Influence of Trap Placement and Design on Capture of the Emerald Ash Borer (Coleoptera: Buprestidae)

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ABSTRACT The key to an effective pest management program for the emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera Buprestidae), is a survey program equipped with tools for detecting and delimiting populations. We studied the effects of trap design, color, and placement on the efficacy of sticky traps for capturing the emerald ash borer. There were significant differences in trap catch along a transect gradient from wooded to open field conditions, with most beetles being caught along the edge, or in open fields, 15–25 m outside an ash (*Fraxinus* spp. L.) (Oleaceae) woodlot. Greater emerald ash borer catch occurred on purple traps than on red or white traps. Traps placed in the mid-canopy of ash trees (13 m) caught significantly more beetles than those placed at ground level. We also describe a new trap design, a three-sided prism trap, which is relatively easy to assemble and deploy.

KEY WORDS emerald ash borer, visual cues, purple, prism trap, trap height

The emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), is an east Asian wood borer that is oligophagous on ash (*Fraxinus* spp. L.) (Oleaceae). A population of *A. planipennis* was discovered in May 2002 and was subsequently found to occur throughout several thousand square kilometers around Detroit, MI, and Windsor, ON, Canada (Haack et al. 2002). Infested ash trees have subsequently been found in Ohio, Maryland, Virginia, Indiana, Illinois, and Pennsylvania (Rauscher and Mastro 2004, Bean 2004, Waltz 2006, IDOA 2007, PA DCNR 2007). Although the emerald ash borer is considered a relatively minor pest in its native range (Yu 1992), since its arrival in North America it has attacked and rapidly killed apparently healthy trees of several ash species, including green (*Fraxinus pennsylvanica* Marshall), white (*Fraxinus americana* L.), and black ash (*Fraxinus nigra* Marshall) (Haack et al. 2002, Poland and McCullough 2006). It is estimated that *A. planipennis* has killed 15 million ash trees in forested and urban areas in southeastern Michigan alone (Poland and McCullough 2006).

Detection of *A. planipennis*, to date, has mostly relied on trap trees and visual surveys. Trap trees are ash trees that have had a band of bark (15 cm in width) removed from the entire circumference. They must be felled and stripped of all bark at the end of the *A. planipennis* flight season to determine the presence or absence of larvae. Visual surveys to determine the presence of symptoms resulting from attack by the beetle (i.e., adult exit holes, bark cracks, epicormic branching, woodpecker feeding sites) are also expensive and labor-intensive. In addition, because these symptoms may be overlooked in sites with lower density populations, newly infested areas can often go undiscovered. A survey tool that exploits the cues that the emerald ash borer uses to locate host trees or other beetles could enhance the current goals of containment and control of North American *A. planipennis* populations.

There is evidence that some *Agrilus* species, including *A. planipennis*, use visual, auditory, and/or semiochemicals cues to locate hosts and potential mates (Cote and Allen 1980, Dunn et al. 1986, Dunn and Potter 1988, Lelito et al. 2007). Oliver et al. (2002) observed that buprestids of several genera (including *Agrilus*) were more attracted to paper traps painted red than to those painted blue, gray, green, yellow, and white and that, in general, buprestids showed a preference for colors in the violet range (400–430 nm). Francese et al. (2005b) found that purple panel traps of corrugated plastic caught more *A. planipennis* than black, green, navy, gray, white, yellow, and red traps (red and yellow traps caught significantly fewer beetles than all other colors). In a subsequent study, purple traps caught significantly more *A. planipennis* than all of the other colors with the exception of white, but overall the trap catch was lower than in the previously mentioned test (Francese et al. 2005a). This reduced capture might have resulted from differences

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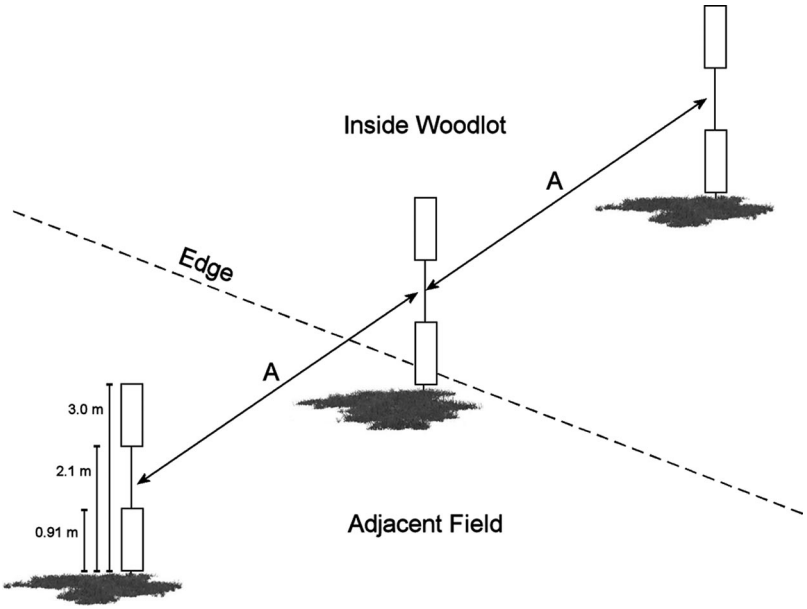

Fig. 1. Layout of a trap line used to study the effect of trap habitat on capture of *A. planipennis* on purple panel traps. The letter A corresponds to the intra-line distance between traps in different habitats. In 2004, this distance was 25 m and in 2005, it was 15 m.

in canopy density and light levels between sites used in the two studies. Light intensity and wavelength distribution can differ markedly between open day-lit and closed forested areas (Kelber 2006).

Vertical placement of traps is a vital component of sampling for some forest insects (Su and Woods 2001, Wermelinger et al. 2007). Buprestids, including some species of *Agrilus*, show a general preference for traps placed in the canopy of trees along the edges of forested areas (Wermelinger et al. 2007). Lance et al. (2007) observed that most adult emerald ash borer flight occurred in the upper and mid-canopy regions of ash trees.

The ongoing goal of this research is to develop a visual trapping system that could be used in conjunction with a semiochemical lure to assist in the detection of early onset infestations of emerald ash borer. The objectives of the studies described herein were to 1) determine the optimal horizontal and vertical placement for traps in relation to an ash woodlot; 2) characterize the effect of color of traps placed in or near an ash woodlot; and 3) design a relatively inexpensive, durable and effective trap.

Materials and Methods

Trap Habitat. In 2004, we established four lines of traps at two sites in Ann Arbor, MI (n = 2 trap lines at each site). Each trap consisted of two panels, 15.2 cm in width by 91.4 cm in height. Panels were constructed from purple corrugated plastic (0.40 cm in thickness; peak wavelengths were 430 nm at 22% reflectance, 600 nm with 6% reflectance, and 670 nm with 16% reflectance) (Coroplast, Dallas, TX), and they were attached to a steel rebar pole (1.27-cm in diameter) at 0.91 m and 3.0 m above the ground (Fig. 1). Both sides of the trap panels were coated with Pestick insect trapping glue (Hummert International, Earth City, MO). Trap lines were set up in a complete-block design and consisted of traps placed in each of three habitats: the edge of an ash woodlot, 25 m inside the woodlot, and 25 m outside the woodlot in an adjacent field (Fig. 1). In 2005, a similar study was performed at two sites in Ann Arbor (n = 2 trap lines) and South Lyon, MI (n = 4 trap lines), with 15 m between traps in each line. Beetles were removed from traps weekly from 25 June to 7 September in 2004 and from 7 June to 2 August in 2005.

Weekly trap catch was summed, and log transformed (n + 0.5) before being statistically analyzed, by analysis of variance (ANOVA) using the General Linear model in Systat 12 (Systat Software, Inc. 2007). Means were separated using Tukey's honestly significant difference (HSD) (α = 0.05). This was repeated for each of the following studies, except where noted.

Relationship of Trap Color and Habitat. In 2005, seven blocks of traps, in a complete block design, were placed at three sites: two sites in Ann Arbor (n = two trap lines; n = two trap lines) and one site in South Lyon (n = three trap lines), MI. Each block consisted of three rows of traps constructed from a single color of each of the following Coroplast stock colors: purple (wavelength and reflectance as noted above), white (peak wavelength from 420 nm through the rest of the visible spectrum at 75–84% reflectance), and red (640 nm at 54% reflectance). The traps used were the four-panel box trap (35.6 by 61.0 cm each) described by Francese et al. (2005b). Traps in each row were hung

from L-shaped steel rebar poles (1.27 cm in diameter) at 1.5 m above the ground, and they were placed along the edge of an ash woodlot, 15 m inside the woodlot, or 15 m outside the woodlot in an adjacent field. The color of each row was assigned randomly within each block, and rows within blocks were placed 15 m away from each other. Traps were coated with Pestick insect trapping glue.

Beetles were removed from traps weekly from 7 June 2005 to 2 August 2005 and returned to the laboratory for counting. Before analysis, catch for each trap was summed over the entire season, and log transformed (n + 0.5). An ANOVA was run using the General Linear model in Systat 12 (Systat Software, Inc. 2007). The main effects that we tested were trap color, trap habitat, and block. The trap color × habitat interaction also was tested. To account for differences in habitat between blocks, that interaction effect also was tested. Finally, to determine whether the lack of randomization between colors between habitat rows, the color × block interaction was tested. Pairwise comparisons were made between overall color effects as well as overall habitat effects using Tukey's HSD (α = 0.05). Additional pairwise comparisons were performed to determine intracolor effect of habitat on trap catch and the intrahabitat effect of color on trap catch. A two-tailed t-test was performed for each of the 18 comparisons with an adjusted α value (0.0027) by means of Bonferroni's correction.

Trap Design. In 2006, four trap designs were tested, each constructed of 0.30-cm thick purple (wavelength and reflectance as noted above) corrugated plastic. The designs included a four-panel (35.6 by 61.0 cm each; 0.87-m^2 trapping surface) box trap similar to the one described in Francese et al. (2005b), a single-panel trap coated with glue on both surfaces (35.6 by 61.0 cm each; 0.43 m^2), a three-panel (35.6 by 59.7 cm each; 0.65 m^2) prism trap (Fig. 2), and a crossvane trap. The crossvane trap consisted of two 45.7- by 61.0- by 0.30-cm-thick corrugated plastic panels with corresponding slots allowing them to fit into each other, forming a crossvane shape. A rectangular hole (5.1 by 12.7 cm) was cut from the middle of each panel reducing the total trapping surface for the crossvane trap to 1.1 m^2. Each crossvane trap had a translucent corrugated plastic top and a purple corrugated plastic bottom (each 33.0 by 33.0 cm). A four-armed stainless steel umbrella rig spreader (Zing Products, Westport, MA) was fastened to the top of the crossvane trap to facilitate hanging. Traps were suspended ≈1.5 m above the ground from rebar poles, coated with Pestick glue, and placed along the edge of an infested woodlot. Six trap lines, in a randomized complete block design, treated as replicates, were placed at one site in Pinckney, MI. Trap catch was recorded weekly from 5 June 2006 to 1 August 2006. Total trap catch and catch per m^2 of trap surface were summed over the entire field season for each trap. Summed data were log transformed (n + 0.5) before statistical analysis, and separate analyses of variance were performed for trap catch and trap catch per m^2.

Trap Height. Three-panel (35.6 by 59.7 cm each) prism traps, constructed of 0.30-cm-thick purple corrugated plastic (wavelength and reflectance as noted above) were used. The outward-facing sides of the panels were coated with Pestick glue. Traps were hung at three heights—1.5, 6.5, or 13 m—above the ground. Traps placed at 13 m were hung from a rope and hoisted up to the desired height by a pulley attached to a branch in the upper crown of a green ash tree. A three-arm modified stainless steel umbrella rig spreader (Zing Products) was attached to the top of the trap with plastic cable ties to provide an anchor point for hanging. The 6.5-m trap was hung similarly from rope that was tied to a loop in the bottom of the spreader of the 13-m trap. Traps hung at 1.5 m were attached to an L-shaped rebar pole (1.25 cm in diameter). Ten vertical trap lines, in a complete block design, were placed in Howell (n = 6 trap lines) and Hartland (n = 4 trap lines), both in Livingston County, MI. Trap catch was recorded weekly from 5 June 2006 to 1 August 2006, and beetles were sexed and summed for each trap over the entire field season, before being log transformed (n), before statistical analysis. In addition to the previously mentioned ANOVA, chi-square analysis was performed to determine whether there were any differences in the overall ratio of females to males caught on traps in the study (α = 0.05). Additional pairwise comparisons were made using chi-square analysis on sex ratios at each height, with an adjusted α value (0.017) by means of Bonferroni's correction.

Results

Trap Habitat. Trap habitat significantly influenced trap catch in 2004 (F = 7.8; df = 2, 6; P = 0.021) and 2005 (F = 10.4; df = 2, 10; P = 0.001). In 2004, mean ± SE catch on traps placed along the edges of the woodlots (7.5 ± 3.8) was higher than on traps placed inside the woodlots (0.0 ± 0.0) but not significantly higher than catch on traps placed in the adjacent fields (1.8 ± 1.4). Additionally, there was no significant difference in trap catch between those placed in the field or in the woodlot. In 2005, traps placed in the adjacent fields (6.7 ± 2.2) caught significantly more beetles than those placed inside the woodlot (0.5 ± 0.2) but not traps placed along the edges (5.2 ± 1.2). Mean trap catch along the edges was also higher than inside the woodlots.

Relationship of Trap Color and Habitat. There were no significant interaction effects for the color x block (F = 0.5; df = 12, 24; P = 0.885) or the habitat x block (F = 1.1; df = 12, 24; P = 0.420). Because these interactions were of little interest otherwise, the ANOVA was rerun with these interaction terms in the model error.

Mean catch of *A. planipennis* was significantly affected by trap color (F = 18.1; df = 2, 48; P < 0.001) and habitat (F = 3.9.; df = 2, 48; P = 0.026). More beetles were caught on purple traps (5.8 ± 1.7 SE) than on red (0.52 ± 0.4) or white (1.0 ± 0.5) traps, whereas mean catches on red and white traps were not

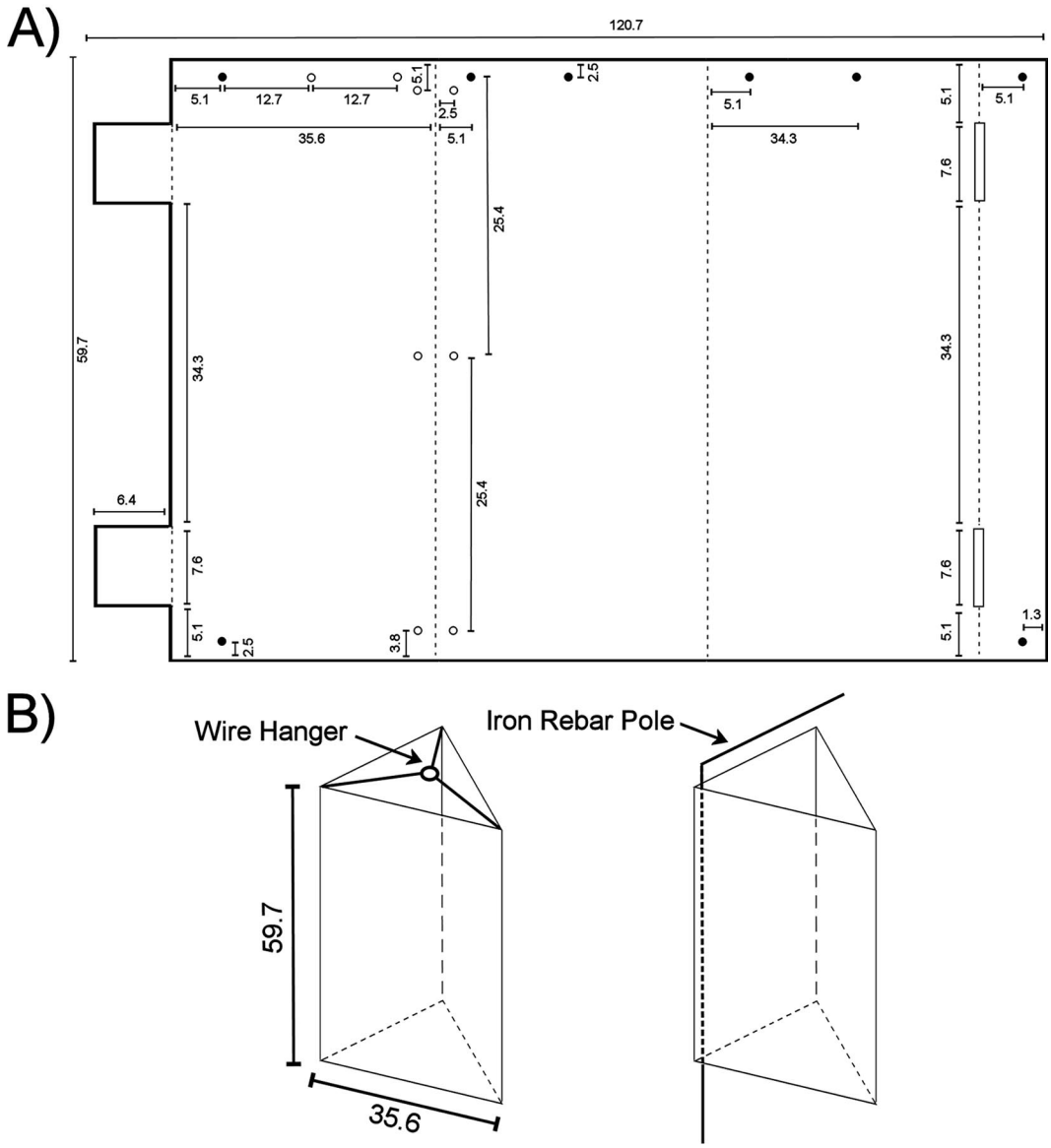

Fig. 2. Emerald ash borer prism trap used in 2006 and 2007. (A) Schematic of a prism trap cut from a single sheet of corrugated plastic. White circles represent holes to be used for attachment points to an iron rebar pole if the trap is to be hung at ground level. Black circles represent holes to be used for attachment points to a wire trap hanger if the trap is to be hung from a tree or other high place. (B) Diagram of the assembled trap showing both a high setup (left) and a low setup (right). All units are in centimeters.

significantly different from each other. Also, more beetles were caught per trap in fields (3.6 ± 1.6) than those placed inside woodlots (1.2 ± 0.7), but there were no differences between traps placed on the edges (2.5 ± 1.0) and traps placed inside the woodlots or in the fields.

The interaction between trap color and habitat was also significant ($F = 2.6$; df = 4, 48; $P = 0.047$). Among purple traps, more *A. planipennis* were caught on traps placed in fields than in woodlots (Fig. 3); however, there was no significant difference on purple traps between the edge and the woodlot or the field. Mean catch on both red and white traps was not significantly different among any of the habitats. Of traps placed on the edge of woodlots and in open fields, purple traps caught more beetles than white or red traps, but white and red traps were not significantly different from one another in those habitats. There was no significant different in catch among traps of any color in the woodlots.

Trap Design. Trap design significantly affected catch among all trap designs ($F = 4.0$; df = 3, 15; $P = 0.029$) (Fig. 4). More beetles were caught on box traps than on crossvane traps, but catch on panel traps and

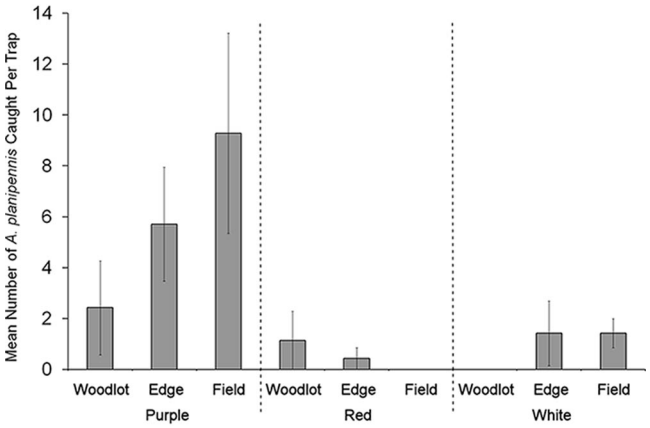

Fig. 3. Mean ± SE catch of *A. planipennis* adults on purple, white, and red four-sided box traps ($n = 7$) placed along the edge of an ash woodlot, 15 m inside the woodlot, and in 15 m outside the woodlot in an adjacent field.

prism traps did not differ significantly from other types of traps. Trap catch as a function of trapping surface area also was significantly affected by trap design ($F = 6.1$; df = 3, 15; $P = 0.007$; Fig. 4). More beetles were caught per square meter of trap surface on flat-paneled traps (box, prism, and two-sided panel traps) than on crossvane traps. Catch per square meter of trapping surface did not differ significantly among flat-paneled traps.

Trap Height. Trap height had a significant effect on overall trap catch ($F = 19.5$; df = 2, 18; $P < 0.001$). More beetles were caught per trap on traps hung at 13 m (229.6 ± 18.9 SE) than on traps hung at 6.5 m (73.6 ± 5.7) or at 1.5 m (58.0 ± 4.5). Traps hung at 6.5 m also caught more beetles per trap than traps hung at 1.5 m.

Trap height played a significant role in catch for both males ($F = 13.0$; df = 2, 18; $P < 0.001$) and females ($F = 21.4$; df = 2, 18; $P < 0.001$), with more members of both sexes caught on traps hung at 13 m than on traps hung at 6.5 or 1.5 m (Fig. 5). However, there was no difference among either sex on traps hung at 6.5 and 1.5 m. The overall ratio of females to males (2,024: 1,155 = 1.75:1) on all traps was significantly different ($\chi^2 = 18.0$, df = 2, $P = 0.0001$), and when compared at different heights, the ratios of females to males were higher at 13 m (1,332:740 = 1.80:1) and 6.5 m (445: 215 = 2.10:1) ($\chi^2 = 169.1$, df = 1, $P < 0.0001$ and $\chi^2 = 80.2$, df = 1, $P < 0.0001$, respectively), but not at 1.5 m (247:200 = 1.24:1) ($\chi^2 = 4.9$, df = 1, $P = 0.026$).

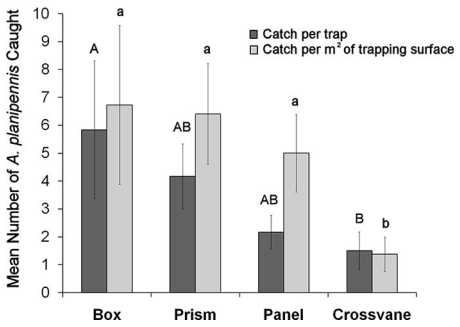

Fig. 4. Mean ± SE catch of *A. planipennis* adults on traps ($n = 6$) constructed from four designs: a four-sided box, a three-sided prism, a two-sided panel, and crossvane. Uppercase letters denote differences in mean trap catch trap catch, whereas lowercase letters denote differences in mean catch per square meter of trapping surface area.

Discussion

At ground height (1.5 m) and slightly above, purple traps placed either directly along the forest edge or in adjacent fields outperformed traps placed inside woodlots. This edge-related increase in catch seems to decline as traps are moved farther away (30 m or more) from infested woodlots (J.A.F., unpublished data). Poland et al. (2005) reported greater capture of *A. planipennis* on herbicide-treated trap trees in open areas than those along the edges or inside of closed canopy stands. In general, buprestids, including those

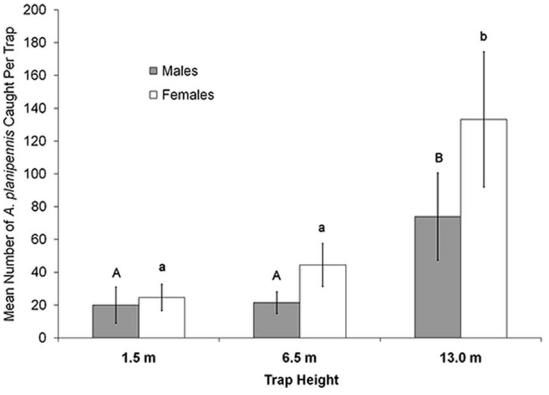

Fig. 5. Mean ± SE catch of *A. planipennis* adults on three-sided purple prism traps ($n = 10$) hung from steel rebar poles at 1.5 m or from ash trees at 6.5 m and 13 m. Uppercase letters denote differences in mean trap catch between males, whereas lowercase letters denote differences in mean trap catch between females.

in the genus *Agrilus*, are more likely to be found outside of forest interiors when sampled across a horizontal gradient (Lindhe et al. 2005; Wermelinger et al. 2007). Timms et al. (2006) found more larval galleries on the south and west facing sides of host trees than on north and east sides, suggesting a preference for ovipositing on the sunnier sides of trees. Like many other buprestids, *A. planipennis* is heliophilic, preferring to spend its time in sunlit, open areas (Yu 1992).

More *A. planipennis* were caught on traps placed high in the tree (13 m) than on lower traps. This is not surprising because most adult *A. planipennis* activity occurs in the tree canopy (Lance et al. 2007, Lelito et al. 2007). Wermelinger et al. (2007) also found that traps placed in the canopy caught more buprestids than those placed in the middle of the tree or near the ground. In other families of beetles, there is a general correlation between trap capture and the feeding, breeding and dispersal habits of the insects caught (Atkinson et al. 1988; Safranyik et al. 2000). Although it can be logistically difficult to place traps at these heights (the use of bucket trucks or tree-climbing equipment being necessary), we observed a four-fold increase in capture between traps placed at the mid-canopy and those placed near the near ground. In detection surveys where the capture of one adult is important, this increase could make the difference between detecting and not detecting a population of *A. planipennis* in areas thought to be uninfested.

Crossvane traps were less effective than box traps, catching fewer *A. planipennis.* Crook et al. (2006) also found that semiochemically baited box traps caught more beetles than crossvane traps baited with identical lures. We propose that the main reason for higher catch on box traps versus the crossvanes is that the crossvanes invert toward the center, giving less outward surface reflectance of light from the purple panels compared with the flat sided box trap. The three flat-paneled traps were not significantly different from each other, but there are several benefits to using the prism trap over the other two designs. It is relatively inexpensive and can be manufactured by machine from a single sheet of corrugated plastic (produced in 1.6-m-wide by 3.2-m-long sheets, with corrugations running lengthwise), whereas the individual panels of the box trap must be cut by hand and then attached to each other, and held in place by a spreader, in the field. The triangular shape of the prism also is sturdier than the box trap and does not require an umbrella rig spreader to maintain its shape. Although the single panel trap caught just as many beetles when tested at the lower height, we do not know how it would it would have performed, or how stable it would have been in the mid- and upper canopy.

Exploiting mate- and host-finding behavior may aid in the development of future trapping systems for this pest. Flat-paneled traps that allow full exposure of the trapping surface to sunlight should be placed in an open area of the mid-canopy, preferably away from the trunk, of an ash tree for optimal catch of *A. planipennis.* In 2008, prism traps, placed in the canopy, will be used as part of a nationwide survey effort to detect undiscovered populations and delimit the known current populations of *A. planipennis* in the United States. New and continuing research to increase trapping sensitivity is being conducted that focuses on further optimizing trap color wavelengths, chemical attractants, trap placement, and the timing of trap placement.

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