Effect of Distance Between Baited Multiple-Funnel Traps on Catches of Bark and Wood-Boring Beetles (Coleoptera: Curculionidae, Cerambycidae) and Associates in North-Central Georgia[1]

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Effect of Distance Between Baited Multiple-Funnel Traps on Catches of Bark and Wood-Boring Beetles (Coleoptera: Curculionidae, Cerambycidae) and Associates in North-Central Georgia[1]

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Abstract In the fall of 2011, we examined the effects of inter–trap distances of 2, 6, and 12 m on catches of bark and wood-boring beetles (and associates) in traps baited with either ethanol + α-pinene (EA) or ipsenol + ipsdienol (SD) in a stand of loblolly pine, *Pinus taeda* L., in northern Georgia. Traps baited with EA interrupted catches of *Ips avulsus* (Eichhoff) (Coleoptera: Curculionidae: Scolytinae) in traps baited with SD at a distance of 2 m but not at distances of 6 or 12 m. In contrast, catches of *I. avulsus* and *Dendroctonus terebrans* (Olivier) in traps with EA were greatest in those traps spaced 2 m from the traps baited with SD and lowest at an inter–trap distance of 12 m. Similarly, catches of *Monochamus titillator* (F.) (Cerambycidae) in traps baited with EA were increased when spaced 2 m from traps baited with SD but not at a spacing of 6 or 12 m. The mean (± SE) diversity of species in traps baited with EA was 19.1 ± 0.5 species/trap and unaffected by distance to traps baited with SD. In contrast, the mean (± SE) species diversity in SD traps was higher in traps 2 m from EA traps (12.8 ± 0.8 species/trap) and lowest in traps 12 m EA traps (8.8 ± 0.5 species/trap). More studies are needed to elucidate the interactions between volatiles emitted from different traps on responses by flying beetles.

Key Words *Ips avulsus*, *Monochamus titillator*, *Dendroctonus terebrans*, pheromones, kairomones

Early-detection programs for nonnative, potentially invasive species of bark and wood-boring beetles (Coleoptera: Buprestidae, Cerambycidae, Curculionidae) use traps baited with attractants (Jackson et al. 2010, Rabaglia et al. 2008). Typically, traps are deployed at distances of ≥30 m between traps to minimize trap interaction and maximize spatial coverage. However, there is little information on the best spacing between traps to minimize interactions between lures in separate traps. The primary concern of trap spacing to program managers is with negative effects (interruptive) as positive effects only strengthen detection abilities.

A few trapping studies on *Dendroctonus* spp. (Curculionidae: Scolytinae) have found interruptive effects of antiaggregation pheromones on catches of beetles to pheromone-baited traps over short distances. Miller (2002) used a linear array of seven multiple-funnel traps spaced 2 m apart with all traps baited with the pheromones *exo-*

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brevicomin and *trans*-verbenol, and the kairomone myrcene, to find that the interruptive effect of verbenone on catches of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, extended over a horizontal distance of 4 m. Similarly, Fettig et al. (2009) found that the distance of the interruptive effect of verbenone on catches of *D. brevicomis* LeConte in multiple-funnel traps baited with the pheromones frontalin and *exo*-brevicomin, and the kairomone myrcene was only 2 m.

Our goal was to assess the effect of inter–trap distance on trap catches of bark and wood-boring beetles over short horizontal distances (2–12 m). In Georgia, bark and wood-boring beetles are broadly attracted to traps baited with bark beetle pheromones and host volatiles (Miller 2006, Miller and Asaro 2005, Miller and Rabaglia 2009). Catches of the southern pine sawyer, *Monochamus titillator* F. (Cerambycidae), in traps baited with the quaternary blend of ethanol + α-pinene + ipsenol + ipsdienol (EA + SD) are greater than those in traps baited with either one of the two binary blends of ethanol + α-pinene (EA) or ipsenol + ipsdienol (SD) (Miller et al. 2011). In contrast, EA reduces catches of the small southern pine engraver, *Ips avulsus* (Eichhoff) (Curculionidae: Scolytinae), in traps baited with SD (Miller et al. 2011). Our objective was to assess the interruptive and additive effects of EA and SD on catches of these two species in traps baited separately with these two binary blends.

Materials and Methods

The study was conducted 7 September–17 November 2011 on the Whitehall Forest (University of Georgia) in Athens, GA. The site (N 33.8915°, W 83.3701°) is a preoperational seed orchard of loblolly pine, *Pinus taeda* L., with trees spaced at 6 m × 6 m. The following lures were purchased from Contech Enterprises Inc. (Victoria, British Columbia, Canada): E—ethanol ultrahigh release (UHR) pouches (0.5 g/d at 25°C); A—**α**-pinene UHR pouches (1–6 g/d at 25°C); S—racemic ipsenol 40-mg bubblecap (0.2 mg/d at 23°C); and D—racemic ipsdienol 40-mg bubblecap (0.1 mg/d at 23°C).

We placed 60 ten-unit multiple-funnel traps (Contech Enterprises Inc.) in 10 blocks of three pairs of traps per block with pairs of traps spaced 48–58 m apart (Fig. 1). Each trap was modified by increasing the center hole of each funnel from 5 to 12 cm thereby allowing placement of lures within the funnels (Miller et al. 2013). Trap pairs were aligned north–south with a spacing of 2, 6, or 12 m between traps in a trap pair, randomly allocated within a block. Each of the two traps within each pair was allocated randomly one of the two following bait combinations: (a) EA, or (b) SD. Each collection cup contained 150–200 ml of Splash RV & Marine Antifreeze (SPLASH Products Inc., St. Paul, MN) (a.i., propylene glycol) as a killing and preservation agent (Miller and Duerr 2008). Catches were collected every 2 weeks with new antifreeze solution added on each occasion. Voucher specimens of all species were deposited in the Collection of Arthropods, Georgia Museum of Natural History, University of Georgia (Athens).

For each species, analyses were conducted with the SigmaStat (ver. 3.01) statistical package (SYSTAT Software Inc., Point Richmond, CA) on total numbers of insects captured per trap throughout the trapping period for species with sufficient number of captured beetles ($N \geq 30$). Unless otherwise noted, trap catch data were transformed by $\ln(Y + 1)$ to ensure homoscedasticity and normality (Pepper et al.

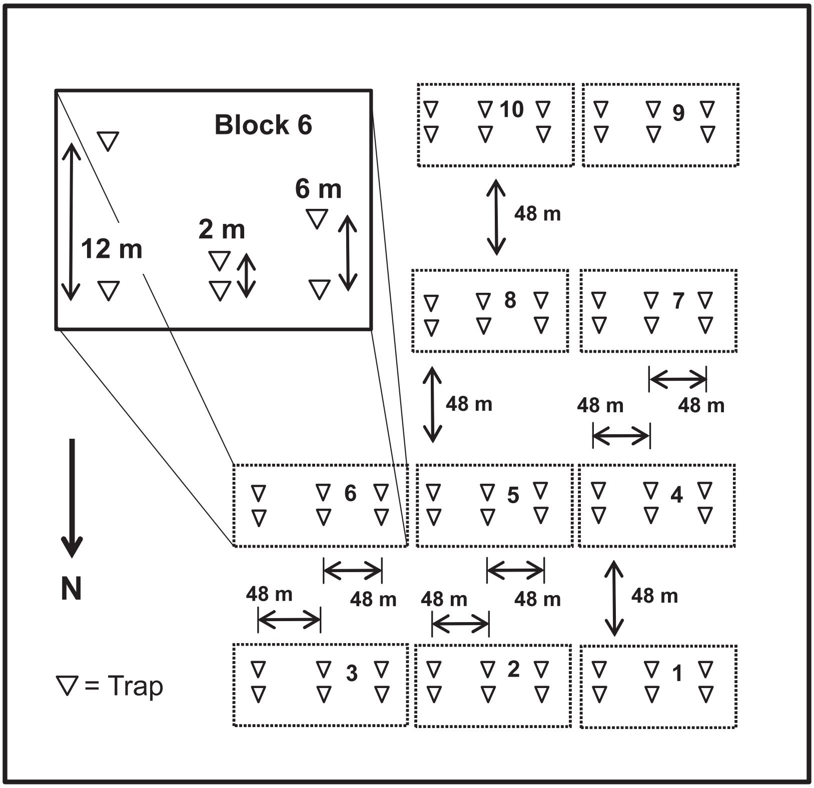

Fig. 1. Trap layout in loblolly pine seed orchard in 2011. Ten replicate blocks (1–10) of six traps per block, set in three pairs of traps spaced 2–12 m apart for a total of 60 traps. Figure not to scale.

1997). Normality and homoscedasticity were verified using the Kolmogorov–Smirnov and Equal Variance tests, respectively. Catch data for traps baited with EA were analyzed separately from those data for traps baited with SD. Data for each analysis were subjected to ANOVA using the following model components: (a) replicate, and (b) distance between traps. The Holm–Sidak multiple comparison test (Glantz 2005) was used to compare means for each species exhibiting a significant treatment effect ($\alpha = 0.05$). The Holm–Sidak test controls the experiment-wise error rate at 0.05.

Results

A total of 28,253 beetles representing 34 species or taxa were captured in the experiment, with the greatest abundance (24,865) in traps baited with SD (Table 1). Of the total number captured in SD traps, *I. avulsus* and *Ips grandicollis* (Eichhoff) accounted for 78% and 19% of total catch, respectively. Only the response of *I.*

avulsus to baited traps was affected by the distance between traps within trap pairs (Table 2). The mean number of *I. avulsus* captured in SD traps was 34% lower at a spacing of 2 m from EA traps than in SD traps at a spacing of 6 m from EA traps; catches in traps spaced 12 m from EA traps were intermediary. The proximity of EA had no effect on catches of *I. calligraphus* (Germar) and *I. grandicollis* in SD traps (Table 2). The same was true for *M. titillator*, *Platysoma* spp. (Histeridae), *Corticeus* spp. (Tenebrionidae), and *Lasconotus* spp. (Zopheridae).

A total of 3,388 beetles were captured in EA traps (Table 1). Bark and ambrosia beetles accounted for 43% of total catch with longhorn beetles and beetle predators/ectoparasites accounting for 18% and 32% of catches, respectively. The responses of three species to EA traps were affected by the proximity of SD traps (Table 3). Catches of *I. avulsus* and *Dendroctonus terebrans* (Olivier) were highest in EA traps spaced 2 m from SD traps and lowest in traps spaced 12 m from SD traps. Catches of both species were intermediary in EA traps spaced 6 m from SD traps. Similarly, catches of *M. titillator* in EA traps were higher at trap spacing of 2 m from SD traps than at trap spacing of 6 or 12 m from SD traps. Trap spacing had no effect on catches of the following ambrosia and bark beetles in EA traps: *Hylastes salebrosus* Eichhoff, *Hylastes tenuis* Eichhoff, *Hypothenemus* spp., *I. grandicollis*, *Xyleborinus saxesenii* (Ratzeburg), *Xyleborus* spp., and *Xylosandrus crassiusculus* (Motschulsky) (Table 3). Similarly, there was no effect on catches of the weevils *Hylobius pales* Herbst and *Pissodes* spp., the longhorn beetle *Xylotrechus sagittatus* (Germar), and the following species of bark beetle predators and associates: *Thanasimus dubius* F. (Cleridae), *Platysoma* spp., *Corticeus* spp., *Lasconotus* spp., *Namuria guttulata* (LeConte), and *Pycnomerus sulcicollis* LeConte (Zopheridae) (Table 3).

Species diversity of bark and wood-boring beetles, and their associates, detected in traps was affected by inter–trap distances for SD traps but not for EA traps (Table 4). The mean diversity in SD traps was higher in traps 2 m from EA traps than in SD traps 12 m from EA traps. The diversity in traps spaced 6 m from EA traps was intermediary. The mean ($\pm$ SE) diversities in EA and SD traps were 19.1 $\pm$ 0.5 and 10.8 $\pm$ 0.5 species/trap, respectively.

Discussion

At times, researchers are concerned that placing traps too close together in an experiment might reduce mean trap catches and reduce the power of means separation tests. It is also possible that rare species might be underrepresented by placing traps over a small area. A rare beetle can only be caught once. However, these concerns may not be relevant to managers of detection programs. It may not matter which trap catches a rare exotic beetle ... just as long as it is caught. Some of our results in this study are consistent with this viewpoint. Traps baited with EA had higher catches of *I. avulsus*, *D. terebrans*, and *M. titillator* were higher near SD traps (2–6 m) (Table 3).

In contrast, interruption of trap attraction should be a concern to managers. Our results on the interruptant effect of EA on attraction of *I. avulsus* to pheromone-baited traps are consistent with those on the effects of verbenone on *D. ponderosae* and *D. brevicomis* (Fettig et al. 2009, Miller 2002). In all cases, the

Table 1. Total catches of beetles (Coleoptera) in traps baited with ethanol + α-pinene (EA) or ipsenol + ipsdienol (SD) ($n = 30$) in 2011 at Whitehall Forest, Athens, GA.

	Treatments	
Family and Species	EA	SD
Cerambycidae		
Acanthocinus nodosus (F.)	2	—
Acanthocinus obsoletus (Olivier)	15	11
Astylopsis arcuatus (LeConte)	2	2
Astylopsis sexguttata (Say)	1	4
Monochamus titillator (F.)	64	68
Xylotrechus colonus (F.)	1	1
Xylotrechus sagittatus (Germar)	476	5
Cleridae		
Thanasimus dubius (F.)	58	23
Curculionidae		
Cnestus mutilatus (Blandford)	3	—
Dendroctonus terebrans (Olivier)	118	9
Dryoxylon onoharaensis Murayama	9	1
Gnathotrichus materiarius (Fitch)	24	5
Hylastes salebrosus Eichhoff	83	6
Hylastes tenuis Eichhoff	80	8
Hylobius pales Herbst	124	12
Hypothenemus spp.	76	—
Ips avulsus (Eichhoff)	533	19,415
Ips calligraphus (Germar)	2	135
Ips grandicollis (Eichhoff)	81	4,677
Orthotomicus caelatus (Eichhoff)	3	2
Pachylobius picivorus (Germar)	1	1
Pissodes spp.	81	6
Xyleborinus saxesenii (Ratzeburg)	363	16
Xyleborus spp.	36	2
Xylosandrus crassiusculus (Motschulsky)	160	3

Table 1. Continued.

Family and Species	Treatments EA	SD
Histeridae		
Plegaderus spp.	26	7
Platysoma spp.	47	30
Passandridae		
Catogenus rufus F.	3	4
Tenebrionidae		
Corticeus spp.	56	39
Trogossitidae		
Temnoscheila virescens (F.)	17	10
Tenebroides spp.	20	13
Zopheridae		
Namuria guttulata (LeConte)	34	12
Lasconotus spp.	619	411
Pycnomerus sulcicollis LeConte	170	9
Total number of beetles	3,388	24,865
Total number of species	34	31

distance effect is small at <6 m. Such distances are not unexpected as antiaggregation pheromones such as verbenone typically facilitate switching of mass attacks from trees saturated with attacks to adjacent unattacked ones (Lindgren and Miller 2002). Selection favors such behaviors as it minimizes intraspecific brood mortality in mass-attacked trees and avoids decomposing hosts. Switching to adjacent trees allows a quick switch of large numbers of beetles needed to overcome a tree's defenses.

The effects of lure separation on increasing attraction of species to their lures may have some implications for trapping studies and programs that do not want to have attacks on adjacent trees (spill-over attacks). In the past two decades, we have had little if any spillover attacks with traps spaced ≥2 m from healthy trees with no obvious damage or prior attack by insects. Our results in this study suggest that traps baited with bark beetle pheromones such as ipsenol and ipsdienol be spaced at least 6 m from any tree with visible damage that might result in the release of host odors such as ethanol or α-pinene.

One clear exception are monitoring traps for the aggressive, tree-killing southern pine beetle, *Dendroctonus frontalis* Zimmermann, which has complicated spatio-

Table 2. Mean (± SE) catches of beetles (Coleoptera) in traps baited with ipsenol + ipsdienol, spaced at distances of 2–12 m from traps baited with ethanol + α-pinene (EA) ($n = 10$).*

		Distance From Trap Baited With EA				
Family and Species	***N***	**2 m**	**6 m**	**12 m**	$F_{2,18}$	***P***
Cerambycidae						
M. titillator	68	2.7 ± 0.7	1.8 ± 0.4	2.3 ± 0.4	0.253	0.779
Curculionidae						
I. avulsus **	**19,415**	**524.8 ± 89.5 a**	**791.2 ± 87.4 b**	**625.5 ± 64.6 ab**	**3.612**	**0.048**
I. grandicollis	4,677	172.7 ± 19.4	150.7 ± 11.7	144.3 ± 19.0	2.673	0.096
I. calligraphus	135	3.4 ± 0.7	4.2 ± 0.9	5.9 ± 1.1	1.748	0.202
Histeridae						
Platysoma spp.**	30	0.6 ± 0.2	1.0 ± 0.4	1.4 ± 0.5	1.102	0.354
Tenebrionidae						
Corticeus spp.	39	1.2 ± 0.5	1.3 ± 0.4	1.4 ± 0.4	0.188	0.830
Zopheridae						
Lasconotus spp.**	411	12.2 ± 2.4	14.3 ± 2.8	14.6 ± 2.1	0.455	0.642

* Means in boldface row followed by different lowercase letters are significantly different at $P = 0.05$ (Holm–Sidak test).
** Analyses conducted on nontransformed data.

Table 3. Mean (± SE) catches of beetles in traps baited with ethanol and α-pinene, spaced at distances of 2–12 m from traps baited with ipsenol and ipsdienol (SD) ($n = 10$).*

Family and Species	*N*	Distance From Trap Baited With SD			$F_{2,18}$	*P*
		2 m	6 m	12 m		
Cerambycidae						
M. titillator	**64**	**4.3 ± 0.9 b**	**1.3 ± 0.5 a**	**0.8 ± 0.2 a**	**14.97**	**<0.001**
X. sagittatus	476	13.2 ± 1.5	16.5 ± 2.7	17.9 ± 1.9	2.669	0.097
Cleridae						
T. dubius	58	2.4 ± 0.9	2.2 ± 0.7	1.2 ± 0.4	0.678	0.520
Curculionidae						
D. terebrans	**118**	**5.4 ± 0.7 b**	**3.6 ± 0.9 ab**	**2.8 ± 0.8 a**	**4.158**	**0.033**
H. salebrosus	83	2.2 ± 0.7	3.6 ± 0.7	2.4 ± 0.4	1.825	0.190
H. tenuis	80	2.6 ± 0.6	2.4 ± 0.4	3.0 ± 1.0	0.002	0.998
H. pales	124	5.4 ± 1.6	4.6 ± 1.0	2.4 ± 0.4	1.276	0.303
Hypothenemus spp.	76	1.5 ± 0.6	2.6 ± 0.7	3.5 ± 0.8	2.373	0.122
I. avulsus	**325**	**24.0 ± 5.5 c**	**7.3 ± 1.6 b**	**1.7 ± 0.5 a**	**26.48**	**<0.001**
I. grandicollis	81	4.5 ± 1.2	2.0 ± 0.6	1.6 ± 0.4	2.727	0.092
Pissodes spp.	81	1.1 ± 0.4	2.8 ± 1.2	4.2 ± 1.8	2.035	0.160
*X. saxesenii***	363	12.5 ± 1.6	11.4 ± 1.6	12.4 ± 2.0	0.165	0.849
Xyleborus spp.	36	1.1 ± 0.5	1.1 ± 0.3	1.4 ± 0.3	0.452	0.643
*X. crassiusculus***	160	6.1 ± 1.5	3.9 ± 0.7	6.0 ± 0.8	1.562	0.237
Histeridae						
Platysoma spp.**	47	2.3 ± 0.7	1.1 ± 0.4	1.3 ± 0.4	1.581	0.233
Tenebrionidae						
Corticeus spp.	56	1.8 ± 0.4	2.1 ± 0.7	1.7 ± 0.4	0.012	0.988
Zopheridae						
Lasconotus spp.**	619	26.9 ± 5.1	19.2 ± 5.3	15.8 ± 2.0	2.218	0.138
N. guttulata	34	0.9 ± 0.4	1.5 ± 0.5	1.0 ± 0.4	0.837	0.449
*P. sulcicollis***	170	6.0 ± 1.2	6.4 ± 1.0	4.6 ± 0.5	0.880	0.432

* Means in boldface rows followed by different lowercase letters are significantly different at $P = 0.05$ (Holm–Sidak test).

** Analyses conducted on nontransformed data.

Table 4. Mean (± SE) number of species detected in traps baited with ethanol and α-pinene (EA) or ipsenol and ipsdienol (SD), spaced at inter–trap distances of 2–12 m ($n = 10$).*

	Distance Between Traps				
Trap Lure	**2 m**	**6 m**	**12 m**	$F_{2,18}$	P
EA	20.0 ± 1.1	19.0 ± 0.8	18.4 ± 0.6	0.842	0.447
SD	12.8 ± 0.8 b	10.8 ± 1.0 ab	8.8 ± 0.5 a	5.684	0.012

* Means in row followed by different lowercase letters are significantly different at $P = 0.05$ (Holm–Sidak test). Analyses conducted on nontransformed data.

temporal aspects in the responses of beetles to pheromones and colonization of trees (Sullivan 2016). Currently, traps used in an operational program for monitoring population dynamics of the southern pine beetle, *D. frontalis*, are spaced at least 15 m from susceptible trees with a (+)-*endo*-brevicomin lure placed 3–4 m from the trap (Billings 2017). Sullivan and Mori (2009) found that catches of beetles in traps baited with the aggregation pheromone, frontalin, and turpentine increase when another pheromone, (+)-*endo*-brevicomin, is placed 4–16 m away from the trap, with maximum catches at a spacing of 4 m. This behavior along with interruptive effects from antiaggregation pheromones such as verbenone likely protects trees from excessive attacks by beetles and switches attacks to focused areas (spots) for maximum population expansion (Sullivan 2016). The expansion of infestations by the southern pine beetle is one of the most rapid and efficient of any aggressive species of bark beetles in North America, with very few trees left untouched as an infestation moves through a stand, much like a wildfire.

Assessing the role of distance between interacting sources of pheromones is difficult due to many uncontrollable factors such as microclimate, stand structure, and insect population density. Several studies have attempted to measure the effective range of baited funnel traps for bark beetles by using a combination of active and passive traps to account for beetle density, and found that the range of traps seems to be greater vertically than horizontally (Byers 2008, 2011). Clearly, more studies are needed to better elucidate the relative roles of inter–trap distance, trap numbers per spot, release rates and compositions of lures, and searching behaviors by beetles in order to better use traps as estimators of population density and detectors of forest health threats.

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References Cited

Billings, R.F. 2017. Revised protocol for predicting southern pine beetle infestation trends with pheromone traps (with use of *endo*-brevicomin). Texas Forest Service, Lufkin, TX. 12 pp.

Byers, J.A. 2008. Active space of pheromone plume and its relationship to effective attraction radius in applied models. J. Chem. Ecol. 34: 1134–1145.

Byers, J.A. 2011. Analysis of vertical distributions and effective flight layers of insects: Three-dimensional simulation of flying insects and catch of trap heights. Environ. Entomol. 40: 1210–1222.

Fettig, C.J., S.R. McKelvey, R.R. Borys, C.P. Dabney, S.M. Hamud, L.J. Nelson and S.J. Seybold. 2009. Efficacy of verbenone for protecting ponderosa pine stands from western pine beetle (Coleoptera: Curculionidae: Scolytinae) attack in California. J. Econ. Entomol. 102: 1846–1858.

Glantz, S.A. 2005. Primer of Biostatistics. McGraw-Hill Professional, New York. 520 pp.

Jackson, L., T. Price and G. Smith. 2010. Exotic Wood Borer/ Bark Beetle National Survey Guidelines. Revised 2010 Manual. USDA–APHIS–Plant Protection and Quarantine, Raleigh, NC. 20 Month 2018. (http://caps.ceris.purdue.edu/survey/manual/ewbb_guidelines)

Lindgren, B.S. and D.R. Miller. 2002. Effect of verbenone on five species of bark beetles (Coleoptera: Scolytidae) in lodgepole pine forests. Environ. Entomol. 31: 759–765.

Miller, D.R. 2002. Short-range horizontal disruption by verbenone in attraction of mountain pine beetle (Coleoptera: Scolytidae) to pheromone-baited funnel traps in stands of lodgepole pine. J. Entomol. Soc. B.C. 99: 103–105.

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. Asaro. 2005. Ipsenol and ipsdienol attract *Monochamus titillator* (Coleoptera: Cerambycidae) and associated large pine woodborers in southeastern United States. J. Econ. Entomol. 98: 2033–2049.

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.

Miller, D.R., C.M. Crowe, B.F. Barnes, K.J.K. Gandhi and D.A. Duerr. 2013. Attaching lures to multiple-funnel traps targeting saproxylic beetles (Coleoptera) in pine stands: Inside or outside funnels? J. Econ. Entomol. 106: 206–214.

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 the southeastern US. J. Chem. Ecol. 35: 435–448.

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. USDA–Forest Service, Res. Pap. 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. USDA–Forest Service, Washington, DC. 12 pp. 20 Month 2018. (http://www.fs.fed.us/foresthealth/publications/EDRRProjectReport.pdf).

Sullivan, B.T. 2016. Semiochemicals in the natural history of southern pine beetle *Dendroctonus frontalis* Zimmermann and their role in pest management. Adv. Insect Physiol. 50: 129–193.

Sullivan, B.T. and K. Mori. 2009. Spatial displacement of release point can enhance activity of an attractant pheromone synergist of a bark beetle. J. Chem. Ecol. 35: 1222–1233.