Attraction of *Agrilus planipennis* (Coleoptera: Buprestidae) and Other Buprestids to Sticky Traps of Various Colors and Shapes

Toby R. Petrice[1], Robert A. Haack[1], and Therese M. Poland[1]

Abstract

The family Buprestidae (Coleoptera) contains numerous economically significant species, including the emerald ash borer (EAB), *Agrilus planipennis* Fairmaire, first discovered in North America in 2002. Effective traps for monitoring spread and population densities of EAB and other buprestids are needed. Studies were conducted in 2008 to test different colors and shapes of sticky traps baited with manuka oil for capturing EAB and other buprestids. Among different trap shapes, an enlarged purple *Agrilus*-shaped silhouette (15 cm wide × 55 cm all) attached to a white background (40 cm wide × 60 cm tall) captured the most buprestid species compared to purple traps (40 cm wide × 60 cm tall) with or without a single dead EAB adult decoy attached at the trap center. The mean number of buprestid species captured per trap were intermediate on purple traps with 25 dead EAB adult decoys, an enlarged green *Agrilus*-shaped silhouette (15 cm wide × 55 cm tall) attached to a white background (40 cm wide × 60 cm tall), and an enlarged EAB photograph (15 cm wide × 55 cm tall) on a white background (40 cm wide × 60 cm tall). There were no significant differences detected among the different trap shapes when total number of buprestids captured per trap were compared. However, purple traps with 25 EAB adult decoys captured significantly more EAB per trap compared to enlarged EAB photographs, enlarged purple *Agrilus*-shaped silhouettes, or purple traps without decoys. In another study, there were no significant differences detected in the mean number of buprestid species, total buprestids, or EAB adults captured per trap among purple, green, or half purple and half green three-sided prism-shaped traps (each side = 40 cm wide × 60 cm tall). Response to different trap shapes and colors varied among some buprestid species and these differences are discussed.

The family Buprestidae (Coleoptera) includes numerous economically significant species in North America, especially in the genus *Agrilus*. Among these is the nonnative invasive species emerald ash borer [EAB, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae)], first discovered in North America in 2002 (Haack et al. 2002). Native to Asia, EAB has become one of the most destructive forest insect pests introduced into North America (Cappaert et al. 2005, Poland and McCullough 2006, Kovacs et al. 2010).

Adult EAB oviposit on ash (*Fraxinus* spp.) trees and likely use both olfactory and visual cues to locate hosts and mates. Research on EAB olfactory cues has focused on host kairomones and possible specific pheromones (Rodriguez-Saona et al. 2006; Crook et al. 2008a, b; Silk et al. 2011; Ryall et al. 2012). Research on visual attraction in EAB has been broad in scope but the number of studies has been limited. Studies have found that EAB adults are attracted

[1]USDA Forest Service, Northern Research Station, 1407 S. Harrison Rd., Michigan State University, East Lansing, MI 48823.
*Corresponding author: (e-mail: tpetrice@fs.fed.us).

to the colors purple (Oliver et al. 2004; Francese et al. 2005, 2008) and green (Crook et al. 2009; Francese et al. 2010). In addition, Lelito et al. (2008) found that EAB adults were attracted to dead EAB adults in the field when placed as decoys on ash leaflets.

Literature suggests buprestids are very visually oriented. For example, in Australia, *Julodimorpha bakewelli* (White) (Coleoptera: Buprestidae) males were found to be attracted to glass bottles (370 mL) that resemble the color and texture of *J. bakewelli* females (Gwynne and Rentz 1983). Domingue et al. (2011) reported that three European *Agrilus* species were attracted to dead *Agrilus* adults attached to foliage. Lelito et al. (2011) found similar attraction for *Agrilus subcinctus* Gory (native) and *Agrilus cyanescens* Ratzeburg (non-native) in the United States. In a field study conducted in Bulgaria, Sakalian et al. (1993) found most beetles, including buprestids, to be attracted to yellow or white conical traps, compared to black, blue, green, orange, or red. In contrast, Oliver et al. (2003) conducted a study in the United States and found buprestids to be most attracted to red-colored traps compared to blue, green or white. In the study by Sakalian et al. (1993), 99% of the buprestids captured were in the genera *Anthaxia* and *Acmaeodera*, which are species that commonly visit flowers. Oliver et al. (2003) captured primarily *Chrysobothris* species (78 %) which are usually not associated with flowers.

Traps for monitoring buprestid populations are limited primarily to single-colored sticky traps. Currently, detection traps for EAB in the U.S. and Canada consist of large, three-sided (each rectangular side = 36 cm wide × 60 cm tall) purple or green corrugated plastic prism-shaped traps (Francese et al. 2010). The outer surface of these traps is coated with insect glue to entrap landing EAB adults. McCullough et al. (2011) and Poland et al. (2011) found that a multicomponent trap was more effective for capturing EAB at low beetle densities compared to three-sided prism traps. More effective traps for monitoring spread and population densities of EAB and other buprestids are needed. In 2008, we conducted studies to evaluate the attraction of buprestids, including EAB, to sticky traps of different shapes or colors, as well as traps with dead EAB adults added as decoys, or with a photograph of an enlarged EAB adult or its silhouette.

Materials and Methods

Studies took place at four sites in Ingham County, Michigan: Legg Park (Lat 42.69 N, Long -84.38 W), Ferguson Park (Lat 42.71 N, Long -84.43 W), Wonch Park (Lat 42.71 N, Long -84.43 W), and a woodlot in Dansville, MI (Lat 42.55 N, Long -84.32 W). The three parks consisted of open grassy areas surrounded by mature trees of mixed hardwood species including green ash, *Fraxinus pennsylvanica* Marsh. The woodlot in Dansville was composed of mixed hardwoods including green and white ash (*Fraxinus americana* L.). At each site, EAB populations were high, as evidenced by abundant dead ash trees with EAB exit holes and live ash trees with numerous woodpecker feeding sites in the bark that were created while foraging for EAB larvae.

Trap shape study. In the first visual trapping experiment there were six treatments (Fig. 1). Three of the treatments consisted of two-sided-rectangular pieces of dark purple corrugated plastic [stock color manufactured by Coroplast, Inc., Vanceburg, KY; see Francese et al. (2010) for reflectance values], 40 cm wide × 60 cm tall, with either A) 25 dead EAB adults (sex not determined) per side attached with a cyanoacrylate adhesive (Loctite® Super Glue, Henkel Corporation, Westlake, OH) in 5 rows of 5 adults each spaced over the entire surface of each side of the trap to serve as decoys, B) 1 dead EAB adult (sex not determined) attached in the center of each side of the trap, or C) no EAB adult decoys (control). The fourth treatment was a 15 cm wide × 55 cm tall enlarged photograph of an EAB adult in dorsal view printed on a white background (modified from original photograph taken by Klaus Bolte, Canadian Forest Service,

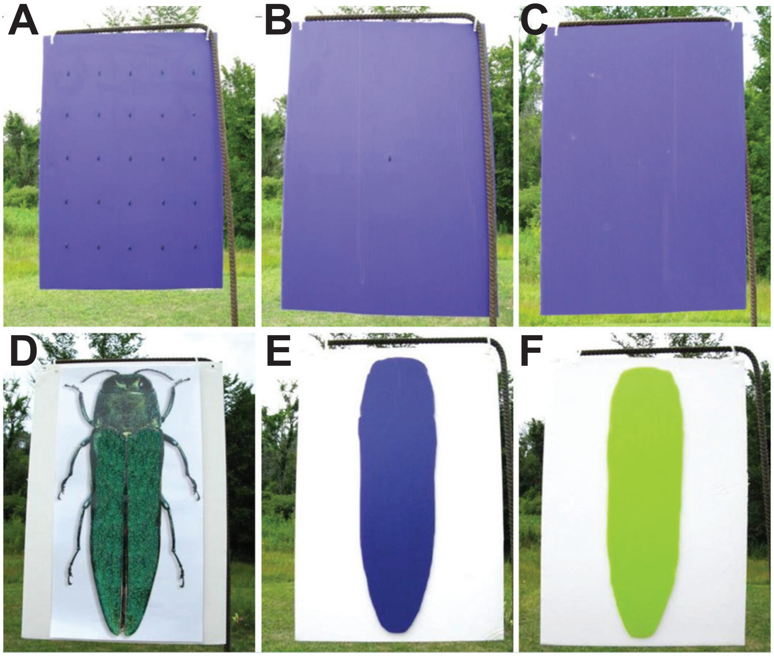

Figure 1. Traps used for trap shape study including: (A) purple rectangle with 25 dead emerald ash borer (EAB) adults, (B) purple rectangle with 1 dead EAB adult attached to center, (C) purple rectangle with no EAB adults (control), (D) enlarged EAB photograph on white background (modified from original photograph taken by Klaus Bolte, Canadian Forest Service, Natural Resources Canada, now retired), (E) purple *Agrilus* silhouette on white background, and (F) green *Agrilus* silhouette on white background. Traps were 40 cm wide × 60 cm tall flat panels with the same treatment duplicated on each side.

Natural Resources Canada, now retired). The last two treatments consisted of a single 15-cm-wide × 55-cm-tall dark purple (Coroplast stock color)) or light green [”young ash green” manufactured by Coroplast, Inc., Vanceburg, KY; see Francese et al. (2009) for reflectance values] silhouette of an adult *Agrilus* beetle viewed dorsally (traced from an enlarged EAB photograph) that was cut from corrugated plastic. *Agrilus* silhouettes and EAB photographs were glued to the center of both sides of a 40 cm wide × 60 cm tall white foam poster board with construction adhesive (Liquid Nails® Heavy Duty Construction Adhesive, Liquid Nails Adhesive, Strongsville, OH). The rationale for the latter three traps types was that EAB and other buprestids are visually attracted to conspecifics (Lelito et al. 2008, Domingue et al. 2011) and enlarged silhouettes might be visible to buprestids from greater distances. Three replicates of each treatment were placed at Legg Park, 3 at Ferguson Park, and 4 at Dansville for a total of 10 replicates. Traps were deployed 13 June 2008 and removed on 12 August 2008.

Trap color study. In the second visual trapping experiment, purple and green three-sided-prism traps were compared (Fig. 2). Traps consisted of a 108 cm × 60 cm rectangular piece of dark purple (Coroplast stock color) or light green (”young ash green”) corrugated plastic folded twice perpendicular to the long edge to make three 36 cm × 60 cm sides. The free ends were fastened together using plastic ties. Treatments included traps that were all purple,

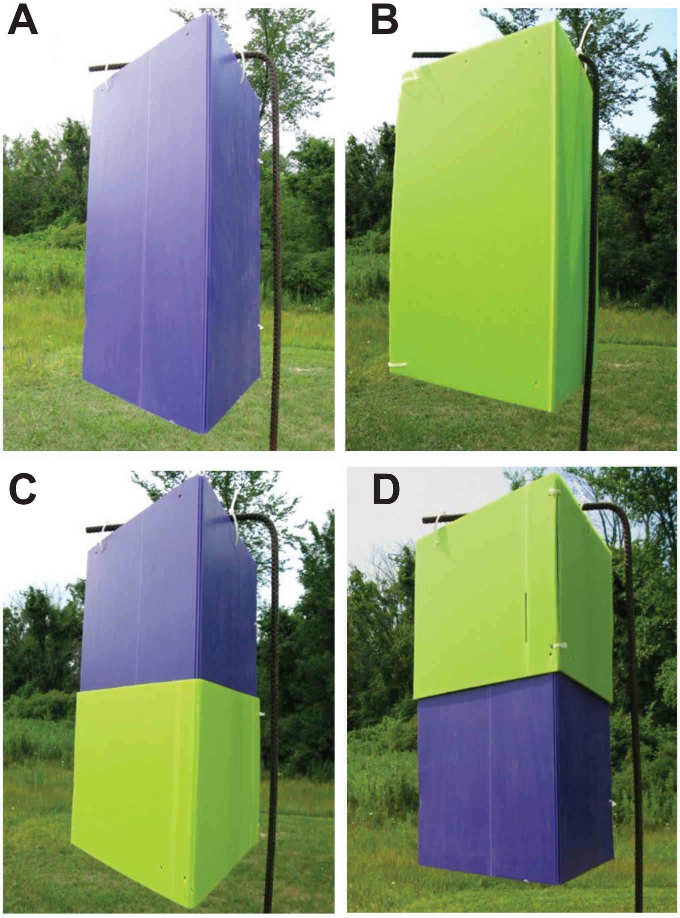

Figure 2. Traps used for trap color study including: (A) all purple prism, (B) all green prism, (C) purple top and green bottom prism, and (D) green top and purple bottom prism. Traps were three-sided with the same treatment on each side. Traps were 36 cm-wide × 60 cm-tall on each side.

all green, purple on the top half and green on the bottom half, or green on the top half and purple on the bottom half. For traps with both purple and green, construction adhesive was used to attach green plastic over the top- or bottom half of the purple plastic. Five replicates each were placed at Legg Park and Wonch Park for a total of 10 replicates. Traps were deployed 13 June 2008 and removed on 12 August 2008.

Trap setup, monitoring, and data analyses. For both studies, all traps were suspended from rebar poles (1.25 cm diam.) approximately 2 m above the ground. The bottom of the rebar pole was inserted into the ground and the top had a 90º bend approximately 0.3 m long, where each trap was attached. Traps were spaced 15 m apart and situated on a forest edge a minimum of 15 m from any ash tree.

All surfaces of each trap were painted with clear Pestick™ insect glue (Hummert International, Earth City, MO). Pestick™ was carefully applied to those traps with the dead EAB adults to avoid covering the individual EAB decoys. Since EAB was the primary species targeted for both trapping experiments, all traps were baited with manuka oil (manufactured by Coast Biologicals, Ltd. Auckland, NZ, distributed by Merchant Ag/Response-Ohio, Inc., Chagrin Falls, OH), a steam distillate from the New Zealand tea tree, *Leptospermum scoparium* J.R. and G. Forst. (Myrtaceae), that has been found to enhance attraction of EAB to sticky traps (Crook et al. 2008b). The manuka oil was dispensed from a cluster of five 0.4-ml polyethylene snap-cap tubes (Fisher Scientific, Pittsburgh, PA) at a total combined release rate of 10 mg/d.

Buprestids were collected from traps every 1–3 d from 14 June through 15 July 2008 (to include EAB peak flight), then collected every 1–2 wk through 12 August 2008. Samples were frozen until they could be cleaned and beetles identified in the laboratory. Hexane was used to remove Pestick™ from beetles prior to identification. Buprestids were identified to species using keys in Fisher (1928), Wellso et al. (1976), Wellso and Manley (2007), and MacRae (2003). Sex of each beetle was determined using morphological characters or dissection of genitalia when required for some species. Female members of the *Agrilus otiosus* species-group and a few related *Agrilus* species cannot be distinguished from one another morphologically (Fisher 1928, MacRae 2003). For this paper, therefore, these females were pooled and referred to as female *A. otiosus*-relatives. Male *Agrilus otiosus*-relatives captured in our study included: *Agrilus arcuatus* (Say), *Agrilus defectus* Leconte, *Agrilus masculinus* Horn, *Agrilus otiosus* Say, and *Agrilus transimpressus* Fall. We pooled all male *A. otiosus*-relatives for statistical analyses which enabled comparison with females, and because males of most species were represented by only a few specimens. In addition, female *Agrilus celti* Knull and *Agrilus egenus* Gory cannot be distinguished from each other morphologically (Fisher 1928), and are referred to as *A. celti* + *A. egenus* in this paper. For statistical analyses, we chose to pool males of both of these species as well.

The percentage of beetles captured per trap was calculated as the number captured by an individual trap expressed as a percentage of the total number captured by all traps within each replicate for the entire flight season. Percentages were calculated for different buprestid groups, individual species, or sexes relative to the total number of the respective buprestid group, species, or sex within each replicate. Replicates that did not capture any specimens of a given buprestid group, species, or sex were excluded from that particular analysis. Responses to different traps were analyzed by genus, species, and sex when adequate numbers existed, i.e., >25 total representatives of a buprestid group or species. Percentage data were normalized using arcsine square root transformations before analyses. The number of species captured was normalized using Log_{10} transformations before analyses. Data were analyzed with PROC GLM (SAS 2008). Means separation was performed with Least Squared Differences when analyses were significant at the $P < 0.05$ level.

Results

Trap shape study. Overall, 776 buprestids were captured on the different shaped traps, representing 4 genera and at least 28 species (Table 1). Of these, 672 individuals were species of *Agrilus*, representing at least 17 species of which 530 individuals were EAB. The next two most abundant buprestid genera captured were *Chrysobothris* (89 individuals and at least 7 species) and *Anthaxia* (12 individuals and at least 3 species). The mean percentage of all buprestids combined per trap did not vary significantly among trap shapes (Fig. 3a; significance values are given in Figs. 3-6). However, there was a significant difference in the mean number of buprestid species captured per trap among the

Table1. Number of male and female buprestids captured in Ingham County, Michigan, June-August 2008, on sticky traps with enlarged purple or green *Agrilus* silhouettes (15 cm wide × 55 cm tall) on white backgrounds; enlarged EAB photographs (15 cm × 55 cm) attached to 40 cm wide × 60 cm tall white background; or 0, 1, or 25 dead EAB adults attached to 40 cm tall × 60 cm wide purple rectangles (see Fig.1). Traps (10 replicates per treatment) were two-sided, coated with Pestick™ insect trapping glue, and baited with manuka oil (10 mg/d).

	Trap type						
Species	**Green silhouette** ♂(♀)	**Purple silhouette** ♂(♀)	**Enlarged EAB photo** ♂(♀)	**Purple with 1 EAB** ♂(♀)	**Purple with 25 EAB** ♂(♀)	**Purple control** ♂(♀)	**Total buprestids captured** ♂(♀)
Agrilus anxius Gory	3(7)	5(4)	13(12)	0(4)	1(2)	0(3)	22(32)
A. bilineatus (Weber)	0	0(2)	0	0	3(7)	1(0)	4(9)
A. celti Knull males[1]	0	0	1	(0)	0	0	1
A. celti + *egenus* females[1]	(3)	(1)	(1)	(0)	(0)	(1)	(6)
A. cyanescens Ratzeburg	0(3)	0(1)	0	0	0(3)	0	0(7)
A. defectus Leconte males[2]	0	0	1	0	0	0	1
A. egenus Gory-males[1]	0	0	1	0	0	0	1
A. granulatus liragus Barter&Brown	0	0	0	0	0	1(0)	1(0)
A. lecontei Saunders	0(2)	0	0	0(1)	0	0	0(3)
A. masculinus Horn males[2]	4	0	0	1	0	0	5
A. obsoletoguttatus Gory	0(3)	0	0	1(2)	0	0	1(5)
A. otiosus Say males[2]	1	0	0	0	0	0	1
A. otiosus-relative females[2]	(18)	(4)	(3)	(1)	(7)	(0)	(33)
A. planipennis Fairmaire	33(54)	34(52)	7(25)	36(59)	46(83)	41(60)	197(333)
A. politus (Say)	0	0	0	0	0	0(1)	0(1)
A. sulcicollis Lacordaire	0	0	0	0	0(2)	0(1)	0(3)
A. transimpressus Fall males[2]	2	0	0	0	0	0	2(0)
A. vittaticollis (Randall)	0(1)	0	0	0	0	0	0(1)
Unidentified *Agrilus*	0(2)	0	0	0(1)	0	0	0(3)
Anthaxia expansa Leconte	0(1)	0	0	0	0	0	0(1)
An. viridicornis (Say)	0(1)	0	0	0	1(0)	0	1(1)
An. viridifrons Gory	0	0	2(1)	0	0(1)	0	2(2)
Unidentified *Anthaxia*	0(1)	0	1(3)	0	0	0	1(4)

Table1. Continued.

	Trap type						
Species	**Green silhouette ♂(♀)**	**Purple silhouette ♂(♀)**	**Enlarged EAB photo ♂(♀)**	**Purple with 1 EAB ♂(♀)**	**Purple with 25 EAB ♂(♀)**	**Purple control ♂(♀)**	**Total buprestids captured ♂(♀)**
Chrysobothris adelpha Harold	0	0	1(2)	1(0)	0	0	2(2)
C. femorata (Olivier)	2(0)	3(10)	5(8)	2(4)	0(1)	1(2)	13(25)
C. quadriimpressa Gory&Laporte	0(1)	5(4)	3(8)	2(1)	0(2)	1(1)	11(17)
C. rugosiceps Melsheimer	0	0(1)	0	0	0	0	0(1)
C. sexsignata Say	0	0(4)	0(1)	0(2)	0	0(3)	0(10)
C. shawnee Wellso&Manley	0	0(2)	0(1)	0	1(0)	0	1(3)
C. viridiceps Melsheimer	0	0	0	0	0	0(1)	0(1)
Unidentified *Chrysobothris*	0	0	0(2)	0	0(1)	0	0(3)
Dicerca lurida (Fabricius)	0(1)	0(2)	0	0	0	0	0(3)
Total buprestids captured	45(98)	47(87)	35(67)	43(75)	52(109)	45(73)	267(509)

[1]Females of these two species cannot be distinguished from one another.

[2]In the *A. otiosus* species group or a close relative. Females in this group cannot be distinguished from one another. See MacRae (2003) for a complete list of species in this group.

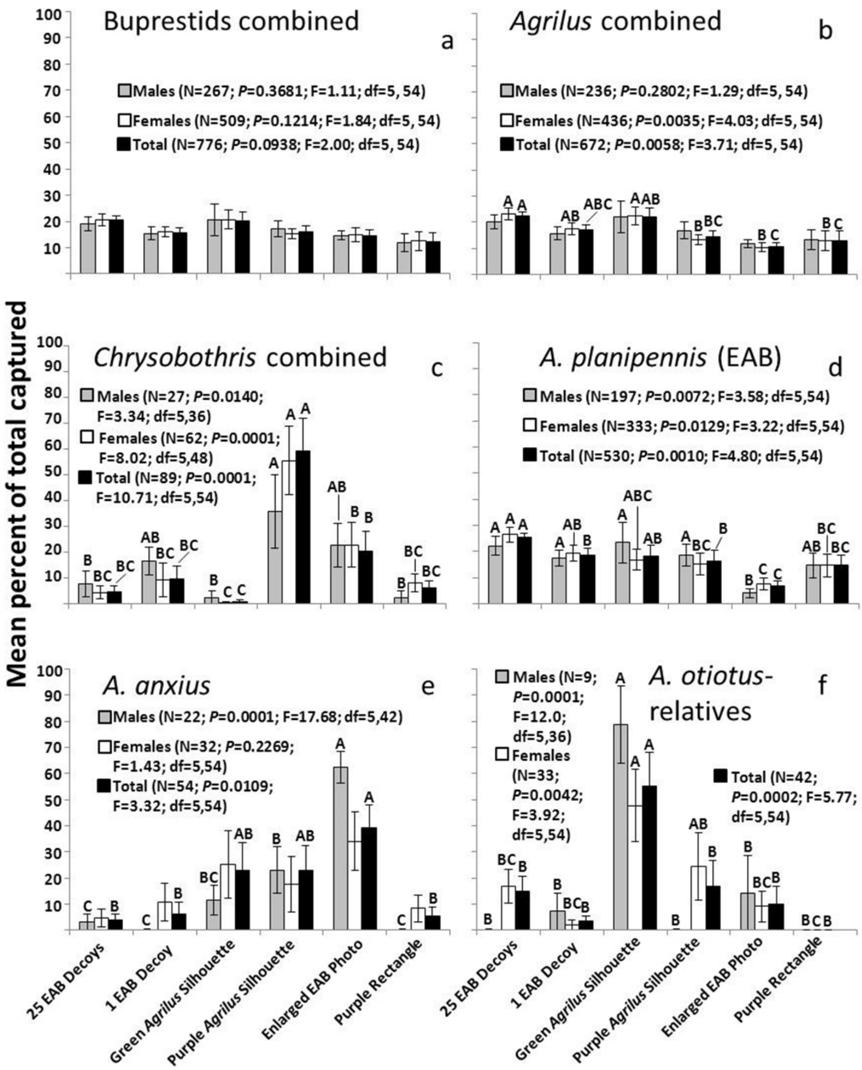

Figure 3. Mean percentage of Buprestidae (a), and the most common buprestid genera and species (b-f),captured per trap in Ingham County, Michigan, during June-August 2008 on sticky traps with enlarged purple or green *Agrilus* silhouettes (15 cm wide × 55 cm tall) on white backgrounds; enlarged EAB photographs on white backgrounds (15 cm × 55 cm); or 0, 1, or 25 dead EAB adults attached to a purple background. Traps (40 cm wide × 60 cm tall) were two-sided and baited with manuka oil (5 mg/d). Means within each buprestid group and sex followed by a different letter are significantly different at the $P < 0.05$ level (LSD, N = 10).

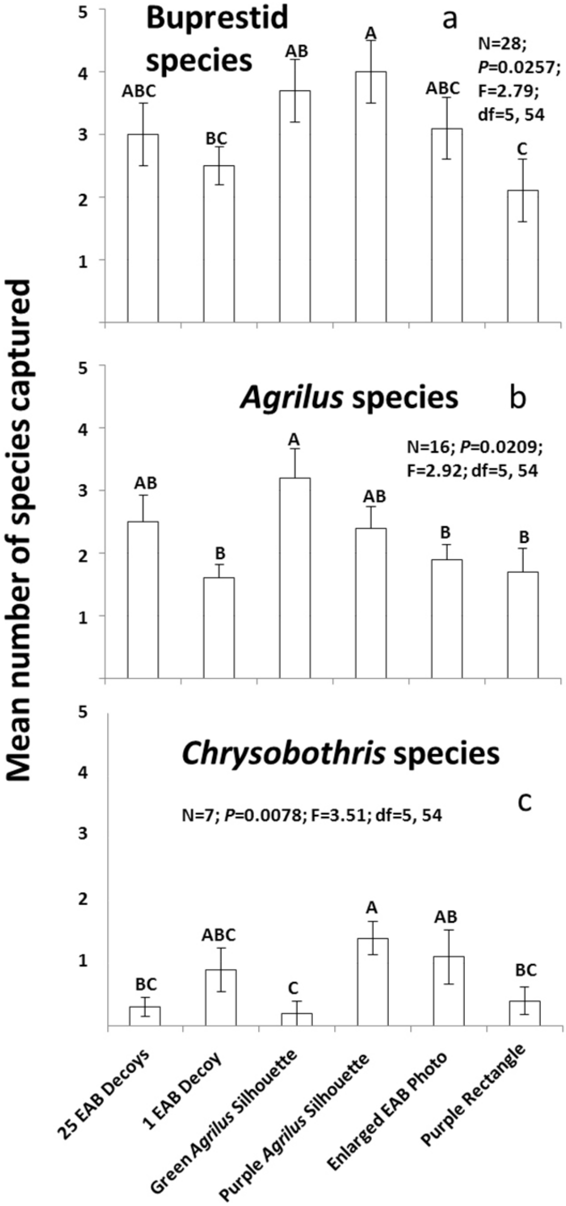

Figure 4. Mean number of Buprestidae (a), *Agrilus* (b), or *Chrysobothris* (c), species captured per trap in Ingham County, Michigan, during June-August 2008 on traps with enlarged purple or green *Agrilus* silhouettes (15 cm wide × 55 cm tall) on white backgrounds; enlarged EAB photographs (15 cm × 55 cm) on white backgrounds; or 0, 1, or 25 dead EAB adults attached to a purple background. Traps (40 cm wide × 60 cm tall) were two-sided and baited with manuka oil (10 mg/d). Means within each buprestid group followed by a different letter are significantly different at the $P < 0.05$ level (LSD, N = 10).

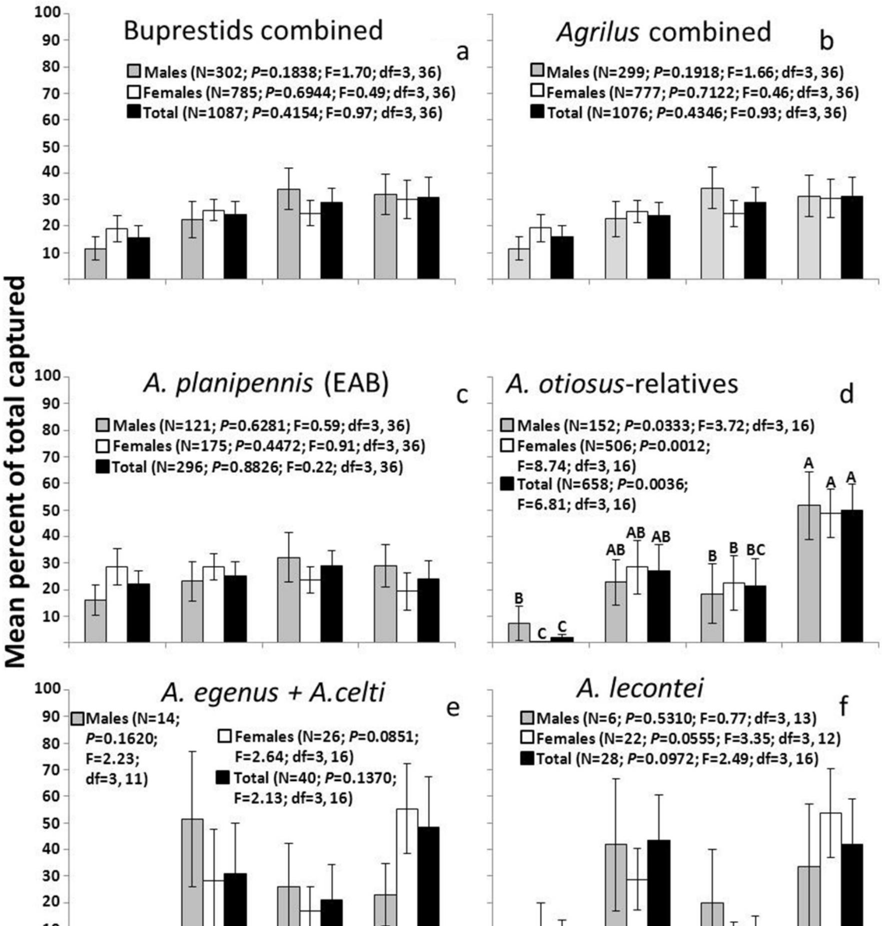

Figure 5. Mean percentage of Buprestidae (a), and the most common genera and species (b-f), captured per trap in Ingham County, Michigan, during June-August 2008 on three-sided prism sticky traps (each side = 36 cm wide × 60 cm tall) that were purple, green, purple on top and green on the bottom, or green on top and purple on the bottom. All traps were baited with manuka oil (10 mg/d). Means within each buprestid group and sex followed by a different letter are significantly different at the $P < 0.05$ level (LSD, N = 10).

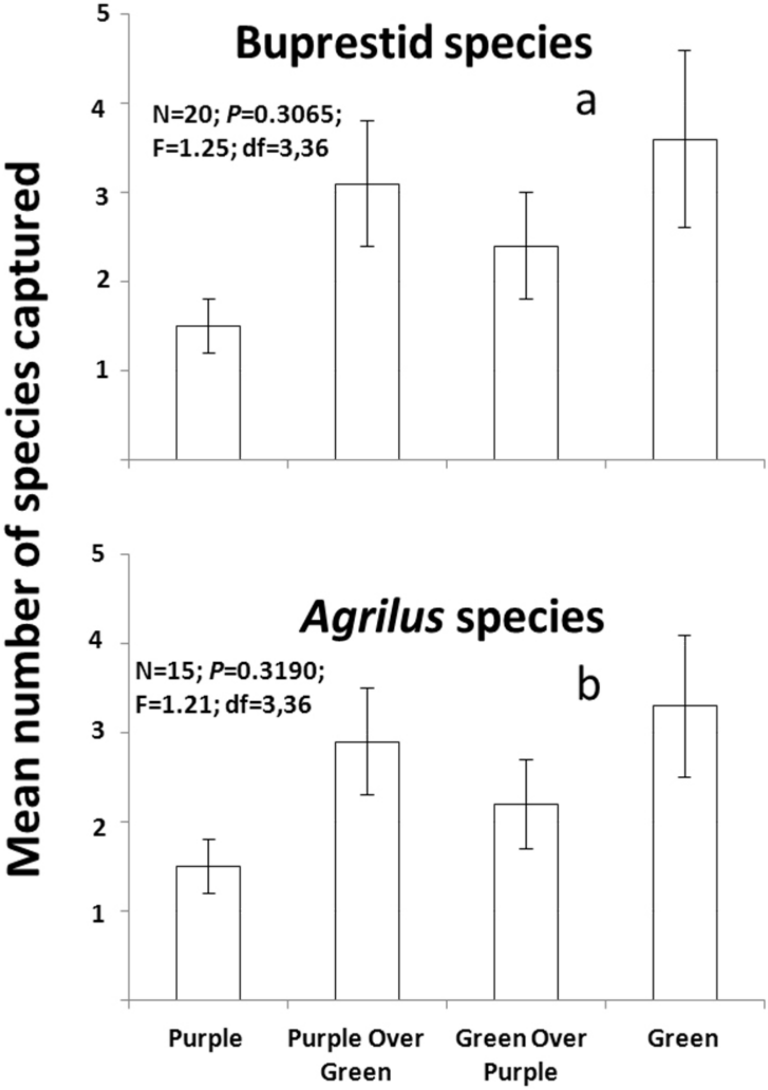

Figure 6. Mean number of Buprestidae (a), or *Agrilus* (b), species captured per trap in Ingham County, Michigan, during June-August 2008 on three-sided prism sticky traps (each side = 36 cm wide × 60 cm tall) that were purple, green, purple on top and green on the bottom, or green on top and purple on the bottom. All traps were baited with manuka oil (10 mg/d). No significant differences were detected among treatments.

different trap shapes (Fig. 4a). The purple *Agrilus* silhouette traps captured significantly more buprestid species compared to the purple traps with a single EAB decoy and the purple traps without EAB decoys, while the mean number of buprestid species captured by the remaining trap types was intermediate between *Agrilus* silhouette and purple traps (Fig 4a).

The mean percentage of all female *Agrilus* captured per trap, and for both sexes combined, was significantly higher for the purple traps with 25 EAB decoys and the green *Agrilus* silhouette traps compared to purple traps without EAB decoys and the enlarged EAB photograph traps (Fig. 3b). The mean percentage of combined *Agrilus* or female *Agrilus* captured on other trap types was intermediate. The mean percentage of all male *Agrilus* combined captured per trap did not vary significantly among trap types, but followed a similar trend as female and combined *Agrilus* in absolute terms.

The mean number of *Agrilus* species captured per trap was significantly higher on the green *Agrilus* silhouette traps compared to the purple traps with one EAB decoy, purple traps without EAB decoys, and the enlarged EAB photograph traps (Fig. 4b). Purple traps with 25 EAB decoys or the purple *Agrilus* silhouette traps captured an intermediate number of *Agrilus* species.

The mean percentage of *Chrysobothris* species combined per trap also varied significantly among treatments (Fig. 3c). Overall, the purple *Agrilus* silhouette traps captured the highest mean percentage of *Chrysobothris* males, females and both sexes combined, green *Agrilus* silhouette traps tended to capture the lowest mean percentages, and the remaining trap types were intermediate (Fig. 3c). Purple *Agrilus* silhouette traps captured significantly more species of *Chrysobothris* than did green *Agrilus* silhouette traps, purple traps with 25 EAB decoys, or purple rectangle traps with no EAB decoys. The remaining treatments captured an intermediate number of *Chrysobothris* species (Fig. 4c).

The mean percentage of EAB males captured per trap was significantly lower on the enlarged EAB photograph traps compared to purple traps with 25 EAB decoys, with 1 EAB decoy, and purple or green *Agrilus* silhouette traps (Fig. 3d). Purple traps without EAB decoys captured an intermediate percentage of EAB males. The mean percentage of EAB females captured per trap was highest on purple traps with 25 EAB decoys and lowest on the enlarged EAB photograph traps (Fig. 3d). Purple traps with one EAB decoy, green or purple *Agrilus* silhouette traps, and purple traps without an EAB decoy captured an intermediate percentage of EAB females. The mean percentage of total EAB of both sexes combined followed a similar trend as for EAB females; females dominated the trap catch.

The mean percentage of *Agrilus anxius* Gory males captured per trap, as well as the percentage of both sexes combined, was significantly higher on the enlarged EAB photograph traps compared to purple traps with 25 EAB decoys, 1 EAB decoy, or no EAB decoys (Fig. 3e). The mean percentage of *A. anxius* males and both sexes combined per trap on purple or green *Agrilus* silhouette traps was intermediate. The mean percentage of *A. anxius* females captured per trap did not vary significantly among trap types but followed a similar trend to *A. anxius* males in absolute terms.

Four species of male *A. otiosus*-relatives were captured on the different trap types, of which *A. masculinus* represented almost 56% (Table 1). The mean percentage of *A. otiosus*-relatives that were males, females, or for both sexes combined was significantly higher on green *Agrilus* silhouette traps compared to the other traps tested (Fig. 3f).

Trap color study. Overall, 1,087 buprestids were captured in the trap color study, representing four genera and at least 20 species (Table 2). Of the total number of buprestids captured, 1,076 were *Agrilus* species that represented 15 species of which 296 were EAB (Table 2). The mean percentage of buprestids

Table 2. Number of male and female buprestids captured in Ingham County, Michigan, June-August 2008, on three-sided prism sticky traps (each side = 36 cm wide × 60 cm tall) that were purple, green, purple on top and green on bottom, or green on top and purple on the bottom (see Fig. 2). Traps (10 replicates per treatment) were coated with Pestick™ insect trapping glue and baited with manuka oil (10 mg/d).

	Trap color				
Species	**All green ♂(♀)**	**Green over purple ♂(♀)**	**Purple over green ♂(♀)**	**All purple ♂(♀)**	**Total buprestids ♂(♀)**
Agrilus anxius Gory	2(1)	0(1)	0(1)	0(2)	2(5)
A. arcuatus (Say) [2]	1	0	0	0	1(0)
A. bilineatus (Weber)	0	0	0(1)	0	0(1)
A. celti Knull males[1]	0	4	3	0	7
A. celti + *egenus* females[1]	(13)	(4)	(9)	(0)	(26)
A. cyanescens Ratzeburg	1(5)	0(2)	0(3)	0	1(10)
A. egenus Gory males[1]	4	1	2	0	7
A. fallax Say	0	0	0(1)	0	0(1)
A. lecontei Saunders	2(12)	1(2)	3(6)	0(2)	6(22)
A. masculinus Horn males[2]	65	24	56	1	146
A. obsoletoguttatus Gory	0(2)	0(1)	0	0(1)	(4)
A. otiosus Say males[2]	1	0	0	0	1
A. otiosus-relative females[2]	(205)	(106)	(193)	(2)	(506)
A. planipennis Fairmaire	22(26)	48(46)	20(44)	31(59)	121(175)
A. ruficollis (Fabricius)	1(0)	0	1(1)	0	2(1)
A. transimpressus Fall males[2]	2	1	0	1	4
A. vittaticollis (Randall)	0(1)	0	0	0	0(1)
Unidentified *Agrilus*	0(19)	0(5)	0(2)	0(0)	0(26)
Anthaxia viridicornis (Say)	2(0)	0	0	0	2(0)
An. viridifrons Gory	1(3)	0	0	0	1(3)
Unidentified *Anthaxia* females	(0)	(0)	(1)	(0)	(1)
Chrysobothris femorata (Olivier)	0	0	0(2)	0	0(2)
C. quadriimpressa Gory&LaPorte	0	0(1)	0	0	0(1)
Dicerca lurida (Fabricius)	(0)	(1)	(0)	(0)	0(1)
Total buprestids	104(287)	79(169)	85(264)	33(66)	301(786)

[1]Females of these two species cannot be distinguished from one another.
[2]In the *A. otiosus* species group or a close relative. Females in this group cannot be distinguished from one another. See MacRae (2003) for a complete list of species in this group.

or *Agrilus* captured did not vary significantly among the trap colors (Fig. 5a, b). Also, the mean number of buprestid or *Agrilus* species captured did not vary significantly among trap colors (Fig. 6a, b).

Considering the more common *Agrilus* species captured, the mean percentage of EAB captured per trap did not vary significantly among the different trap colors (Fig. 5c). The mean percentage of *A. otiosus*-relatives that were males, females, or for both sexes combined per trap was significantly higher on green traps compared to purple traps, while the percentage captured on green over purple or purple over green combination traps tended to be intermediate (Fig. 5d). Four species of male *A. otiosus*-relatives were captured, of which 96% were *A. masculinus* (Table 2). The mean percentage of *A. celti* + *A. egenus* or *Agrilus lecontei* Saunders captured per trap did not vary significantly among trap colors (Fig. 5e). However, the percentage of *A. lecontei* females captured was almost significant (P = .0555) with more tending to be captured on green traps than on purple traps (Fig. 5f).

Discussion

Some studies have confirmed that visual cues are used by several species of Buprestidae to locate and select their mates (Gwynne and Rentz 1983; Lelito et al. 2008, 2011; Domingue et al. 2011), so it is likely that visual cues are also important for buprestids to locate and select their host plants. The host range of buprestids includes most woody species (both conifers and hardwoods) but most buprestids are restricted to hosts within a single plant family or genus (Nelson et al. 2008). Given the variability in color and shape among buprestid adults and the variation in hue and reflectance among tree species (Campbell and Borden 2005), it is not surprising that trap preference varied among the buprestid genera and species collected in our study.

In the trap-shape study, purple *Agrilus* silhouette traps captured the most buprestid and *Chrysobothris* species, while green *Agrilus* silhouette traps captured the most *Agrilus* species. The *Agrilus* shape combined with the green or purple color of the silhouette may explain why these traps were most attractive. Also, the white background surrounding the silhouettes may have enhanced attraction to these traps. Background contrast is believed to play an important role in host location by insects (Prokopy and Owens 1983). We realize that the treatments used in the present study limit the strength of interpretation that can be made regarding the effects of the white background and the *Agrilus* silhouettes. Nevertheless, in our trap color study where no white background colors were used, significant differences were not detected for the number of buprestid or *Agrilus* species captured among green, purple, or green-purple combination traps. Future studies are warranted to compare different background colors with *Agrilus* silhouettes and other shapes to further elucidate differences in attractiveness of these types of traps.

Although, trap color or shape did not significantly affect the overall number of buprestid individuals captured, genus and species level differences were found. EAB decoys and *Agrilus* silhouettes, with the exception of the enlarged EAB photograph, tended to increase attraction of EAB to the traps. Although the EAB photograph appeared to the human eye as the same color as an actual EAB adult beetle, it was not very attractive to EAB in our study. It is possible that EAB perceive color and light reflecting from two-dimensional photographs differently than they would from actual three-dimensional insects. Furthermore, the cuticle of EAB adults is iridescent and reflects many colors due to pigmentation and structural characteristics (Baker et al. 2011), which may not be the same as a two-dimensional photograph. The effect that the insect trapping glue may have had on the distortion and reflectance of the EAB photograph should also be acknowledged. Crook et al. (2009) found that the insect trapping glue used in their study, which was very similar in transparency and consistency to the glue we used, increased reflectance by 2.5%. It is also possible that the white background that surrounded the EAB photograph deterred attraction, however, the white backgrounds of the purple or green *Agrilus* silhouette traps did not appear to reduce attraction of EAB.

We expected attraction to traps with EAB decoys to be higher for male EAB compared to females, given that *Agrilus* males usually seek females for mating rather than vice versa. Lelito et al. (2008) found only males to alight on ash leaflets where dead EAB adults had been placed. Therefore, it is puzzling that the addition of 25 EAB decoys to the purple rectangular traps in our study increased the overall attraction of EAB females, but not males. Francese et al. (2010) found EAB females to be more attracted to purple than males, and suggested that purple mimics the color of tree bark to EAB. It is possible that EAB females may orient toward other EAB adults, especially if they are against certain background colors such as purple because their presence indicates the location of a suitable host, i.e., females may tend to land on a host near other EAB adults. Lelito et al. (2007) observed wild EAB males in the field that hovered above dead beetles pinned to the ash leaflets and then rapidly and accurately dove onto the body of the beetle decoy. Therefore, it is possible in our study that some males landed on the dead EAB decoys and were able to fly away without being captured because the decoys were not coated with Pestick™. Furthermore, male EAB are more attracted to green compared to females (Francese et al. 2010), and perhaps, if we had placed EAB decoys on a green background in our study the response of males to the EAB decoys would have been stronger.

Responses by *A. anxius* to the various trap designs and colors were different from those of EAB. Significantly more *A. anxius* males were captured on the enlarged EAB photograph traps than on purple rectangle traps with or without EAB decoys, and captures on green and purple *Agrilus* silhouette traps were intermediate. Although significant differences were not detected, *A. anxius* females followed a similar pattern as the *A. anxius* males. It is unclear whether the silhouettes themselves attracted *A. anxius* males or if attraction was due primarily to the white background that surrounded the EAB photographs and the purple and green *Agrilus* silhouettes. Supporting this latter hypothesis is the fact that the background bark color of many birch (*Betula*) species is white, which is likely an important visual cue for this *Agrilus* species to locate its host. *Agrilus anxius* was also found to be attracted to white corrugated plastic sticky traps baited with host volatiles (Gary Grant, Canadian Forest Service, personal communication 2009, now deceased).

While significant differences in the percentage of EAB adults captured per trap were not detected among purple, green and purple-green combination traps, there was a general trend of male EAB to be more attracted to green, while female EAB were more attracted to purple. This trend is consistent with the findings of previous studies by Crook and Mastro (2010) and Francese et al. (2010).

Green is apparently much more attractive than purple for the *A. otiosus*-relatives. Both sexes were most attracted to green-colored traps in both of our studies. Attraction to green may be host related for the *A. otiosus*-relatives because members of this group tend to oviposit on small branches (Hespenheide 1969, MacRae 1991) that would most often be in the canopy where green-colored foliage is typically present. Furthermore, most *A. otiosus*-relatives attack dead or severely weakened branches rather than healthy live branches (MacRae 1991), and the shade of light green used for our traps may appear similar to foliage of weakened or dying trees, i.e., chlorotic foliage that is slightly yellow or lighter in color. Although significant differences were not detected, *Agrilus lecontei* and *A. egenus* + *A. celti* responded in a similar pattern in our trap color study and tended to prefer green colored traps.

In the trap shape study, *Chrysobothris* species were most attracted to the purple *Agrilus* silhouette traps. Interestingly, the green *Agrilus* silhouette traps were among the least attractive traps for *Chrysobothris*. Furthermore, no *Chrysobothris* were captured on the all-green traps in our trap color study, albeit, only three *Chrysobothris* individuals were captured in that study. Oliver et al. (2003) found colors in the red spectrum (which would include purple) to be most attractive to buprestids, especially *Chrysobothris*. Moreover, Oliver et al. (2003) found white traps were moderately attractive to *Chrysobothris* spp., so perhaps it was the combination of the white and purple that enhanced attraction of *Chrysobothris* in our trap shape study. Future studies that include traps with different purple shapes and all white traps would help determine if the purple *Agrilus* silhouette contributed to the attraction of *Chrysobothris* to this type of trap or if it was merely attraction to the two colors combined.

In the present study, attraction to different trap colors and shapes varied among buprestid genera and species. Therefore, to effectively monitor buprestid populations, multiple trap shapes and colors should be considered when conducting general surveys. More studies are warranted to determine the most attractive color and shape combination for individual buprestid species, especially those of economic importance.

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