Relative Performance of Lindgren Multiple-Funnel, Intercept Panel, and Colossus Pipe Traps in Catching Cerambycidae and Associated Species in the Southeastern United States

DANIEL R. MILLER[1] AND CHRISTOPHER M. CROWE

United States Department of Agriculture, Forest Service, Southern Research Station, 320 Green Street, Athens, GA 30602

J. Econ. Entomol. 104(6): 1934–1941 (2011); DOI: http://dx.doi.org/10.1603/EC11166

ABSTRACT In 2004, we evaluated the relative performance of 8-unit Lindgren multiple-funnel (funnel), Intercept panel (panel), and Colossus pipe (pipe) traps, baited with ethanol and α-pinene lures, in catching saproxylic beetles (Coleoptera) in pine stands in northern Florida and western South Carolina. Panel traps were as good as, if not better than, funnel and pipe traps for catching Cerambycidae. In particular, more *Monochamus titillator* (F.) were captured in panel traps than in pipe and funnel traps. Of three species of Buprestidae captured in our study, most *Buprestis lineata* F. were caught in panel traps, whereas most *Acmaeodera tubulus* (F.) were caught in funnel traps. Catches of *Chalcophora virginiensis* Drury and the root-feeding weevils *Hylobius pales* Herbst and *Pachylobius picivorus* LeConte (Curculionidae) were unaffected by trap type. Among bark beetles (Curculionidae: Scolytinae), catches of *Ips grandicollis* (Eichhoff) were unaffected by trap type, whereas most *Dendroctonus terebrans* (Olivier) were caught in panel traps, most *Hylastes salebrosus* Eichhoff were caught in panel and pipe traps, and most *Hylastes tenuis* Eichhoff were caught in funnel traps. Among ambrosia beetles (Curculionidae: Scolytinae), panel traps caught the most *Xyleborinus saxesenii* (Ratzeburg), whereas pipe traps caught the most *Xyleborus* Eichhoff spp. More *Xylosandrus crassiusculus* (Motschulsky) and *Dryoxylon onoharaensis* (Murayama) were caught in panel and funnel traps than in pipe traps. Among bark beetle predators, more *Platysoma* Leach spp. (Histeridae) were caught in pipe and panel traps than in funnel traps, whereas most *Lasconotus* Erichson spp. (Zopheridae) were caught in funnel traps. Variation among trap performance for various species suggests that managers should consider more than one type of trap in their detection programs.

KEY WORDS *Monochamus titillator*, Cerambycidae, Curculionidae, Scolytinae, Buprestidae

The Lindgren multiple-funnel trap is routinely used in national programs for the detection of exotic and invasive saproxylic beetles, particularly bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) (Brockerhoff et al. 2006, Rabaglia et al. 2008, Jackson et al. 2010). The multiple-funnel trap consists of a series of black, plastic funnels arranged vertically over a collection cup (Lindgren 1983). In British Columbia, baited multiple-funnel traps are an integral component of mass trapping programs for ambrosia beetles in wood-processing areas (Lindgren and Fraser 1994, Borden et al. 2001). In the southern United States, baited multiple-funnel traps are used to detect high-risk areas of the southern pine beetle, *Dendroctonus frontalis* Zimmermann for directing forest management efforts (Clarke 2001).

The Intercept panel trap, also called the cross-vane panel trap, has gained popularity in trapping larger wood boring species such as longhorn beetles (Cerambycidae) and woodwasps (Hymenoptera: Siricidae) (Sweeney et al. 2006, Nehme et al. 2010, Dodds and de Groot 2011). The trap consists of crossed vanes of corrugated, black plastic suspended vertically over a large funnel and collection cup (Czokajlo et al. 2003). The cross-vane panel trap is recommended for detection of *Tetropium* spp. (Cerambycidae) by the U.S. Department of Agriculture–Animal and Plant Health Inspection Services–Cooperative Agricultural Pest Survey (CAPS) (Jackson et al. 2010). An experimental trap called the Colossus pipe trap recently was developed and consists of a vertical tube made of soft, black plastic suspended over a large funnel and collection cup. The pipe trap attempts to mimic the "wading pool pipe trap" popular in the southeastern United States in the 1980s. The wading pool pipe trap consisted of a black stovepipe placed in a child's wading pool (half-filled with water) and baited with turpentine, and caught hundreds of bark and wood boring

The use of trade names and identification of firms or corporations does not constitute an official endorsement or approval by the United States Government of any product or service to the exclusion of others that may be suitable. Funding for this research was provided by the USDA Forest Service.

[1] Corresponding author, e-mail: dmiller03@fs.fed.us.

Fig. 1. Eight-unit multiple-funnel trap (left), Intercept panel trap (middle) and Colossus pipe trap (right) used in our study. (Online figure in color.)

beetles in Florida and Georgia (Clements and Williams 1981, Fatzinger 1985).

Our objective was to evaluate the relative performance of three commercial traps (baited with ethanol and α-pinene) in catching common saproxylic beetles in the southeastern United States. Ethanol and α-pinene are broadly attractive to a diverse group of saproxylic beetles in the southeastern United States (Allison et al. 2004, Miller 2006, Miller and Rabaglia 2009). Our goal is to provide managers with relative measures of efficacy for various target groups of beetles in their selection of trap type in their detection programs.

Materials and Methods

Two experiments were conducted in 2004 using three different traps designed to catch bark and wood boring beetles (Fig. 1). Intercept panel traps (Panel) were obtained from integrated pest management (IPM) Technologies (Portland, OR). Phero Tech Inc. (now Contech Enterprises, Victoria, British Columbia) supplied 8-unit multiple-funnel (Funnel) and Colossus pipe traps (Pipe) as well as ultra-high release (UHR) 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 ≈1 and 2 g/d, respectively, at 23°C. Rates were provided by the manufacturer.

We employed a behavioral choice type of experiment in a randomized complete block design for both experiments. Ten replicate blocks of three traps per block were set in mature pine stands with one of each trap type within a block: 1) pipe, 2) funnel, and 3) panel. All traps were baited with ethanol and (–)-α-pinene UHR pouches. Traps were set 8–12 m apart within a block, whereas blocks were set 15–50 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 3 m of any tree. Collection cups contained ≈150 ml of a pink solution of propylene glycol (Peak RV and Marine Antifreeze, Old World Industries Inc., Northbrook, IL) as a killing and preservation medium (Miller and Duerr 2008). Collections of catches were made every 2 wk, with glycol solution replaced on each occasion with fresh solution.

Experiment 1 was conducted 30 March–16 June in the Apalachicola National Forest (30.400° N, −84.485° W; elevation = 21 m AMSL) near Tallahassee, FL, whereas experiment 2 was conducted 14 April–29 June in the Sumter National Forest (34.483° N, −81.651° W; elevation = 121 m AMSL) near Union, SC. Experiment 1 was located in a stand of slash, *Pinus elliottii* Engelmann and longleaf pine, *P. palustris* Miller (Pinaceae), whereas experiment 2 was located in a stand of loblolly pine, *P. taeda* L. Both stands had experienced prescribed burning during the previous year.

Data were analyzed with the SYSTAT (ver. 11.00.01) and SigmaStat (ver. 3.01) statistical packages (SYSTAT Software Inc., Point Richmond, CA). To determine the treatment effects over both locations for species with sufficient numbers (N>30) at both locations, as well as any interaction between treatment and location, the data were subjected to two-way analysis of variance (ANOVA) using the following model components: 1) location, 2) treatment, and 3) location x treatment (model 1). Trap catch data for model one were transformed by ln(Y+1) to remove heteroscedasticity (Pepper et al. 1997). For species with sufficient numbers at only one location, the data were subject to 2-way ANOVA using the following model components: 1) replicate, and 2) treatment (model 2). Model two also was used before conducting the Holm–Sidak multiple comparison procedure to compare means of each species among trap types separately for each location (Glantz 2005). Transformations for data used in model 2 were not required as all data sets satisfied the assumptions of normality and homogeneity of variance (locations analyzed separately). Species names and authors 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

Cerambycidae. We captured 1,463 common longhorn beetles across both locations. The most abundant species in trap catches were *Xylotrechus sagittatus*

Table 1. Significance levels for ANOVA (Model 1) on effects of treatment and location on catches of saproxylic beetles in Florida (Expt. 1) and South Carolina (Expt. 2)

Family Species	Replicate (nested within L)		Treatment (T)		Location (L)		T x L	
	$F_{(18,36)}$	P	$F_{(2,36)}$	P	$F_{(1,36)}$	P	$F_{(2,36)}$	P
Cerambycidae								
Acanthocinus nodosus	3.126	0.002	4.677	0.016	14.821	<0.001	0.531	0.593
Arhopalus rusticus	1.368	0.207	3.369	0.046	27.655	<0.001	1.093	0.346
Monochamus titillator	1.094	0.396	15.976	<0.001	36.625	<0.001	3.045	0.060
Xylotrechus sagittatus	2.612	0.007	13.058	<0.001	6.960	0.012	2.187	0.127
Curculionidae								
Hylobius pales	1.159	0.342	1.394	0.261	421.534	<0.001	0.015	0.985
Pachylobius picivorus	2.998	0.002	6.507	0.004	2.737	0.107	0.157	0.855
Curculionidae: Scolytinae								
Dendroctonus terebrans	2.886	0.003	53.405	<0.001	0.609	0.440	1.366	0.268
Dryoxylon onoharaensis	1.932	0.046	63.406	<0.001	0.068	0.795	0.022	0.979
Hylastes salebrosus	2.323	0.015	60.985	<0.001	71.521	<0.001	0.007	0.993
Hylastes tenuis	1.059	0.427	13.842	<0.001	77.116	<0.001	0.249	0.781
Ips grandicollis	1.105	0.386	0.118	0.889	473.270	<0.001	0.164	0.850
Xyleborinus saxesenii	1.581	0.119	88.520	<0.001	171.768	<0.001	8.115	0.001
Xyleborus spp.	2.702	0.005	85.832	<0.001	120.413	<0.001	3.511	0.040
Xylosandrus crassiusculus	2.645	0.006	11.832	<0.001	40.433	<0.001	0.617	0.545
Trogositidae								
Temnochila virescens	1.423	0.180	18.014	<0.001	0.984	0.328	0.502	0.609
Tenebroides collaris	0.694	0.794	3.375	0.045	18.320	<0.001	0.033	0.967

(Germar), *Monochamus titillator* (F.), *Arhopalus rusticus* (LeConte), and *Acanthocinus nodosus* (F.), which all exhibited significant treatment effects with no significant interaction between treatment and location (Table 1). In Florida, catches of *X. sagittatus* in funnel traps were greater than those in pipe traps with catches in panel traps intermediate between the other two treatments (Fig. 2A). In South Carolina, catches of *X. sagittatus* in panel and funnel traps were greater than those in pipe traps (Fig. 2B). In contrast, catches of *M. titillator* were greater in panel traps than in funnel and pipe traps at both locations (Fig. 2C and D). In South Carolina, catches of *A. nodosus* were greater in panel traps than in funnel traps with catches in pipe traps intermediate between the other two treatments (Fig. 2 F). The Holm–Sidak multiple-comparison test could not discern any differences among treatments for *A. nodosus* in Florida (Fig. 2E) or *A. rusticus* at either location (Fig. 2G and H) although ANOVA found significant treatment effects for both species (Table 1). There was no significant treatment effect of trap type on catches of *Acanthocinus obsoletus* (Olivier) in Florida ($F_{2,18} = 3.459$, $P = 0.054$; Fig. 2I) with a mean (±SE) trap catch of 2.8 ± 0.4 ($N = 84$). Only 24 *A. obsoletus* were caught in South Carolina.

Buprestidae. Only three species of flatheaded woodborers were captured in sufficient numbers for statistical analyses, with a total catch of only 337 across both locations. There was a significant treatment effect on catches of *Buprestis lineata* F. in South Carolina ($F_{2,18} = 8.195$, $P = 0.003$). Catches in panel traps were greater than those in pipe traps with catches in funnel traps intermediate between the other two treatments (Fig. 3A). Only 24 *B. lineata* were captured in Florida. Catches of *Acmaeodera tubulus* (F.) exhibited a significant treatment effect ($F_{2,18} = 7.653$, $P = 0.004$) with greater numbers caught in funnel traps than in panel and pipe traps (Fig. 3B). There was no treatment

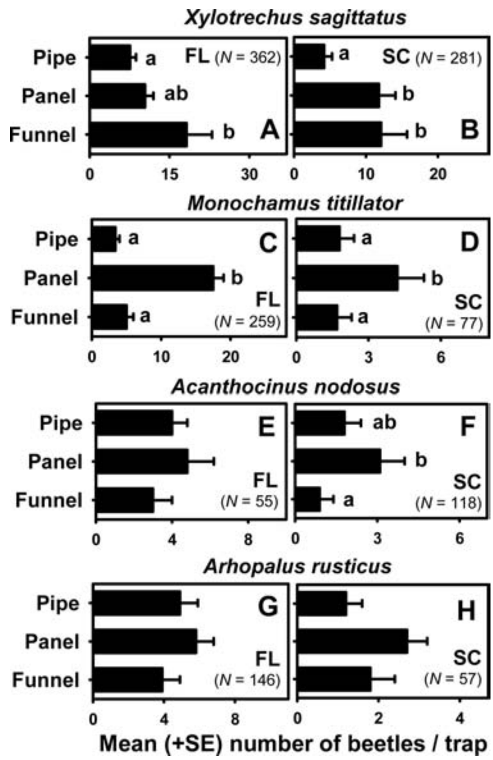

Fig. 2. Effects of Colossus pipe (Pipe), Intercept panel (Panel), and Lindgren multiple-funnel (Funnel) traps on catches of *X. sagittatus* (A,B); *M. titillator* (C,D); *A. nodosus* (E,F); and *A. rusticus* (G,H) (Cerambycidae) when baited with ethanol and (–)-α-pinene in Florida (FL) and South Carolina (SC). Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak test). N = Total catch per species and location.

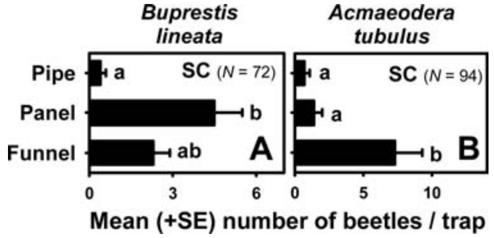

Fig. 3. Effects of Colossus pipe (Pipe), Intercept panel (Panel), and Lindgren multiple-funnel (Funnel) traps on catches of *B. lineata* (A) and *Acmaeodera tubulus* (B) (Buprestidae) when baited with ethanol and (–)-α-pinene in Florida (FL) and South Carolina (SC). Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak test). N = Total catch per species and location.

effect on catches of *Chalcophora virginiensis* (Drury) in South Carolina ($F_{2,18} = 1.500$, $P = 0.250$) with a mean trap catch (±SE) of 4.0 ± 0.7 ($N = 121$). In Florida, we captured only 13 *C. virginiensis* and only 13 *Chalcophora georgiana* Leconte.

Curculionidae. We caught significant numbers of *Pachylobius picivorus* LeConte and *Hylobius pales* Herbst in our study with total catch of 3,366 across both locations. Trap type had a significant effect on catches of *P. picivorus* (Table 1), although the Holm–Sidak multiple-comparison test could not discern any differences among treatments at either location for *P. picivorus* (Fig. 4). There was no significant treatment effect on trap catches of *H. pales* (Table 1) with overall mean (±SE) catches of 1.6 ± 0.4 and 46.7 ± 4.6 in Florida and South Carolina, respectively ($N = 47$ and $N = 1,401$, respectively).

Curculionidae: Scolytinae. Bark beetles were the second most abundant group of saproxylic beetles captured in our study, with a total catch of 13,420 across both locations. Trap type had no effect on catches of *Ips grandicollis* (Eichhoff) at either location (Table 1) with overall mean (±SE) catches of 90.9 ± 4.7 and 12.3 ± 0.8 in Florida and South Carolina, respectively ($N = 2,726$ and $N = 368$, respectively). In contrast, catches of *Dendroctonus terebrans* (Olivier), *Hylastes tenuis* Eichhoff, and *Hylastes salebrosus* Eichhoff were affected by trap treatment with no significant interaction with location (Table 1). At both locations, catches of *D. terebrans* in panel traps were

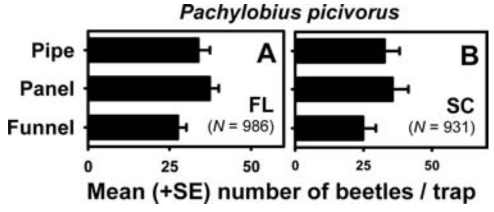

Fig. 4. Effects of Colossus pipe (Pipe), Intercept panel (Panel), and Lindgren multiple-funnel (Funnel) traps on catches of *P. picivorus* (A,B) (Curculionidae) when baited with ethanol and (–)-α-pinene in Florida (FL) and South Carolina (SC). N = Total catch per species and location.

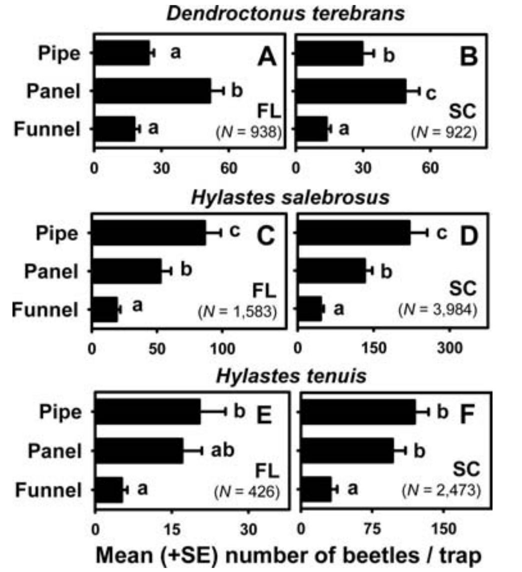

Fig. 5. Effects of Colossus pipe (Pipe), Intercept panel (Panel), and Lindgren multiple-funnel (Funnel) traps on catches of the bark beetles *D. terebrans* (A,B); *H. salebrosus* (C,D); and *H. tenuis* (E,F) (Curculionidae: Scolytinae) when baited with ethanol and (–)-α-pinene in Florida (FL) and South Carolina (SC). Means followed by the same letter are not significantly different at $P = 0.05$ (Holm–Sidak test). N = Total catch per species and location.

greater than those in pipe and funnel traps (Fig. 5A and B). Catches of *D. terebrans* were greater in pipe traps than in funnel traps in South Carolina but not Florida. At both locations, catches of *H. salebrosus* were greatest in pipe traps, followed by catches in panel traps and then catches in funnel traps (Fig. 5C and D). Catches of *H. tenuis* were greatest in pipe and panel traps and lowest in funnel traps at both locations (Fig. 5E and F).

Ambrosia beetles were the most abundant group of saproxylic species, with a total catch of 22,980 across both locations. The four most abundant species were *Xyleborinus saxesenii* (Ratzeburg), *Xyleborus* Eichhoff spp., *Xylosandrus crassiusculus* (Motschulsky), and *Dryoxylon onoharaensis* (Murayama). Catches of all four species were affected by treatments (Table 1). There was a significant interaction between location and treatment for *X. saxesenii,* although the overall result on trap catches was the same in Florida and South Carolina. At both locations, catches of *X. saxesenii* were greatest in panel traps and lowest in pipe traps with catches in funnel traps intermediate between the two (Fig. 6A and B). The overall effect of trap type on catches of *Xyleborus* spp. was the same at both locations (Fig. 6C and D) even though there was a significant interaction between treatment and location (Table 1). The greatest catches of *Xyleborus* spp. were in pipe traps and the lowest catches were in funnel traps with catches in panel traps intermediate between the other two treatments at both locations (Fig. 6C and D). Catches of *X. crassiusculus* and *D.*

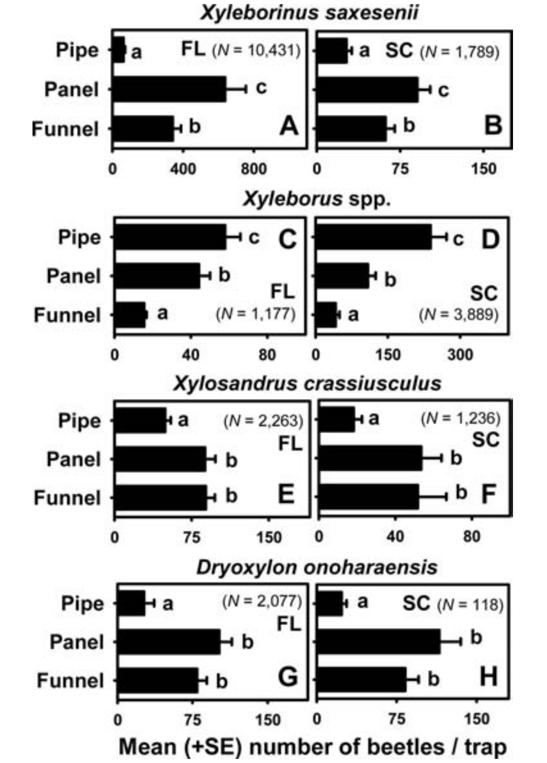

Fig. 6. Effects of Colossus pipe (Pipe), Intercept panel (Panel), and Lindgren multiple-funnel (Funnel) traps on catches of the ambrosia beetles *X. saxesenii* (A,B); *Xyleborus* spp. (C,D); *X. crassiusculus* (E,F); and *D. onoharaensis* (G,H) (Curculionidae: Scolytinae) when baited with ethanol and (–)-α-pinene in Florida (FL) and South Carolina (SC). Means followed by the same letter are not significantly different at P = 0.05 (Holm-Sidak test). N = Total catch per species and location.

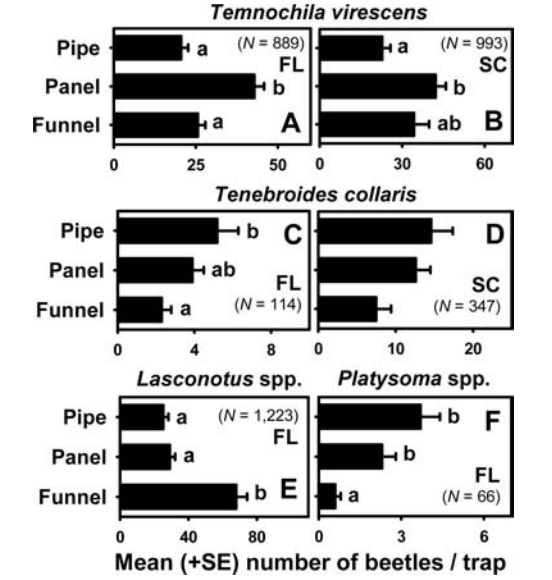

Fig. 7. Effects of Colossus pipe (Pipe), Intercept panel (Panel), and Lindgren multiple-funnel (Funnel) traps on catches of *T. virescens* (A,B); *T. collaris* (C,D) (Trogositidae); *Lasconotus* spp. (E); (Zopheridae); and *Platysoma* spp. (F) (Histeridae) when baited with ethanol and (–)-α-pinene in Florida (FL) and South Carolina (SC). Means followed by the same letter are not significantly different at P = 0.05 (Holm–Sidak test). N = Total catch per species and location.

onoharaensis were both affected by trap treatment without any significant interaction between Florida and South Carolina (Table 1). At both locations, panel and funnel traps caught more *X. crassiusculus* and *D. onoharaensis* than pipe traps with no difference between panel and funnel traps for either species (Fig. 6E–H).

Cleridae, Cucujidae, Histeridae, Trogositidae, and Zopheridae. Six species of bark and ambrosia beetle predators were captured in our study, with a total count of 4,120 across six families of Coleoptera. Catches of *Temnochila virescens* (F.) and *Tenebroides collaris* (Sturm) (Trogositidae) were affected by trap type with no interaction with location (Table 1). In Florida, catches of *T. virescens* were greater in panel traps than in funnel and pipe traps (Fig. 7A) whereas the greatest catches of *T. virescens* in South Carolina were in panel traps and the lowest catches were in pipe traps with funnel traps intermediate between the two other treatments (Fig. 7B). In Florida, catches of *T. collaris* were greater in pipe traps than in funnel traps with panel trap catches intermediate between the two other treatments (Fig. 7C). Even though the Holm–Sidak multiple-comparison test could not discern any differences among treatments for *T. collaris* in South Carolina (Fig. 7D), the catch pattern is likely the same for *T. collaris* in South Carolina as in Florida, as there was no significant interaction between treatment and location (Table 1).

Treatments had a significant effect on catches of *Lasconotus* Erichson spp. (Zopheridae) in Florida ($F_{2,18} = 28.748, P < 0.001$) with catches in funnel traps greater than those in pipe and panel traps (Fig. 7E). Catches of *Platysoma* Leach spp. (Histeridae) in Florida were affected by trap treatment ($F_{2,18} = 10.215$, $P = 0.001$) with catches in pipe and panel traps greater than those in funnel traps (Fig. 7 F). There was no significant treatment effect on catches of *Thanasimus dubius* (F.) (Cleridae) in South Carolina ($F_{2,18} = 2.382$, $P = 0.121$) with a mean ($\pm$SE) trap catch of 11.6 ± 1.6 ($N = 347$). Catches of *Cucujus clavipes* (F.) (Cucujidae) were not affected by trap type in South Carolina ($F_{2,18} = 1.929, P = 0.174$) with a mean ($\pm$SE) trap catch of 4.7 ± 0.7 ($N = 141$). Catches of *T. dubius* and *C. clavipes* were <10 in Florida as were catches of *Platysoma* spp. and *Lasconotus* spp. in South Carolina.

Discussion

The effects of trap attributes on catches of saproxylic insects have received some attention in recent years, particularly for larger species such as longhorn beetles because of introductions of exotic woodborers into North America. Black intercept traps are better

Table 2. Summary of trap performance for saproxylic beetles from Figs. 2–7

Highest performance	Wood borers	Bark beetles	Ambrosia beetles	Weevils	Predators
Panel	*M. titillator*	*D. terebrans*	*X. saxesenii*		*T. virescens* (FL)
Funnel	*A. tubulus*				*Lasconotus* spp.
Pipe			*Xyleborus* spp.		
Panel & Funnel	*X. sagittatus*		*X. crassiusculus*		*T. virescens* (SC)
	B. lineata		*D. onoharaensis*		
Panel & Pipe	*A. nodosus* (SC)	*H. salebrosus*			*T. collaris* (FL)
		H. tenuis			*Platysoma* spp.
None	*A. rusticus*	*I. grandicollis*		*H. pales*	*T. dubius*
	A. nodosus (FL)			*P. picivorus*	*T. collaris* (SC)
	A. obsoletus				
	C. virginiensis				

than clear intercept traps in catching *Monochamus scutellatus* (Say), *Monochamus mutator* LeConte, and the buprestid *Buprestis maculativentris* Say (de Groot and Nott 2001). The length of funnel traps (i.e., number of funnels) can affect catches of some species of saproxylic beetles. In Florida, more *A. rusticus* were captured in 16-unit multiple-funnel traps than in 8-unit traps, all baited with ethanol and α-pinene (Miller and Crowe 2009). Escape of trapped longhorns and associated species in collection cups can be reduced with the use of a liquid solution of water and salt or propylene glycol (Morewood et al. 2002, de Groot and Nott 2003, Sweeney et al. 2006, Miller and Duerr 2008).

In our study, the relative performance of three types of commercial traps in catching woodborers and associated saproxylic beetles varied between species (Table 2), and differed from other studies in part. We found that in the southeastern United States, Intercept panel traps were as good as, if not better than, 8-unit multiple-funnel and Colossus pipe traps in catching five common species of pine Cerambycidae: *X. sagittatus, M. titillator, A. nodosus, A. obsoletus,* and *A. rusticus* (Table 2). In particular, greater numbers of *M. titillator* were caught in panel traps than in pipe and funnel traps.

McIntosh et al. (2001) found that an experimental cross-vane trap outperformed a 12-unit multiple-funnel trap in catching *M. scutellatus* and *M. obtusus* in British Columbia. In contrast, Morewood et al. (2002) found that catches of *M. scutellatus* and *M. obtusus* Casey were not different between 12-unit multiple-funnel and an experimental cross-vane trap (baited with ethanol and α-pinene). Similarly, de Groot and Nott (2001) found no difference in catches of *M. scutellatus, M. mutator,* and *M. notatus* (Drury) between experimental pipe and experimental cross-vane intercept traps, or between 12-unit multiple-funnel and Intercept panel traps for *M. scutellatus* and *M. mutator,* although a black, experimental cross-vane trap caught the most *M. scutellatus* (de Groot and Nott 2003).

We found that funnel and panel traps caught more *X. sagittatus* than pipe traps (Table 2), whereas the panel trap seemed to weakly outperform the other two traps for *A. rusticus* and *A. nodosus.* Catches of *A. obsoletus* were unaffected by trap type. Similarly, Dodds et al. (2010) found that Intercept panel traps caught more *X. sagittatus* than 12-unit multiple-funnel traps, whereas *Asemum striatum* (L.) and *Acmaeops proteus* Kirby were largely unaffected by trap type. McIntosh et al. (2001) found that an experimental cross-vane trap outperformed a multiple-funnel trap in catching *Arhopalus* Audinet-Seville spp., *Asemum* Eschscholtz spp., and *Xylotrechus longitarsis* Casey. Similarly, Morewood et al. (2002) found that more *X. longitarsis, Arhopalus asperatus* (LeConte) and *A. striatum* were caught in cross-vane traps than in similarly-baited 12-unit multiple-funnel traps.

With respect to Buprestidae, we found that panel traps caught more *B. lineata* than pipe traps (Table 2). Trap type had no effect on catches of *C. virginiensis* to traps baited with ethanol and α-pinene, whereas catches of *A. tubulus* were greater in funnel traps than in pipe and panel traps. McIntosh et al. (2001) found that an experimental cross-vane trap outperformed a multiple-funnel trap with *Buprestis adjecta* (LeConte) and *C. virginiensis* but not with *Buprestis laeviventris* (LeConte), *Buprestis aurulenta* L., *Dicerca tenebrosa* (Kirby), and *Chrysobothrix* Eschscholtz spp. Morewood et al. (2002) found no effect of trap type on catches of the buprestids *C. virginiensis, D. tenebrosa, Cypriacis aurulenta* (L.), *Buprestis lyrata* Casey, and *Buprestis subornata* (LeConte) when baited with ethanol and α-pinene in British Columbia. Similarly, de Groot and Nott (2003) found no difference between 12-unit multiple-funnel and Intercept panel traps for catching *B. maculaventis, Dicerca tenebrosa* (Kirby) and *C. virginiensis* in Ontario.

Some variation in trap performance is evident among associated species of saproxylic beetles. In our study, we found that catches of two species were highest in panel traps and catches of another species were highest in pipe traps. Panel and funnel traps performed equally for two other species, whereas and pipe and panel traps performed equally for two other species. There was no effect of trap type on catches of the eighth species (Table 2). Neither species of weevils were affected by trap type. In monitoring trap performance for eight species of bark and ambrosia beetles in New Hampshire, Dodds et al. (2010), found that catches of two species were higher in Intercept panel traps than in 12-unit funnel traps. The perfor-

Table 3. Dimensional differences between 8-unit multiple-funnel (Funnel), Intercept panel (Panel) and Colossus pipe (Pipe) traps

Feature	Funnel	Panel	Pipe
Visual ht	77 cm	113 cm	163 cm
Visual width	19 cm	31 cm	21 cm
Interception Area	0.35 m^2	0.88 m^2	0.70 m^2
Catchment area of bottom funnel	0.03 m^2	0.10 m^2	0.25 m^2

mance of the two traps was no different among the remaining six species.

We hypothesize that most of the variation in trap performance likely relates to interactions of host-choice and landing behaviors by beetles with trap attributes and release rates of ethanol and α-pinene. The physical attributes of the traps present differences in visual silhouettes for orientation, interception areas for immediate knock-down, and catchment areas of bottom collection funnels (Fig. 1; Table 3). Plumes of host attractants are likely affected by trap shape and positioning of lures on traps.

There is very little empirical data about the decisions saproxylic beetles make in search of a suitable host. The current hypothesis that silhouette alone can explain trap performance does not seem to be the complete picture. Extensive studies are required to describe the types of behaviors that saproxylic beetles exhibit as they approach or circle a target. Landing behaviors, once a choice is made, may well explain the propensity of one trap to outperform another type of trap in catching beetles. Some species may take off soon after landing, possibly landing again on the same trap or moving on to another host or trap. Exploratory behaviors once a beetle lands on a tree may result in an increased potential of capture in traps like the funnel trap. Most saproxylic beetles orient to stumps, downed trees and scattered woody debris rather than live standing trees. Unlike standing trees, downed woody debris can be tangled and complicated to orient through, with beetles exploring such structures to find appropriate breeding materials.

Understanding these behaviors and the variation between species may help us to better understand the community ecology of saproxylic insects as well as to develop better monitoring tools for native and exotic species. Based on our results and those of Dodds et al. (2010), we suggest that government agencies should consider more than one type of trap in their detection programs when targeting a broad spectrum of saproxylic beetles as no single trap type seems to be the best performer for all species of saproxylic beetles in the southeastern United States.

Acknowledgments

We thank Chris Asaro and Dana Johnson for field and laboratory assistance; the staff of the Sumter and Apalachicola National Forests for access and field assistance; and Jeremy Allison, Kevin Dodds, and two anonymous referees for reviews of the manuscript.

References Cited

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

Borden, J. H., L. J. Chong, R. Gries, and H. D. Pierce, Jr. 2001. Potential for nonhost volatiles as repellents in integrated pest management for ambrosia beetles. Integr. Pest Manag. Rev. 6: 221–236.

Brockerhoff, E. G., D. C. Jones, M. O. Kimberley, D. M. Suckling, and T. Donaldson. 2006. Nationwide survey for invasive wood-boring and bark beetles (Coleoptera) using traps baited with pheromones and kairomones. For. Ecol. Manag. 228: 234–240.

Clarke, S. 2001. Review of the operational IPM program for the southern pine beetle. Integr. Pest Manag. Rev. 6: 293–301.

Clements, R. W., and H. G. Williams. 1981. Attractants, techniques, and devices for trapping bark beetles. U.S. Dep. Agric.–Forest Service, Southeastern Forest Experiment Station Research Note SE–309. Asheville, NC.

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. U.S. Dep. Agric.–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, M. J. Wingfield and P. de Groot (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.

Fatzinger, C. W. 1985. Attraction of the black turpentine beetle (Coleoptera: Scolytidae) and other forest Coleoptera to turpentine-baited traps. Environ. Entomol. 14: 768–775.

Glantz, S. A. 2005. Primer of biostatistics, p. 520. McGraw-Hill Professional, New York.

de Groot, P., and R. Nott. 2001. Evaluation of traps of six different designs to capture pine sawyer beetles (Coleoptera: Cerambycidae). Agric. For. Entomol. 3: 107–111.

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.

ITIS. 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. U.S. Dep. Agric.–APHIS, PPQ. Raleigh, NC. 246 p. (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 dryland log sorting area in British Columbia. For. Chron. 70: 159–163.

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. 2009. Length of multiple-funnel traps affects catches of some bark and wood boring beetles in a slash pine stand in northern Florida. Fla. Entomol. 92: 506–507.

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.

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.

Nehme, M. E., M. A. Keena, A. Zhang, T. C. Baker, Z. Xu, and K. Hoover. 2010. Evaluating the use of male-produced pheromone components and plant volatiles in two trap designs to monitor *Anoplophora glabripennis.* Environ. Entomol. 39: 169–176.

Pepper, W. D., S. J. Zarnoch, G. L. DeBarr, P. de Groot, and C. D. Tangren. 1997. Choosing a transformation in analyses of insect counts from contagious distributions with low means. U.S. Dep. Agric.–Forest Service, Southern Research Station Research Paper SRS–5. Asheville, NC.

Rabaglia, R., D. Duerr, R. Acciavatti, and I. Ragenovich. 2008. Early detection and rapid response for non-native bark and ambrosia beetles, 12 p. U.S. Dep. Agric.-Forest Service, Forest Health Protection, Washington, DC. (http://www.fs.fed.us/foresthealth/publications/EDRRProjectReport.pdf).

Sweeney, J., J. M. Gutowski, J. Price, and P. de Groot. 2006. Effect of semiochemical release rate, killing agent, and trap design on detection of *Tetropium fuscum* (F.) and other longhorn beetles (Coleoptera: Cerambycidae). Environ. Entomol. 35: 645–654.

Received 20 May 2011; accepted 27 August 2011.