EFFECT OF TRAP HEIGHT ON ABUNDANCE AND SPECIES DIVERSITY OF CERAMBYCID BEETLES CAPTURED IN FORESTS OF EAST-CENTRAL ILLINOIS

BY

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THESIS

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Abstract

Trapping surveys that target wood-boring insects are usually deployed in the forest understory simply for convenience, but the abundance and species diversity of captured insects may be greatly influenced by the height of traps above the ground. Here, I assess how the vertical position of traps above the forest floor, and the type of trap bait, influence the abundance and diversity of cerambycid beetles that were captured in forested areas of east-central Illinois. Traps were set at three heights above the ground (~1.5 m in understory, ~6 m in lower canopy, ~12 m in the mid canopy), and were baited with either a fermenting bait or a blend of chemicals that were known pheromone components of cerambycids native to the study area. The twelve traps captured 845 cerambycid beetles of 49 species in the subfamilies Cerambycinae, Lamiinae, Lepturinae, Parandrinae, and the related Disteniidae. Adults of the cerambycine *Eburia quadrigeminata* (Say) were attracted by fermenting bait, and most were captured by traps at the highest position. Four species were attracted by the pheromone blend, including the cerambycines *Phymatodes aereus* (Newman), *Phymatodes lengi* (Joutel) and *Xylotrechus colonus* (F.), and the lamiine *Astylidius parvus* (LeConte). Most adult *P. lengi* were trapped in the mid canopy, whereas the remaining species were captured primarily in the understory. These findings suggest that trapping surveys of native communities of cerambycids, and quarantine monitoring for newly introduced exotic species, would be improved by including a variety of trap baits and distributing traps across vertical strata of forests.

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Introduction

The longhorned beetles (Cerambycidae) are among the most diverse insect groups, with an estimated 35,000 species worldwide (Slipinski et al. 2011). The endophytic larvae are generally beneficial in forest ecosystems because they break down dead woody plants, however some species are important pests because they kill living trees or damage trees felled for lumber or firewood (Craighead 1923, Linsley 1959). Due to their endophytic nature, cerambycids are readily transported by international commerce, concealed within nursery stock, solid wood packing materials, and other wood products (e.g., Haack 2006, Cocquempot and Lindelöw 2010). Several species of exotic cerambycids have invaded North America and become serious economic pests, notably the Asian longhorned beetle, *Anoplophora glabripennis* (Motschulsky) (Haack et al. 2010).

The economic importance of some native cerambycid species, and the continuing threat that exotic species will be introduced, have inspired research on methods of trapping the adults to manage native species and exotic species that have established (e.g., Nehme et al. 2010, Maki et al. 2011), and to monitor for new exotic species (e.g., Narai et al. 2015). Trapping also can be a valuable tool for assessing biodiversity and developing methods of conserving cerambycid species that are endangered or threatened (e.g., Ray et al. 2014). Researchers have sought to improve methods of trapping cerambycids by modifying basic trap design (e.g., stovepipe, funnel, panel traps), trap size, trap color, and coatings that render traps more effective in capturing insects (e.g., Bouget et al. 2008, Miller and Crowe 2011, Allison et al. 2014). Trap lures have been developed that are broadly attractive to wood-boring insects, using plant volatiles such as ethanol and α-pinene, bark beetle pheromones that apparently act as kairomones, and combinations thereof (Miller 2006, Miller et al. 2011). Certain species of cerambycids also may be attracted to traps with fermenting baits that mimic the volatile profiles of their decaying host trees or fermenting tree sap that the adults consume (Linsley 1959). Sex or aggregation-sex pheromones of cerambycids may be effective in attracting multiple species (e.g., Hanks et al. 2014), or for targeting particular species (e.g., Ray et al. 2009, 2014), and may be strongly synergized by plant volatiles (e.g., Sweeney et al. 2004, Hanks et al. 2012).

Trapping surveys that target wood-boring insects usually are deployed in the forest understory simply for convenience (Dodds 2014), but the abundance and species diversity of captured insects may be greatly influenced by the height of traps above the ground (e.g., Ulyshen and Hanula 2007, Dodds 2014). Adult cerambycids may be more abundant within certain vertical strata of the forest due to seeking food, mates, or appropriate sites for oviposition. For example, species that feed as adults on tree pollen or tender bark of branchlets must regularly return to the tree canopy (Linsley 1959). Species whose larvae develop in branches or twigs of living trees may spend most of their adult lives in the tree canopy, whereas those that breed in roots of trees, or downed trees and branches may rarely fly at higher altitudes. For example, adults of the European cerambycid *Clytus tropicus* (Panzer) apparently rarely leave the forest canopy, and this behavior probably is responsible for its designation as rare (Mannerkoski et al. 2010). In contrast, adults of the North American *Orthosoma brunneum* (Forster) rarely leave the forest understory because they do not feed, and their larvae develop in decaying trees on the forest floor (Ulyshen and Hanula 2007).

Here, I assess how the vertical position of traps in forest of east-central Illinois, and the type of trap bait, influence the abundance and diversity of cerambycid beetles that they capture. Traps were set at three heights above the forest floor (understory, lower canopy, and mid-canopy), and were baited with either a blend of chemicals that were known to be pheromones of many local cerambycid species, or with a fermenting bait. The pheromone bait was intended to attract beetles that were searching for mates, whereas the fermenting bait was expected to attract those that were searching for food or larval hosts. The trap height effect has rarely been tested using synthetic pheromones of cerambycids as bait (see Graham et al. 2012), and never tested using a fermenting bait, to my knowledge.

Materials and Methods

Study sites. The two sites in east-central Illinois that were used for this experiment that were ~19 km apart: Forest Glen Preserve (Vermilion Co. Conservation District, 728 ha; 40.01516°N, –87.56771°W), and Vermilion River Observatory (Vermilion Co., 193 ha, University of Illinois natural area; 40.065553°N, -87.561327 °W). Both sites were secondary forests dominated by species of Acer, Carya, Fagus, and Quercus.

Field experiment. Beetles were captured with flight intercept traps (black corrugated plastic panels, Alpha Scents, Inc., West Linn, OR) coated with Fluon® to improve capture efficiency (Northern Products, Woonsocket, RI; for details, see Graham et al. 2010). Trap basins were filled with ~300 ml of saturated brine to kill and preserve captured beetles.

A set of traps comprised three traps In different trees that were ~12m apart, one trap at each of three heights above the ground: ~1.5 m (understory), ~6 m (lower canopy), and ~12 m (mid-canopy). Traps at the lowest height were hung from low branches such that their bottoms were ~0.5 m above the ground, as in previous field experiments (e.g., Hanks et al. 2014). Traps at the two highest positions were suspended from tree branches of neighboring trees with strong nylon rope. The ropes were deployed in mid-April 2014, before trees leafed out, by tying a monofilament throw line to a weighted bag, launching the bag over an upper branch with a powerful slingshot (Big Shot®, Sherrill Inc., Greensboro, NC), tying the rope to the throw line, and pulling it over the branch. Traps were stabilized by attaching a rope from the trap bottom to a stake in the ground.

For each set of three traps, those at the two lowest positions were in shagbark hickories, *Carya ovata* (Mill.) K. Koch, whereas those at the highest position were in white oaks, *Quercus alba* L., due to the availability of suitably high and horizontal branches in that species. Although this experimental design confounds the highest trap position with tree species, it was deemed worthwhile because many species of the local cerambycid fauna are polyphagous, and their larvae feed in both oaks and hickories (Lingafelter 2007).

Two sets of traps (separated by ~30 m) were installed at each of the two field sites in east-central Illinois. At each study site, one set of three traps was baited with a blend of synthetic pheromones and the other with a fermenting bait mixture, with treatments assigned randomly to trap sets on day one. The pheromone blend was a generic blend of cerambycid aggregation-sex pheromones (Hanks et al. 2012), including racemic 3-hydroxyhexan-2-one, syn-2,3-hexanediol, racemic 2-methylbutan-1-ol, monochamol, (E)-fuscumol, and (E)-fuscumol acetate (25 mg per enantiomer in 1 ml isopropanol). This blend was dispensed from re-sealable polyethylene sachets (5.1 × 7.6 cm, BagettesTM model 14770, Cousin Corp., Largo, FL) that contained a cotton roll (1 × 4 cm dental wick, Patterson Dental Supply, Inc., St. Paul, MN). The fermenting bait was prepared by combining beer (355 ml, Rolling Rock®, Latrobe Brewing Co., St. Louis, MO), molasses (100 ml), one half banana (thinly sliced), granulated sugar (50 g), and baker's yeast (34 g Fleischmann's Associated British Foods, London, UK), and diluting to 1 liter with water. Fermenting bait was dispensed by loading 250 ml into polyethylene sachets (10 × 15 cm, BagettesTM model 14772, Cousin Corp.) with two holes (~5.5 mm) punched from the top and above the liquid, so as to increase release rate of volatiles while excluding insects such as moths and wasps that may have been attracted by the odors.

The traps were deployed from 5 May to 23 September 2014 and checked for beetles every 1-3 d. Lure treatments were rebaited and switched between sets (within sites) every ~2 wk to control for location effects. Specimens that were collected from the traps were placed in vials of 70% ethanol to preserve them for identification later. Taxonomy of captured beetles follows Lingafelter (2007). Representative specimens of all species are available from the laboratory collection of LMH.

Sources of chemicals. (R)-3-hydroxyhexan-2-one, monochamol, (E)-fuscumol, and (E)-fuscumol acetate were purchased from Bedoukian Research (Danbury, CN), and racemic 2-methylbutan-1-ol from Sigma-Aldrich (St. Louis, MO). Syn-2,3-hexanediol was synthesized as described by Lacey et al. (2004).

Data analysis. Data were analyzed separately for beetle species that were represented by at least 10 specimens. Differences between treatments in mean numbers of beetles captured were tested with the nonparametric Friedman's test (PROC FREQ with CMH option; SAS Institute 2011) because assumptions of analysis of variance were violated by heteroscedasticity (Sokal and Rohlf 1995). Pairs of treatment means were compared with the nonparametric Nemenyi multiple comparison test (Elliot and Hynan 2011, Zar 2010). Replicates with no specimens in any trap were dropped from analyses. Differences between trap height treatments in species richness (i.e., total number of cerambycid species captured over the season) were tested with the $\chi 2$ test (assuming an even distribution across heights). Differences between the sexes in their response to either trap height or bait were tested with the $\chi 2$ test for 25 beetles per treatment (pooled across dates).

Results

Traps hung from tree branches captured 845 cerambycid beetles of 49 species in the subfamilies Cerambycinae, Lamiinae, Lepturinae, and Parandrinae, and a species in family Disteniidae (Table 1). Twenty nine species (~59%) were represented by five or fewer specimens, of which nineteen species were represented by a single specimen. The most abundant species was the cerambycine *Anelaphus pumilus* (Newman), with 349 specimens. The pheromone blend was a much stronger attractant, with 726 (~86%) of beetles captured by traps baited with pheromone blend compared to 121 beetles in traps baited with fermenting bait (means 3.3 ± 0.4 and 0.55 ± 0.08, respectively; Friedman's $Q1,438 = 72.0$, $P < 0.0001$). However, species richness was similar for traps baited with fermenting bait (23 species) and those baited with the pheromone blend (19 species; $\chi 2$ test $P > 0.05$).

Traps at the three heights captured similar numbers of cerambycid beetles, with 276, 284, and 285 beetles in traps at the low, medium, and high positions respectively (Table 1; $\chi 2 = 0.17$, $P = 0.9$). Species richness of captured beetles also was similar for traps at the heights (Figure 1; $\chi 2 = 1.2$, $P = 0.6$). Twenty species (~41% of the total) were captured by traps at all three positions. The number of species that were unique to one particular trap position was greatest for the high traps, with eleven species, compared to three and four species for the low and medium traps (Table 1). However, these findings may be misleading because the unique species invariably were represented by very small sample sizes (usually one beetle).

Of the fifteen most numerous species, all but one were more strongly attracted to traps baited with the blend of synthetic pheromones than to the fermenting bait (Table 2). The exception was the cerambycine *Eburia quadrigeminata* (Say), with 27 of 29 (~93%) of adults captured by traps baited with the fermenting blend (Table 2). Capture of that species also was strongly influenced by the height of traps within the fermenting bait sets, with 25 of the 27 beetles (~93%) captured by the highest traps (Figure 2A). Of the remaining species, only the cerambycine *Xylotrechus colonus* (F.) was captured by fermenting bait traps in numbers sufficient for a statistical test of the trap height treatment. Most adults of that species (~73%) were captured by traps at the lowest height (Figure 2B).

Among the fourteen species that were attracted by the pheromone blend, only four were significantly influenced by trap height, including cerambycines *Phymatodes aereus* (Newman), *Phymatodes lengi* (Joutel), and *X. colonus*, and the lamiine *Astylidius parvus* (LeConte) (Figure 3). The lowest traps captured the greatest number of *X. colonus* (as with the fermenting bait traps), but also *P. aereus* and *A. parvus, whereas* most *P. lengi* were trapped in the highest traps (Figure 3).

Sex ratios of captured beetles approximated 50% across all treatments, ranging from 46 to 55% for the fermenting bait and pheromone blend treatments, and from 52 to 56% for the three height treatments ($\chi2$ tests, $P > 0.05$). This suggests that males and females were similarly influenced by trap bait and height. Sex ratios of beetles within treatments were not significantly different from 50% for nearly all of the most abundant species. The one exception was *P. lengi*, with four males and sixteen females captured by traps in the highest position that were baited with the pheromone blend (sex ratio 80%, significantly different from 50%, $\chi2 = 7.2$, $P = 0.0073$).

Discussion

This study supports the hypothesis that traps baited with fermenting baits may attract species that would not be attracted by synthetic pheromones, and also supports the hypothesis that positioning traps in multiple vertical strata of the forest will maximize the number and species diversity of cerambycids that will be captured. Thus, trapping surveys that are intended to assess the species composition and abundance of native species, or to monitor for newly introduced exotic species, may be improved by including a variety of trap baits, and distributing traps across vertical strata of forests.

Attraction of *E. quadrigeminata* to traps baited with the fermenting mixture confirm fermenting baits are effective for sampling this species and is consistent with field studies that have tested various types of fermenting baits (Frost and Dietrich 1929, Champlain and Knull 1932, Galford 1980, Hanks and Miller 2013). Adult females of that species oviposit in wounds in the bark of trees, which allows their larvae to gain entrance to the heartwood where they feed (Craighead 1923). Sap produced from these wounds may ferment, releasing volatiles that attract beetles of both sexes to potential oviposition sites, and adults also may feed on the sap. Adult *E. quadrigeminata* apparently were not attracted by any components of the blend of synthetic pheromones, as apparently has been the case in intensive field bioassays of cerambycid pheromones (e.g., Hanks and Miller 2013, Hanks et al. 2014). Volatile pheromones may not be involved in mate location for that species, as suggested by the absence of pheromone glands in males that are associated with pheromone production in other cerambycines (Ray et al. 2006). The fact that most adult *E. quadrigeminata* were captured in the highest traps suggests that adults were seeking tree wounds and perhaps mates within the canopy of trees.

Although the fermenting bait attracted fewer beetles than did the pheromone blend, the possibility remains that beetles were attracted by it. My field bioassay was designed only to compare attractiveness of fermenting bait and pheromones, lacking blank controls that would have allowed a test to confirm low levels of attraction to fermenting bait. Alternatively, the few beetles in the fermenting bait treatment may have responded to visual cues associated with the black panel traps, or were intercepted passively by traps (e.g., McIntosh et al. 2001). However, *X. colonus* already was known to be attracted by fermenting baits (Galford 1980), and n fact ethanol synergizes attraction of that species to synthetic pheromone (Hanks et al. 2012, Handley et al. 2015).

Attraction of beetles in the subfamily Cerambycinae to traps baited with synthetic pheromones was consistent with what is known of their pheromone chemistry. In fact, the blend of synthetic pheromones used in the present study also attracted adults of several species in previous field trials (e.g., Hanks and Millar 2014). Many of these species were attracted to the (R)-3-hydroxyhexan-2-one in the blend, known to be the sole or primary component of their pheromones, including *A. pumilus*, *P. aereus*, *P. lengi*, and *X. colonus*, but also *Neoclytus m. mucronatus* (F.), *Parelaphidion aspersum* (Haldeman), *Phymatodes amoenus* (Say), and *Phymatodes varius* (F.) (Mitchell et al. 2013, 2015). The pheromone of *Phymatodes testaceus* (L.) has yet to be identified, although it is known to be attracted by racemic 3-hydroxyhexan-2-one (Hanks and Millar 2013). Adult *Neoclytus a. acuminatus* (F.) undoubtedly were attracted by the syn-2,3-hexandiol in the blend, which contained the SS-enantiomer, its sole pheromone component (Lacey et al. 2004).

Attraction of adult lamiines to the pheromone blend apparently also provides evidence of their pheromone chemistry, and adult *A. parvus*, *Aegomorphus modestus* (Gyllenhal in Schoenherr), *Graphisurus despectus* (LeConte), *Graphisurus fasciatus* (Degeer), and *Lepturges angulatus* (LeConte) were attracted by the same blend of pheromones, and to fuscumol and/or fuscumol acetate alone, in previous field studies (Mitchell et al. 2011, Hanks et al. 2012, Hanks and Millar 2013). Certain stereoisomers of those compounds are produced by males (unpub. data), and attraction of conspecifics in the present study provides further evidence that they are pheromones (unpub. data).

Species that responded to the synthetic pheromones at a particular height treatment may indicate preferences for certain vertical strata within forests in searching for mates. Thus, adult *A. parvus*, *P.*

aereus, and *X. colonus* may seek mates primarily in the forest understory, such as on downed trees or fallen branches. Adult *X. colonus* showed a similar preference for lower forest strata in the experiment conducted in Michigan (Graham et al. 2012). *Phymatodes lengi* has been among the most common species trapped in previous field studies that used pheromone-baited traps near ground level (Hanks et al. 2014), the present study suggests that even greater numbers could have been captured by traps in the forest canopy. Adults of that species apparently do not feed (unpub. data), suggesting that they are most abundant in the canopy because that is where the larvae feed. That behavior may explain why larval hosts of *P. lengi* have remained unknown (see Lingafelter 2007).

The absence of a significant trap height effect for the most abundant species, *A. pumilus*, suggests that adults were equally distributed across vertical strata of the forest. The dominance of that species, and inconsistencies among the remaining species in how they were influenced by trap height, resulted in the even distribution of cerambycids in general. Such inconsistencies among species also may explain the insignificant trap height effect in a study conducted in Michigan, regardless of whether traps were baited with synthetic pheromone of cerambycids or ethanol with α-pinene (Graham et al. 2012). However, there has been no consensus among other field studies that tested the effect of trap height for cerambycids, with diversity and abundance increasing (Ulyshen and Hanula 2007) or decreasing (Wermelinger et al. 2007, Dodds 2014) with trap height. General trends in the distribution of cerambycids probably are strongly influenced by the flight behavior of their dominant species.

Tables

Table 1. Taxonomy and numbers of cerambycid beetles that were captured in east-central Illinois by panel traps baited with either a blend of synthetic pheromones or fermenting bait, and positioned at three height above the ground: Low (~1.5 m), Medium (~6 m), or High (~12 m).

	Pheromone bait			Fermenting bait			
Taxonomy	Low	Medium	High	Low	Medium	High	Total
Cerambycinae							
Anaglyptini							
Cyrtophorus verrucosus (Olivier)	3	1	1	2			7
Callidiini							
Phymatodes aereus (Newman)	24	20	1			1	46
Phymatodes amoenus (Say)	14	12	17	1		2	46
Phymatodes lengi Joutel	3	1	20			1	25
Phymatodes testaceus (L.)	5	4	3				12
Phymatodes varius (F.)		2	3				5
Clytini							
Clytoleptus albofasciatus (Laporte & Gory)					1		1
Megacyllene caryae (Gahan)	3	2					5
Neoclytus a. acuminatus (F.)	10	6	3	3			22
Neoclytus m. mucronatus (F.)	5	3	4			3	15
Neoclytus scutellaris (Olivier)			3		1	5	9
Xylotrechus colonus (F.)	35	19	13	11	1	2	81

Table 1 (cont.).

	Pheromone bait			Fermenting bait			
Taxonomy	Low	Medium	High	Low	Medium	High	Total
Eburiini							
Eburia quadrigeminata (Say)			2	2	2	23	29
Elaphidiini							
Anelaphus pumilus (Newman)	98	151	99		1		349
Anelaphus villosus (F.)						1	1
Elaphidion mucronatum (Say)	2	1	1	1		2	7
Parelaphidion aspersum (Haldeman)	1	7	3			2	13
Parelaphidion incertum (Newman)	1	1	6		1	2	11
Stenosphenus notatus (Olivier)			1				1
Neoibidionini							
Heterachthes quadrimaculatus var. *pallidus* Haldeman					1		1
Tillomorphini							
Euderces picipes (F.)						1	1
Euderces pini (Olivier)				1			1
Trachyderini							
Purpuricenus axillaris Haldeman						2	2
Lamiinae							
Acanthocinini							

Table 1 (cont.).

Taxonomy	Pheromone bait			Fermenting bait			Total
	Low	Medium	High	Low	Medium	High	
Astylidius parvus (LeConte)	17	6	4	1	1		29
Astylopsis collaris (Haldeman)			1				1
Astylopsis macula (Say)			1				1
Graphisurus despectus (LeConte)	4	6	4	2	1	3	20
Graphisurus fasciatus (Degeer)	6	9	6	1	3	4	29
Hyperplatys maculata Haldeman	1	1					2
Leptostylus transversus (Gyllenhal in Schoenherr)	1				2		3
Lepturges angulatus (LeConte)	5	7	2			2	16
Lepturges confluens (Haldeman)			2			2	4
Sternidius alpha (Say)	1					3	4
Acanthoderini							
Aegomorphus modestus (Gyllenhal in Schoenherr)	3	3	8	1		4	19
Dorcaschematini							
Dorcaschema cinereum (Olivier)			1				1
Monochamini							
Goes tigrinus (Degeer)			1				1
Microgoes oculatus (LeConte)			1				1
Pogonocherini							

Table 1 (cont.)

Taxonomy	Pheromone bait Low	Pheromone bait Medium	Pheromone bait High	Fermenting bait Low	Fermenting bait Medium	Fermenting bait High	Total
Ecyrus d. dasycerus (Say)			1				1
<u>Saperdini</u>							
Saperda discoidea F.					1		1
Saperda imitans Felt & Joutel				2			2
Lepturinae							
<u>Lepturini</u>							
Bellamira scalaris (Say)	1						1
Brachyleptura rubrica (Say)			1	1		1	3
Stenelytrana emarginata (F.)						1	1
Strangalia bicolor (Swederus)					1		1
<u>Rhagiini</u>							
Gaurotes cyanipennis (Say)					1		1
Stenocorus cinnamopterus (Randall)	1	1	1		1	1	5
Stenocorus schaumii (LeConte)	1						1
Parandrinae							
<u>Parandrini</u>							
Neandra brunnea (F.)			1				1

Table 1 (cont.).

	Pheromone bait			Fermenting bait			
Taxonomy	Low	Medium	High	Low	Medium	High	Total
Disteniidae							
Disteniini							
Elytrimitatrix undata (F.)	1	1		1	1	2	6
Total:	246	264	215	30	20	70	845

Table 2. Mean (± 1 SE) number of beetles per trap of the most abundant cerambycid species that were captured by traps baited with a blend of synthetic pheromones or fermenting bait. The pheromone blend: racemic 3-hydroxyhexan-2-one, *syn*-2,3-hexanediol, racemic (*E*)-fuscumol, racemic (*E*)-fuscumol acetate, monochamol, and racemic 2-methylbutan-1-ol (25 mg per enantiomer in 1 ml isopropanol). Fermenting bait was created by mixing beer, molasses, sliced banana, granulated sugar, and bakers yeast. Asterisks indicate significance of Friedman's *Q*: *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

		Trap lure contents		
Subfamily	Species	Pheromone blend	Fermenting bait	Friedman's *Q*
Cerambycinae	*A. pumilus*	4.1 ± 0.73	0.012 ± 0.012	$Q_{1,168}$ = 76.9***
	E. quadrigeminata	0.056 ± 0.056	0.75 ± 0.29	$Q_{1,72}$ = 12.1**
	N. a. acuminatus	0.37 ± 0.08	0.059 ± 0.05	$Q_{1,102}$ = 15.0***
	N. m. mucronatus	0.36 ± 0.085	0.09± 0.067	$Q_{1,66}$ = 8.3**
	P. aspersum	0.46 ± 0.16	0.083 ± 0.06	$Q_{1,48}$ = 4.7
	P. aereus	1.88 ± 0.65	0.042 ± 0.04	$Q_{1,48}$ = 16.2***
	P. amoenus	2.05 ± 0.42	0.14 ± 0.08	$Q_{1,42}$ = 15.9***
	P. lengi	0.80 ± 0.22	0.033 ± 0.03	$Q_{1,60}$ = 13.4**
	P. testaceus	0.50 ± 0.16	0	$Q_{1,48}$ = 10.8**
	X. colonus	0.54 ± 0.07	0.13 ± 0.04	$Q_{1,246}$ = 31.5***
Lamiinae	*A. modestus*	0.31 ± 0.077	0.11 ± 0.047	$Q_{1,90}$ = 4.5*
	A. parvus	0.60 ± 0.15	0.044 ± 0.03	$Q_{1,90}$ = 15.2***
	G. despectus	0.39 ± 0.10	0.17 ± 0.08	$Q_{1,72}$ = 3.6
	G. fasciatus	0.39 ± 0.09	0.15 ± 0.05	$Q_{1,108}$ = 5.3*
	L. angulatus	0.42 ± 0.14	0.061 ± 0.04	$Q_{1,66}$ = 6.6*

Figures

Figure 1. Venn diagram showing the total number of cerambycid species captured by traps that were positioned at three vertical positions in the forest canopy, regardless of trap bait, and the number captured at multiple positions: ~1.5 m ("Low"), ~6 m ("Medium"), and ~12 m ("High)

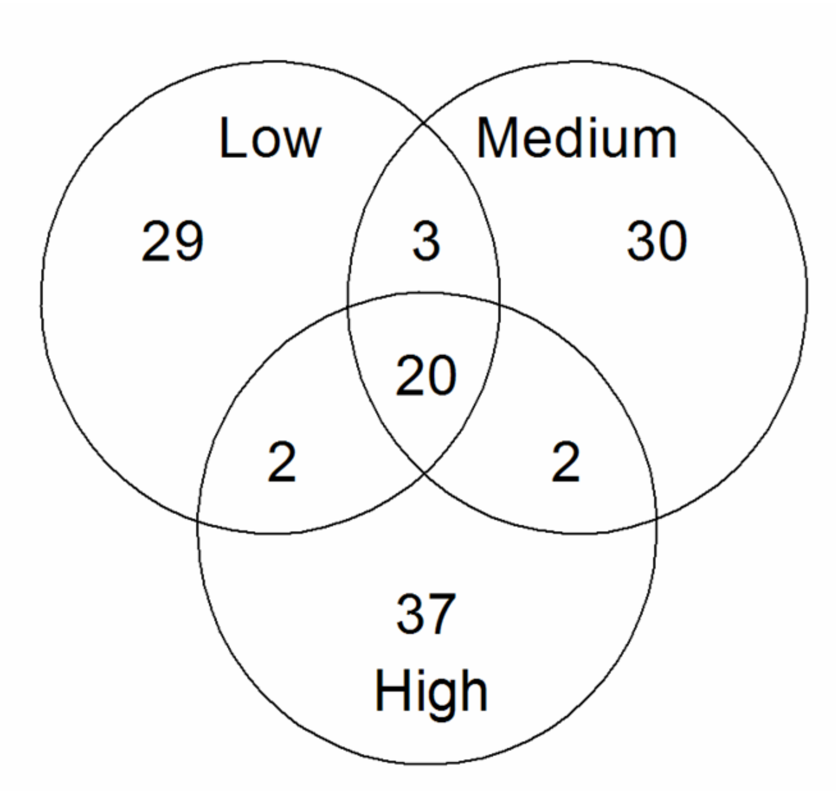


Figure 2. Mean (±1 SE) number of beetles captured per trap (sexes combined) with respect to height of trap above the ground for cerambycine beetles of two species that were attracted by fermenting bait. Traps were suspended from tree branches at three height above the ground: ~1.5 m ("Low"), ~6 m ("Medium"), and ~12 m ("High"). Means significantly different for *Eburia quadrigeminata* (Say) and *Xylotrechus colonus* (F.): Friedman's $Q_{2,33} = 13.4$, $P = 0.0012$; $Q_{2,33} = 8.1$, $P = 0.015$, respectively. Means within species and year with the same letters are not significantly different (Nemenyi test, $P < 0.05$).

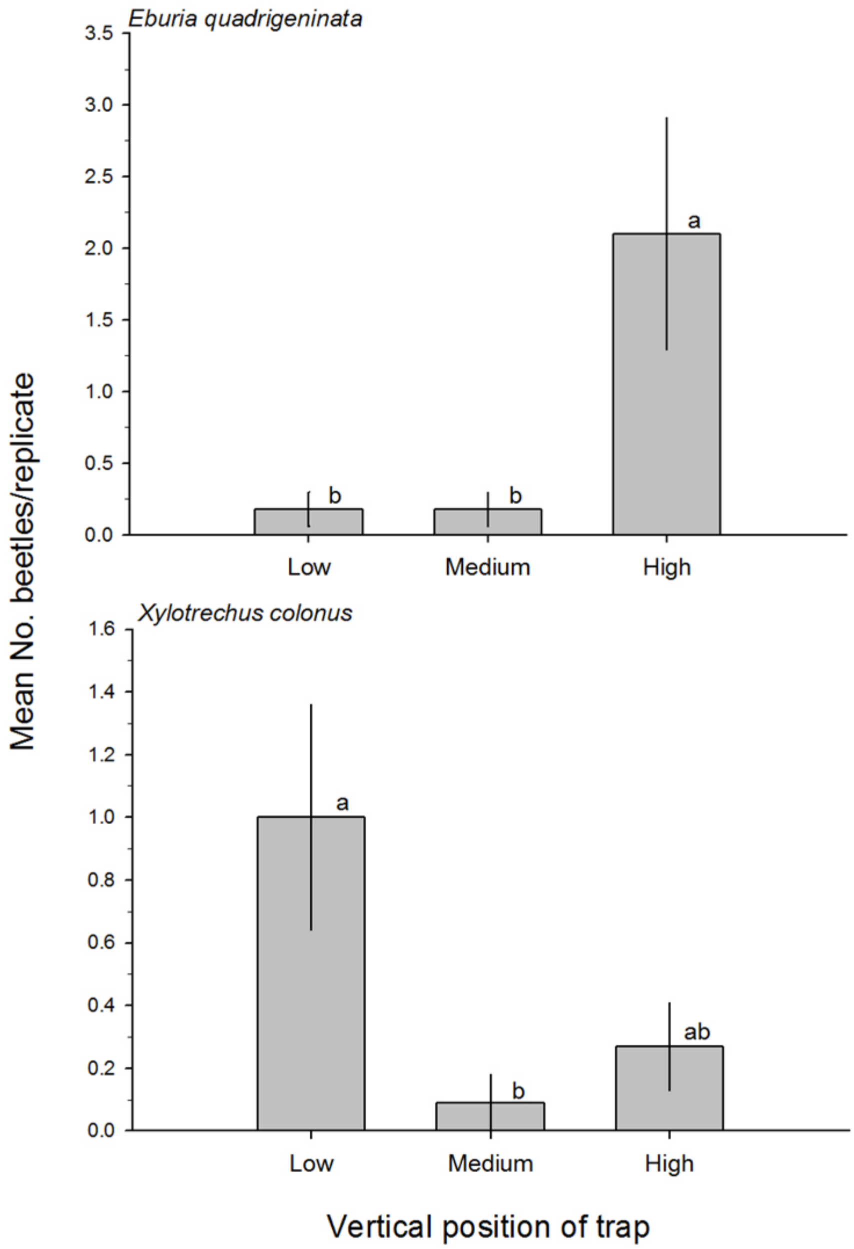
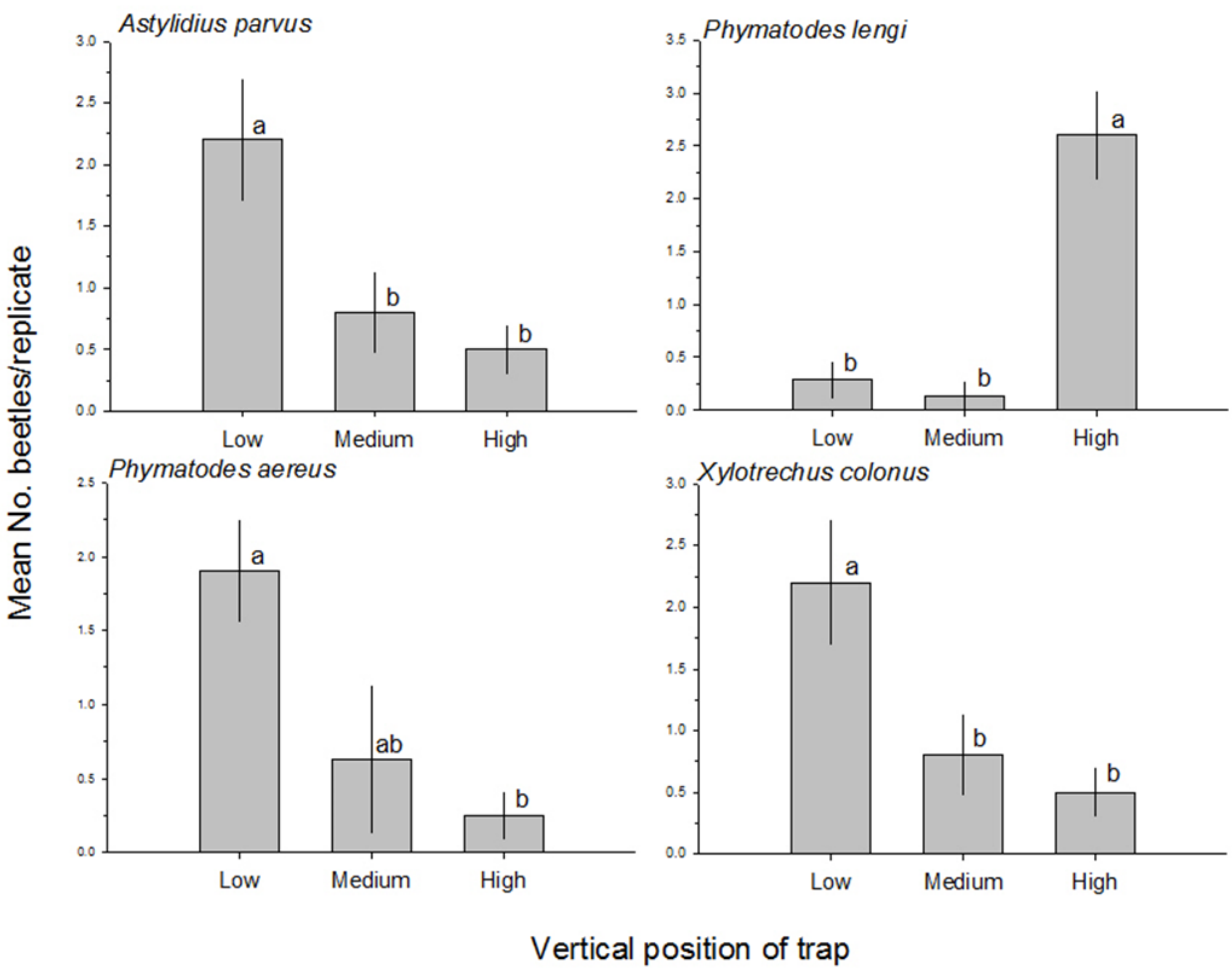


Figure 3. Mean (±1 SE) number of beetles captured per trap (sexes combined) with respect to height of trap above the ground for cerambycid beetles of four species that were attracted by a blend of synthetic pheromones. Traps were suspended from tree branches at three heights above the ground: ~1.5 m ("Low"), ~6 m ("Medium"), and ~12 m ("High). Means significantly different for *Astylidius parvus* (LeConte), *Phymatodes aereus* (Newman), *Phymatodes lengi* (Joutel), and *Xylotrechus colonus* (F.): Friedman's $Q_{2,24} = 11.9$, $P = 0.0025$; $Q_{2,27} = 7.8$, $P = 0.012$; $Q_{2,21} = 15.0$, $P = 0.0006$; and $Q_{2,30} = 8.1$, $P = 0.015$, respectively. Means within species with the same letters are not significantly different (Nemenyi test, $P < 0.05$).



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