Trap Type Affects Catches of Bark and Woodboring Beetles in a Southern Pine Stand[1]

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Abstract In 2012, we tested the relative efficacy of four commercial types of insect traps (panel; standard multiple-funnel; modified multiple-funnel; and sea, land, and air Malaise [SLAM]) for capturing bark and woodboring beetles (Coleoptera) in a pine stand in northcentral Georgia. All traps were baited with ethanol, α-pinene, ipsenol, and ipsdienol lures. The SLAM trap outperformed the panel trap for diversity and abundance of Cerambycidae. Mean catches of *Asemum striatum* (L.) in SLAM traps were greater than those in all other traps. SLAM traps caught more *Acanthocinus obsoletus* (LeConte) and *Xylotrechus sagittatus* (Germar) than standard multiple-funnel funnel and panel traps. The greatest numbers of *Monochamus titillator* (F.) were in SLAM and modified multiple-funnel traps. In contrast, SLAM traps were inferior to all other trap types in trapping bark beetles (Curculionidae: Scolytinae). More *Dendroctonus terebrans* (Olivier), *Hylastes porculus* Erichson, and *Hylastes salebrosus* Eichhoff were captured in panel traps than the other types of traps. Catches of *Ips avulsus* (Eichhoff), *Ips calligraphus* (Germar), *Orthotomicus caelatus* (Eichhoff), and *Pityophthorus* spp. were the same in panel, standard multiple-funnel, and modified multiple-funnel traps. Our data suggest that combinations of trap types should be considered in maximizing the effectiveness of detection programs for pine bark and woodboring beetles.

Key Words Cerambycidae, Curculionidae, multiple-funnel trap, panel trap, SLAM

Detection programs for bark and woodboring beetles (Coleoptera) in North America commonly use one of two commercial types of intercept traps (multiple-funnel or panel) (Bowers et al. 2018, Rabaglia et al. 2019). Originally designed to capture ambrosia beetles (Lindgren 1983), the multiple-funnel trap (baited with semiochemicals) has been used for decades to monitor populations of ambrosia beetles in and around wood-processing areas in British Columbia, Canada, to prioritize management actions for minimizing degradation of lumber (Lindgren and Borden 1983, Lindgren and Fraser 1994). Similarly, baited multiple-funnel traps are used in the southern United States to monitor populations of the southern pine beetle, *Dendroctonus frontalis* Zimmermann (Curculionidae: Scolytinae) and its associated predator *Thanasimus dubius* F. (Cleridae) to determine epidemic status of *D. frontalis* and help focus management actions to minimize mortality of southern pines (Billings and Upton 2010, Dodds et al. 2018, Hassett et al. 2016).

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First designed to catch Douglas-fir beetles, *Dendroctonus pseudotsugae* Hopkins (Scolytinae), the panel trap was found to be an effective trap for woodborers in general (Allison and Redak 2017, Czokajlo et al. 2001). The need for efficacious traps for longhorn woodborers (Cerambycidae) became apparent with invasions of exotic species such as the Asian longhorned beetle, *Anoplophora glabripennis* Motschulsky, and persistent threats from *Monochamus* spp., vectors for the pinewood nematode (Eyre and Haack 2017, Rassati et al. 2019).

Choosing one trap type for several taxa of interest is difficult as trapping results differ between and within species. With respect to bark and ambrosia beetles (Scolytinae), Petrice et al. (2004) in New York found that multiple-funnel traps baited with ethanol and α-pinene caught more *Hylurgus ligniperda* (F.) and *Tomicus piniperda* (L.) than panel traps with the same baits; catches of four other scolytine species including *Xyleborinus saxesenii* Ratzeburg were unaffected by trap type. With a similar lure blend in Georgia, the panel trap outperformed the multiple-funnel trap for *X. saxesenii* as well as for *Xyleborus* spp., *Dendroctonus terebrans* (Olivier), *Hylastes salebrosus* Eichhoff, and *Hylastes tenuis* Eichhoff but not for four other scolytines (Miller and Crowe 2011). In the northeastern United States, Dodds et al. (2010) found beetle catches were greater in panel traps than in funnel traps for *Gnathotrichus materiarius* (Fitch) and *Hylurgops pinifex* (Fitch) but not for six other scolytine species.

With respect to longhorn woodborers (Cerambycidae), researchers have attempted to design better traps for the past three decades with mixed results (Allison et al. 2014, de Groot and Nott 2001, Graham et al. 2012, Graham and Poland 2012, McIntosh et al. 2001, Morewood et al. 2002, Sweeney et al. 2006). For example, in Georgia the panel trap outperformed the multiple-funnel trap for *Acanthocinus nodosus* (F.) and *Monochamus titillator* (F.) but not for two other common pine cerambycids, which were unaffected by trap type (Miller and Crowe 2011). Similarly, the panel trap was better than the multiple-funnel trap for *Asemum striatum* (L.) but not for two other cerambycid species in northeastern United States (Dodds et al. 2010). In contrast, Allison et al. (2014) conducted two experiments in Louisiana with traps baited with separate lure blends per experiment targeting Lamiinae and Cerambycinae. They found that catches of lamiines and cerambycines in the two experiments, respectively, were higher in multiple-funnel traps than in panel traps.

One operational problem with multiple-funnel traps is that some of the current lures for Cerambycidae (such as those releasing the host compounds ethanol and α-pinene) are too big to fit within the funnels and are typically attached to the sides of the trap. In designing the multiple-funnel trap, Lindgren (1983) noted that smoke released from a source within the funnels dispersed from all the funnels whereas a smoke source on the outside of the trap resulted in a limited point source of smoke emission and dispersion. A recent modification of increasing the opening size of funnels in the standard multiple-funnel now allows lures to be placed within the funnels, resulting in increased performance of the multiple-funnel trap for pine longhorn beetles compared to the standard multiple-funnel trap (Miller et al. 2013a). In Georgia, catches of five common cerambycid species in modified multiple-funnel traps baited with ethanol, α-pinene, ipsenol, and ipsdienol lures (hung within the funnels) were significantly greater (by 108–429%) than those in standard multiple-funnel traps with the same lures hung outside the funnels (Miller et al. 2013a).

Using attractants for hardwood species of Cerambycidae, Dodds et al. (2015) evaluated the standard and modified multiple-funnel traps along with the panel trap at four locations in the eastern United States. They added the sea, land, and air Malaise (SLAM) trap to the mix of trap types. In contrast to the other trap types with bottom collectors, the SLAM trap has a top collector, which is a beneficial feature for detecting phototropic beetles. Many species of Cerambycidae are known to feed and breed in tree canopies or open shrubland (USDA 1985). In Massachusetts and Georgia, Dodds et al. (2015) found that abundance and diversity of cerambycids were highest in baited SLAM traps. Moreover, SLAM traps caught the greatest number of unique species at all four locations. SLAM and/or modified multiple-funnel traps outperformed panel and standard multiple-funnel traps in trapping seven species of Cerambycidae in Georgia, Louisiana, and Massachusetts (Dodds et al. 2015).

Our goal was to evaluate the four commercial insect traps baited with attractants for pine species of bark and woodboring beetles in a stand of southern pines. The combination of ethanol, α-pinene, ipsenol, and ipsdienol is broadly attractive to pine bark and woodboring beetles in southeastern United States (Miller et al. 2011, 2013b, 2015).

Materials and Methods

A trapping study was conducted in the Scull Shoals Experimental Forest in northcentral Georgia (N 33.7731°, W 83.2396°) to test the effects of trap type (baited with pine volatiles and pine engraver beetle pheromones) on catches of beetles that inhabit pine trees. The dominant species at the trapping site was *Pinus taeda* L. with *Pinus echinata* Miller, *Quercus alba* L., *Quercus falcata* Michaux, *Carya tomentosa* (Poirier), and *Liquidambar styraciflua* L. also present. As in Dodds et al. (2015), the following types of intercept traps were used in this study: (a) standard 12-unit black multiple-funnel trap (Contech Enterprises, Delta, British Columbia, Canada) (Fig. 1A); (b) black panel trap (Contech Enterprises) (Fig. 1B); (c) 10-unit black multiple-funnel trap (Synergy Semiochemicals, Burnaby, British Columbia, Canada) (Fig. 1C) modified as in Miller et al. (2013a) by increasing the size of the bottom diameter of each funnel; and (d) standard SLAM trap ($1.1 \times 1.1 \times 1.1$ m) (MegaView Science Co. Ltd., Taichung City, Taiwan) (Fig. 1D).

Traps were set 13 September–25 October 2012 in a randomized complete block design with 10 replicate blocks. All traps were hung on twine strung between trees such that traps were spaced 8–12 m from each other and $\geq$2 m from any tree. The collection cups at the bottom of the panel and funnel traps were approximately 0.5 m above ground level (AGL) whereas the collection cups at the top of the SLAM traps were approximately 1.5 m AGL. All collection cups contained 100–150 ml of propylene glycol antifreeze (SPLASH RV and Marine Antifreeze, Fox Packaging Inc., St. Paul, MN) (Miller and Duerr 2008). Each trap was baited with black ethanol and blue α-pinene lures (Contech Enterprises), and white racemic ipsenol and white racemic ipsdienol bubble-cap lures (Synergy Semiochemicals). The release rates from these lures were 0.5 g/d, 1–2 g/d, 0.1–0.2 mg/d, and 0.1–0.2 mg/d, respectively (determined by the manufacturers at 23°C). The enantiomeric composition of α-pinene was 75% (−): 25% (+). All chemical purities were >95%.

Fig. 1. Trap types used in northcentral Georgia (13 September–25 October 2012): 12-unit standard multiple-funnel trap (F); panel trap (P); 10-unit modified multiple-funnel trap (M); and sea, land, and air Malaise trap (SLAM [S]). All traps were baited with black ethanol, blue α-pinene, white ipsenol, and white ipsdienol lures.

Lures were hung on the outside of the standard multiple-funnel and SLAM traps (Fig. 1A, D) whereas lures were hung in the inside of the modified multiple-funnel and panel traps (Fig. 1B, C). Voucher specimens were deposited in the University of Georgia Collection of Arthropods (Athens, GA).

For species caught in total numbers $\geq$30, the SYSTAT (ver. 13) and SigmaStat (ver. 3.01) statistical packages (SYSTAT Software Inc., Point Richmond, CA) were used to analyze trap catch data, transformed by $\ln(Y + 1)$ as needed to ensure normality and homoscedasticity (Pepper et al. 1997); normality and homoscedasticity were verified with the Shapiro–Wilk and Levene's tests, respectively. Effects of trap types on catches of each species was determined by mixed-model analysis of variance using block as a random factor and trap type as the fixed factor. Analyses were followed by the Holm–Sidak multiple comparison procedure ($P < 0.05$); the Holm–Sidak procedure controls the experiment-wise error rate at 0.05 (Glantz 2005). For two species, data for SLAM traps were omitted in the analyses because of zero total catches in these traps (Reeve and Strom 2004). In these instances, the mean catches for the remaining treatments were tested for difference from zero using a *t* test with Bonferroni correction for multiple contrasts.

Results

Cerambycidae. We detected 12 species of cerambycids for a total of 1,477 longhorn beetles captured in our study; 41% of all cerambycids were caught in SLAM traps (Table 1). The mean diversity of cerambycid species per replicate was greater in SLAM traps than in panel traps (Table 2). Mean catches of *As. striatum* in SLAM traps were greater than those in all other traps. SLAM traps caught more *Acanthocinus obsoletus* (LeConte) and *Xylotrechus sagittatus* (Germar) than standard funnel and panel traps. The greatest numbers of *M. titillator* were in SLAM and modified funnel traps and the lowest numbers in standard funnel and panel traps. Trap type had no effect on catches of *Astylopsis arcuata* (LeConte) ($F = 2.618$; df $= 3, 27$; $P = 0.071$); mean ± SE trap catch $= 1.3 \pm 0.3$.

Curculionidae. Twenty-five species of snout, bark, and ambrosia beetles were detected in our study; SLAM traps caught only 3% of total curculionids (Table 1). The mean diversity of curculionid species per replicate was lower in SLAM traps than in all other trap types (Table 2). Catches of *D. terebrans* and *Hylastes porculus* Erichson were highest in panel traps and lowest in SLAM traps (Table 2). Panel traps caught more *H. salebrosus* than standard funnel and SLAM traps. For *Ips avulsus* (Eichhoff), more beetles were caught in standard funnel traps than in SLAM traps. Catches of *H. tenuis*, *Ips calligraphus* (Germar), *Orthotomicus caelatus* (Eichhoff), and *Pityophthorus* spp. were all lower in SLAM traps than in the other three trap types, with no differences among the funnel and panel traps. Trap type had no effect on catches of *Hylobius pales* (Herbst) ($F = 1.461$; df $= 3, 27$; $P = 0.247$); mean ± SE trap catch $= 3.1 \pm 0.5$.

Discussion

Clearly, catches of bark and woodboring beetles were affected by trap type in our study. As in Miller and Crowe (2011), both multiple-funnel and panel traps were

Table 1. Total catches of bark and woodboring beetles (Coleoptera) in standard 12-unit multiple-funnel (F); panel (P); modified 10-unit multiple-funnel (M); and sea, land, and air Malaise (SLAM [S]) traps baited with ethanol, α-pinene, ipsenol, and ipsdienol.

	Trap Type				
Family, Species	**F**	**P**	**M**	**S**	**Total**
Cerambycidae					
Acanthocinus nodosus (F.)	1	—	3	2	6
Acanthocinus obsoletus (LeConte)	46	31	77	182	336
Arhopalus rusticus (L.)	1	1	2	—	4
Asemum striatum (L.)	12	9	16	36	73
Astylopsis arcuata (LeConte)	12	6	11	25	54
Astylopsis sexguttata (Say)	1	3	6	12	22
Curius dentatus Newman	—	—	—	1	1
Eupogonius tomentosus (Haldeman)	1	—	—	—	1
Monochamus titillator (F.)	129	110	201	235	675
Neoclytus acuminatus (F.)	—	—	—	3	3
Xylotrechus colonus (F.)	1	—	—	2	3
Xylotrechus sagittatus (Germar)	81	43	73	102	299
Total no. of Cerambycidae	285	203	389	600	1,477
Curculionidae					
Ambrosiodmus tachygraphus (Zimmermann)	—	—	—	1	1
Cnestus mutilatus (Blandford)	1	—	—	—	1
Corthylus columbianus Hopkins	—	—	—	1	1
Cossonus spp.	—	1	1	—	2
Dendroctonus terebrans (Olivier)	232	408	210	11	861
Dryoxylon onoharaense (Murayama)	3	—	1	—	4
Gnathotrichus materiarius (Fitch)	1	3	1	1	6
Hylobius pales (Herbst)	33	26	43	21	123
Hylastes porculus Erichson	52	109	50	8	219
Hylastes salebrosus Eichhoff	31	59	37	2	129
Hylastes tenuis Eichhoff	37	44	52	8	141
Hypothenemus rotundicollis (Eichhoff)	—	—	5	—	5
Ips avulsus (Eichhoff)	141	66	40	2	249

Table 1. Continued.

	Trap Type				
Family, Species	**F**	**P**	**M**	**S**	**Total**
Ips calligraphus (Germar)	30	48	65	3	146
Ips grandicollis (Eichhoff)	7	7	1	2	17
Myoplatypus flavicornis (F.)	7	13	4	—	24
Orthotomicus caelatus (Eichhoff)	32	46	32	—	110
Pachylobius picivorus (Germar)	—	—	—	4	4
Pissodes nemorensis Germar	—	1	—	2	3
Pityophthorus spp.	17	20	18	—	55
Xyleborinus saxesenii (Ratzeburg)	6	8	4	—	18
Xyleborus bispinatus Eichhoff	1	3	1	—	5
Xyleborus ferrugineus (F.)	—	—	1	—	1
Xyleborus pubescens Zimmermann	3	5	3	—	11
Xylosandrus crassiusculus (Motschulsky)	2	—	4	—	6
Total no. of Curculionidae	636	867	573	66	2,142

effective for trapping bark beetles and snout weevils with panel traps more effective for a few species; SLAM traps were clearly ineffective (Table 2), although the addition of a bottom collector can improve trap catches (Dodds et al. 2010). Four of five species of cerambycids (*Ac. obsoletus*, *As. striatum*, *M. titillator*, and *X. sagittatus*) were more common in SLAM or SLAM and modified-funnel traps than in panel or standard funnel traps. These data are similar to those for four species of cerambycids captured in Georgia and four species captured in Massachusetts with the same trap types, baited with hardwood lure blends (Dodds et al. 2015). As in Miller et al. (2013a), modified multiple-funnel traps in our study were as good as, if not better than, standard multiple-funnel traps in trapping cerambycids (Table 2).

Our results and those of Dodds et al. (2010, 2015) strongly suggest a benefit of using a canopy Malaise trap such as the SLAM trap as part of any program broadly assessing the diversity of Cerambycidae in forested areas. SLAM traps can detect the highest diversity of total and unique cerambycid species (Dodds et al. 2015). The biggest obstacle to operational use of the SLAM trap may be its cost at four to six times the cost of the other two traps. Managers may find it more cost-effective to buy and deploy more panel or multiple-funnel traps for the same money. The issue of the top collector as a useful feature for increasing captures of cerambycid species may be one that needs further study. It might be possible to modify an existing panel trap with a top collector without increasing the cost too much and still retain the ability to capture bark and ambrosia beetles.

Table 2. Mean ± SE catches of beetles in 12-unit standard multiple-funnel (F); panel (P); 10-unit modified multiple-funnel (M); and sea, land, and air Malaise (SLAM [S]) traps (all baited with ethanol, α-pinene, ipsenol, and ipsdienol). Means for a species followed by the same letter are not significantly different at $P = 0.5$ (Holm–Sidak test).

Family, Species	**Mean ± SE trap catches**			
	F	**P**	**M**	**S**
Cerambycidae				
Mean ± SE no. of species	4.4 ± 0.4 ab	3.5 ± 0.6 a	5.1 ± 0.4 ab	5.7 ± 0.6 b
Acanthocinus obsoletus	4.6 ± 1.2 a	3.1 ± 1.2 a	7.7 ± 2.5 ab	18.2 ± 4.8 b
Asemum striatum	1.2 ± 0.4 a	0.9 ± 0.4 a	1.6 ± 0.5 a	3.6 ± 1.0 b
Monochamus titillator	12.9 ± 3.3 a	11.0 ± 2.1 a	20.1 ± 2.3 b	23.5 ± 3.4 b
Xylotrechus sagittatus	8.1 ± 2.6 ab	4.3 ± 1.4 a	7.3 ± 2.1 ab	10.2 ± 2.3 b
Curculionidae				
Mean ± SE no. of species	9.6 ± 0.6 b	10.7 ± 0.3 b	10.6 ± 0.6 b	3.5 ± 0.6 a
Dendroctonus terebrans	23.2 ± 4.0 b	40.8 ± 9.7 c	21.0 ± 3.7 b	1.1 ± 0.7 a
Hylastes porculus	5.2 ± 1.5 b	10.9 ± 2.6 c	5.0 ± 1.5 b	0.8 ± 0.2 a
Hylastes salebrosus	3.1 ± 1.1 b	5.9 ± 1.4 c	3.7 ± 0.6 b	0.2 ± 0.2 a
Hylastes tenuis	3.7 ± 0.6 b	4.4 ± 1.0 b	5.2 ± 0.7 b	0.8 ± 0.4 a
Ips avulsus	14.1 ± 8.3 b	6.6 ± 4.9 ab	4.0 ± 2.1 ab	0.2 ± 0.1 a
Ips calligraphus	3.0 ± 0.6 b	4.8 ± 1.0 b	6.5 ± 1.2 b	0.3 ± 0.2 a
Orthotomicus caelatus	3.2 ± 0.6 *	4.6 ± 1.0 *	3.2 ± 1.2 *	0
Pityophthorus spp.	1.7 ± 0.7 *	2.0 ± 0.4 *	1.8 ± 0.8 *	0

* For species with no catches in SLAM traps, means for remaining trap treatments are significantly different from zero at $P < 0.05$ (multiple *t* tests per species with Bonferroni correction).

Results from our study add further evidence of interspecific variation in trap efficacies for Cerambycidae, not surprising given the variation in life histories of Cerambycidae. In our study, catches of *M. titillator* were greatest in modified multiple-funnel traps and SLAM traps (Table 2) whereas Dodds et al. (2015) found no effect of trap type on catches of *Monochamus carolinensis* (Olivier). In Bouwer et al. (2020), SLAM traps were inferior to panel and multiple-funnel traps for *Monochamus scutellatus* (Say); panel and SLAM traps were equally effective for *Monochamus notatus* (Drury) and *Monochamus maculosus* (= *mutator*) (Haldeman). In Dodds et al. (2015), SLAM traps were better than panel and modified multiple-funnel traps for catching *Graphisurus fasciatus* (DeGeer), *Neoclytus acuminatus* (F.), and *Neoclytus scutellaris* (Olivier), whereas modified multiple-funnel traps were better than the other two for *Knulliana cincta* (Drury); panel and modified multiple-funnel traps were better than SLAM traps for *Phymatodes aeneus* (Newman).

Intraspecific variation in catches of cerambycids further confounds selection of trap types, likely reflecting geographic variation in behavioral responses and/or variation in lures used in studies. In Dodds et al. (2015), three different lure blends were used across four locations in eastern United States. For *X. sagittatus*, they found that catches were unaffected by trap type in Massachusetts whereas in Louisiana catches were lower in SLAM traps than in panel traps. In our study, catches of *X. sagittatus* were greater in SLAM traps than in panel traps (Table 2). For *Xylotrechus colonus* (F.), Dodds et al. (2015) found that catches were unaffected by trap type in Massachusetts whereas in Louisiana and Georgia catches were greater in SLAM traps than in panel or modified multiple-funnel traps. In contrast, catches of *X. colonus* in New York were greater in modified multiple-funnel traps than in panel or SLAM traps (Dodds et al. 2015). Modified multiple-funnel traps outperformed SLAM traps for catching *Neoclytus mucronatus* (F.) in Louisiana but not in Massachusetts and Georgia where catches were the same in both trap types. Similarly, SLAM traps outperformed multiple-funnel traps for catching *N. scutellaris* in Georgia but not in Louisiana and Massachusetts. Further research to identify the factors underlying intraspecific variation should be conducted in order to assuage concerns by managers.

Managers of insect trapping programs typically use specific traps, lures, and protocols that maximize the likelihood of trapping a specific target species or species group. However, managers of trapping programs that broadly target bark and woodboring beetles should consider using a combination of several types of traps. This is particularly true for efforts to detect new invasive species, assuming that patterns exhibited by native species are likely to be reflected by nonnative species when they invade the United States.

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