intercept panel and colossus pipe traps in catching Cerambycidae and associated species in the southeastern United States. J. Econ. Entomol. 104: 1934–1941.

Miller, D. R., and D. A. Duerr. 2008. Comparison of arboreal beetle catches in wet and dry collection cups with Lindgren multiple funnel traps. J. Econ. Entomol. 101: 107–113.

Miller, D. R., and R. J. Rabaglia. 2009. Ethanol and (–)-α-pinene: attractant kairomones for bark and ambrosia beetles in southeastern USA. J. Chem. Ecol. 35: 435–448.

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

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

Rabaglia, R., D. Duerr, R. Acciavatti, and I. Ragenovich. 2008. Early detection and rapid response for non-native bark and ambrosia beetles. USDA–Forest Service, Forest Health Protection, Washington, DC. (http://www.fs.fed.us/foresthealth/publications/EDRRProjectReport.pdf).

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