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Comparison of Different Trap Colors and Types for Capturing Adult *Agrilus* (Coleoptera: Buprestidae) and Other Buprestids

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Abstract

Numerous research studies have focused on the development of effective traps for surveying and monitoring for emerald ash borer, *Agrilus planipennis* (Fairmaire) (Coleoptera: Buprestidae), since it was discovered in North America. However, little attention has been placed on developing effective traps for monitoring and surveying other *Agrilus* and Buprestidae. In 2009–2011, we conducted several studies to test the attractiveness of different trap colors and types of sticky traps to *Agrilus* and other Buprestidae. We found green (peak reflectance: 530–536 nm, 57.6%) sticky traps that consisted of custom colored corrugated plastic, and were coated with insect trapping glue to be the most effective traps for capturing the most *Agrilus* individuals and species. These same green traps were also effective at capturing other buprestid genera, with the exception of *Chrysobothris* which were most attracted to purple sticky traps. In 2012, we conducted a study to compare the three most effective sticky traps from our 2009–2011 studies along with black and green (530 nm, 57% reflectance) multifunnel traps for capturing *Agrilus* and other Buprestidae. Overall, we found Coroplast™ green sticky traps to be the most effective traps for capturing the most *Agrilus* individuals. Green multifunnel traps captured more buprestids compared to black multifunnel traps. In addition, green multifunnel traps captured the most *Agrilus* species. .

Since the discovery of emerald ash borer, *Agrilus planipennis* (Fairmaire) (Coleoptera: Buprestidae), in North America (Haack et al. 2002), numerous research studies have focused on the development of effective traps for surveying and monitoring this non-native species. A study by Oliver et al. (2003) found many buprestid species were attracted to colors in the violet range (400-420 nm). This finding led researchers to test attraction of *A. planipennis* to traps of different colors (Francese et al. 2005). Electroretinogram studies showed that *A. planipennis* adults responded strongly to colors in the violet and green spectrum, and field studies confirmed that *A. planipennis* was attracted to purple and green traps (Crook et al. 2009, Francese et al. 2010). Subsequent studies tested traps produced in different shades of purple and green, as well as different trap shapes, trap types, and the additive effect of using dead adults as decoys on the traps (Francese et al. 2011, Francese et al. 2013b, Francese et al. 2013a, Petrice et al. 2013, Poland and McCullough 2014).

The family Buprestidae contains over 15,000 species worldwide, most of which are woodborers or leafminers (Bellamy 2008). This family includes numerous economically important pests, especially those in the genus *Agrilus*. However, with the exception of *A. planipennis*, little attention has been placed on developing effective traps for monitoring and surveying programs (Domingue and Baker 2012). In addition to the study by Oliver et al. (2003) mentioned above, only a few other researchers have reported that species of Buprestidae were attracted to specific

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colors and other visual cues. Sakalian et al. (1993) found that most of the buprestid species captured in their study, most of which are known to visit flowers, were more attracted to yellow or white compared to black, blue, green, orange or red traps. Gwynne and Rentz (1983) found that *Julodimorpha bakewelli* (White) males were attracted to and attempted to copulate with a specific brand of glass beer bottle that had a similar color and texture to the elytra of *J. bakewelli* females. Several species of male *Agrilus* were attracted to dead *Agrilus* adults when used as decoys and placed on host plants (Lelito et al. 2007, Domingue et al. 2011, Lelito et al. 2011). One species of *Agrilus* was attracted to the elytron of a similarly colored Cicindelidae (Coleoptera) species (Lelito et al. 2011). Petrice et al. (2013) found some species of Buprestidae were more attracted to green traps when compared to purple, and that adding dead adults as decoys or using enlarged silhouettes of an adult *Agrilus* attracted more of some buprestid species. Petrice and Haack (2014) found that *Agrilus sulcicollis* Lacordaire females were most attracted to purple and white sticky traps when compared to green and yellow traps, while males did not show a specific attraction to any of the four colors tested. In contrast, Domingue et al. (2013) found that *A. sulcicollis* adults, along with several other European *Agrilus* species, in Hungary, were most attracted to small green sticky traps placed horizontally on tree branches compared to purple or white traps. However, they did not report which sexes were captured in their study.

In 2009–2011, we conducted several studies to test the attractiveness of different trap colors and different types of sticky traps to *Agrilus* adults and other Buprestidae. In 2012, we conducted a study to compare the three most effective sticky traps from our earlier studies with two different colors of multifunnel traps for capturing *Agrilus* and other Buprestidae.

Material and Methods

Traps on ash (*Fraxinus*) for *Agrilus subcinctus*. In 2009, we tested attraction of *Agrilus subcinctus* Gory, a borer native to North America, to different colored sticky traps. Adult *A. subcinctus* feed on ash foliage and oviposit on dead ash twigs (Petrice et al. 2009). We tested green, purple, white, and yellow sticky traps that were 7.6-cm-wide × 12.7-cm-tall (Fig. 1A). Green, purple and white traps were constructed from corrugated plastic (Coroplast™, Inc., Vanceburg, KY). The green corrugated plastic (Coroplast™ green; peak reflectance: 530–536 nm, 57.6%) was custom created by Coroplast™, Inc., to match the color that Crook et al. (2009) and Francese et al. (2010) found to be attractive to *A. planipennis*. Both purple (Coroplast™ purple; peak reflectance: 433-437 nm, 26.7%) and white (Coroplast™ white; peak reflectance: 436-438 nm, 96%) were stock colors manufactured by Coroplast™, Inc. Yellow (yellow sticky card; peak reflectance: 561-572, 70.4%) traps were standard insect sticky traps commonly used for trapping a variety of insects attracted to foliage (Olson Products, Inc., Medina, OH). A FieldSpec Pro full range spectrophotometer (Analytical Spectral Devices, Inc., Boulder, CO) was used to measure spectral reflectance of each color tested. Reflectance was measured approximately every 3 nm within the visible and near-infrared portion of the spectrum (350-1000 nm; Fig. 2A).

One trap of each of the four colors was stapled to a 2.5 cm × 2.5 cm × 50 cm wooden pole. Traps were randomly arranged on each pole with a 7.5 cm gap between each card. All traps were coated with Pestick™ insect glue (Hummert International, Earth City, MO). Traps were placed in ash trees with canopies that had been killed by emerald ash borer the previous 1–2 yr. As a consequence, these trees had numerous live sprouts growing from their lower trunks. Each pole (5 in total) was suspended horizontally from a dead limb just above live sprouts with foliage that were growing along the trunk. Traps were placed in the field near Webberville, Ingham County, MI (Lat 42.66°N, Long 84.20°W) on 15 May 2009. *Agrilus subcinctus* were removed from traps every 2 wks through 24 June 2009.

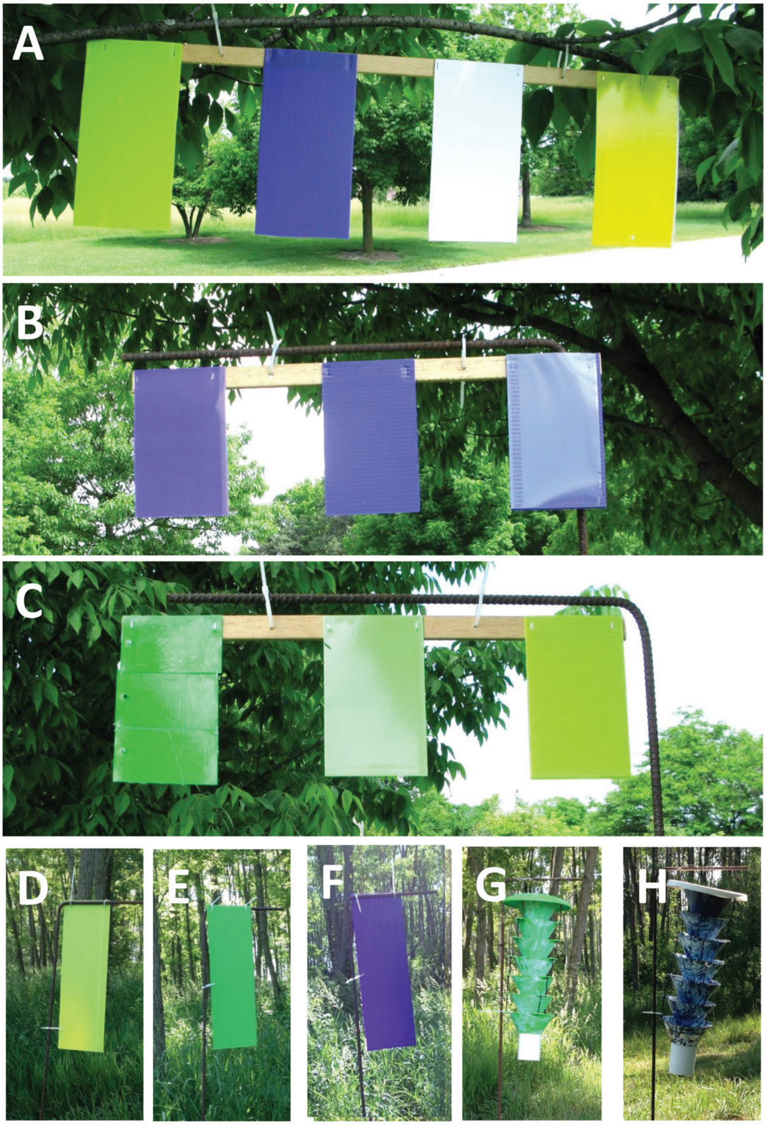

Figure 1. A) Traps used for the 2009 *Agrilus subcinctus* (trap dimensions were smaller than those pictured) and 2011 hybrid poplar and honeylocust trapping studies. From left to right: Coroplast™ green, Coroplast™ purple, Coroplast™ white, and yellow sticky card. B) Purple traps used for the 2011 purple and green trap comparison study. From left to right: Alpha Scents purple sticky, Coroplast™ purple, and Coroplast™ purple with clear sticky sheet. C) Green traps used for the 2011 purple and green trap comparison study. From left to right: three Alpha Scents dark green sticky traps stapled together, Alpha Scents light green sticky, and Coroplast™ green traps. D-H) traps used for 2012 trap comparison: D) Coroplast™ green; E) Sabic green; F) Corplast purple; G) Green funnel; and H) black funnel.

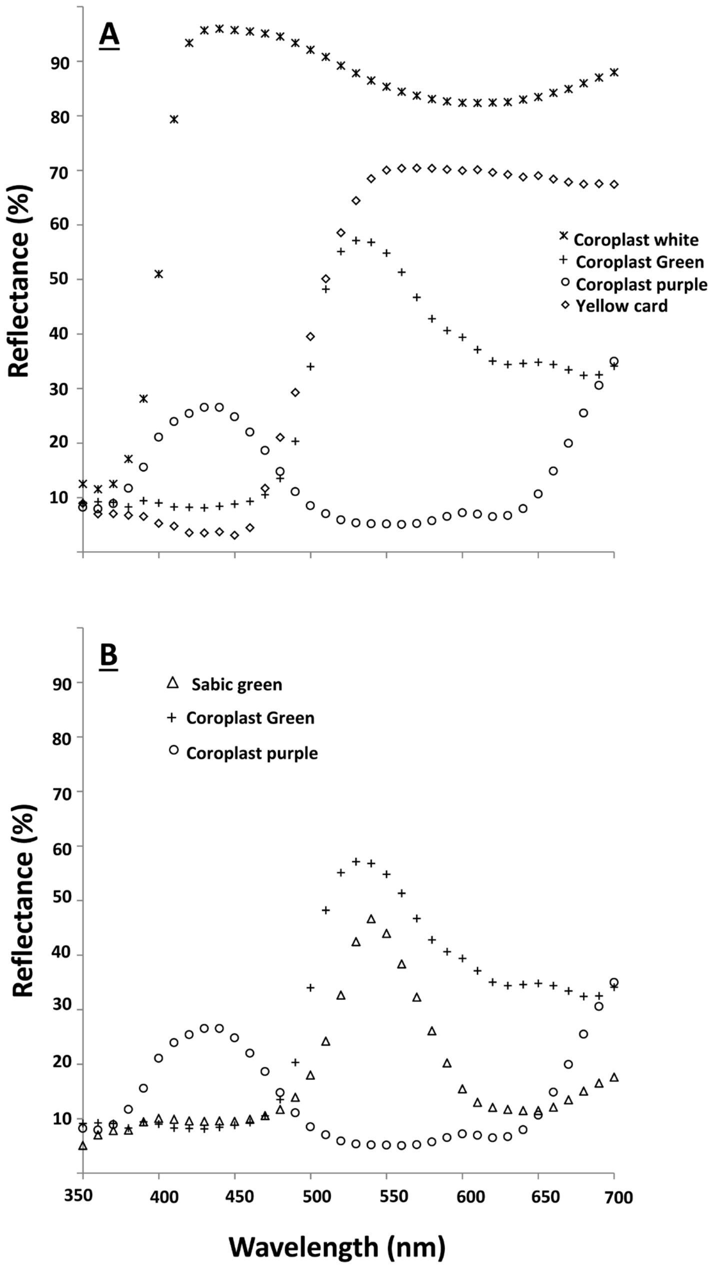

Figure 2. Reflectance spectra of A) Coroplast™ green, yellow sticky card, Coroplast™ purple, and Coroplast™ white sticky traps tested in the 2009 *Agrilus subcinctus* study and the 2011 hybrid poplar and honeylocust studies; and B) Coroplast™ green, Coroplast™ purple, and Sabic green tested in 2012.

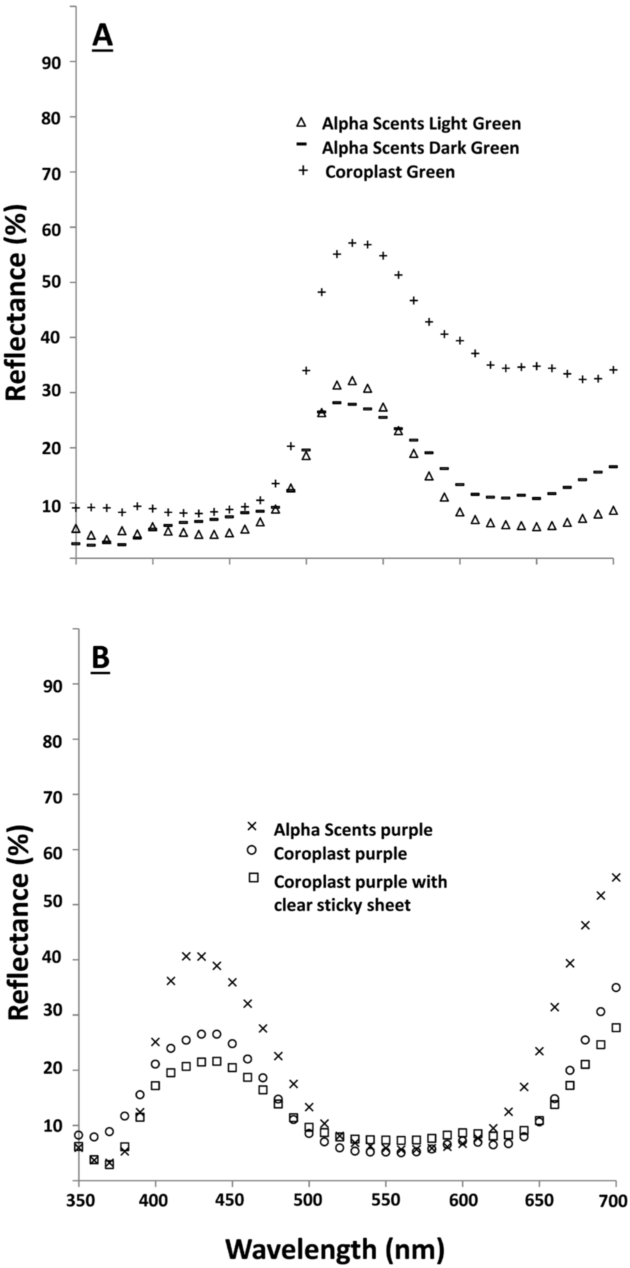

Figure 3. Reflectance spectra of A) Alpha Scents light green, Alpha Scents dark green, and Coroplast™ green; and B) Alpha Scents purple, Coroplast™ purple with clear sticky film, and Coroplast™ purple with Pestick™ tested in the 2011 green and purple color comparison study.

Traps on hybrid poplars (*Populus* spp.). In 2011, we tested the attraction of various buprestid species to different colored traps placed in a 16-yr-old, 1 ha, hybrid poplar planting at Michigan State University Tree Research Center, Ingham County, MI (Lat 42.67°N, Long 84.47°W). Bordering this planting was a 22-yr-old, 1 ha, planting of black locust, *Robinia pseudoacacia* L. We tested green, purple, white, and yellow traps (the same trap materials used above for *A. subcinctus*) that were 15-cm-wide × 30-cm-tall (Fig. 1A). One card of each of the four colors was stapled to a single, 1-m-long wooden pole in random order with 15-cm-spacing between cards. All traps were coated with Pestick™. Wooden poles (N = 10 with 4 traps on each) were suspended horizontally just below the foliage on the lower limbs of hybrid polar trees that were located along the perimeter of the planting. The lower limbs of poplar trees in this study were several meters above the ground, so traps were suspended from ropes that were placed over the lowest limbs of each tree using throw bags (SherrillTree, Inc., Greensboro, North Carolina). Ropes attached to traps were used to pull traps into the canopy and suspend them close to the foliage. Trap height ranged from 2–15 m above the ground. Traps were placed in the field on 31 May 2011 and removed on 27 July 2011. Traps were checked once every 10–14 days and all buprestid species were removed.

Traps on honeylocust (*Gleditsia triacanthos* L.). In 2011, we tested the attraction of various buprestid species to different colored traps placed in a 21-yr-old, 1 ha, honeylocust planting at Michigan State University Tree Research Center, Ingham County, MI (Lat 42.67°N, Long 84.47°W). Traps tested were the same colors and size as those used in the hybrid poplar study described above (Fig. 1A). We suspended 10 wooden poles with traps, approximately 1.5–2m above the ground from the lower branches of honeylocust trees located along the perimeter of the planting. Traps were placed in the field on 31 May 2011 and removed on 27 July 2011. Traps were checked every 10–14 days and all buprestid species were removed and identified.

Purple and green sticky trap comparison. In 2011, we compared three different green and three different purple sticky traps (Fig. 1B). Purple traps included the standard Coroplast™ purple trap coated with Pestick™, standard Coroplast™ purple trap covered with a clear sticky sheet (WindowBugCatcher™, Alpha Scents, Inc., West Linn, OR), and a custom purple sticky sheet made by Alpha Scents. The green traps consisted of Coroplast™ green coated with Pestick™, three (each 12.5 wide × 7.5 cm tall) dark green sticky cards (Alpha Scents, Inc.) stapled together to make a single trap, and a custom light green sticky sheet made by Alpha Scents. Overall size of each trap was 12.5 cm wide × 22.5 cm tall. Spectral reflectance was measured for these traps following the same procedure described for the *A. subcinctus* traps (Fig. 3A and 3B).

One of each of the green trap types or one of each of the purple trap types were stapled to wooden poles, i.e., wooden poles contained all three green or all three purple traps (Fig. 1B and 1C). Traps were attached to a wooden pole in a randomized order with 15 cm space separating each trap. Wooden poles (10 with green traps and 10 with purple traps) were suspended from metal rebar poles with the bottom of each rebar pole inserted into the ground and wooden poles with traps attached to a 90^{o} bend (approximately 0.3 m long) at the top of each rebar pole. The top of each trap was suspended approximately 2 m above the ground. Traps were placed in a 30-yr-old, 2 ha, green ash, *Fraxinus pennsylvanica* Marshall, planting that was showing approximately 50% canopy die back due to *A. planipennis* infestation at Kellogg Experimental Forest, Kalamazoo County, MI (Lat 42.37°N, Long 85.36°W). Traps were placed in the field on 17 June 2011, and insects were collected and traps removed on 14 July 2011.

Sticky trap and multifunnel trap comparison. In 2012, we tested the attraction of various buprestid species to three different colored sticky traps and two different colored multifunnel traps at Michigan State University Tree Research Center, Ingham County, MI (Lat 42.67°N, Long 84.47°W). The corrugated plastic sticky traps we tested included Coroplast™ green, medium green (Sabic green; Francese et al. 2013), and Coroplast™ purple (Fig. 2B). Multifunnel traps consisted of the standard black multifunnel traps (Contech Enterprises,Inc., Delta, British Columbia, Canada), along with green multifunnel traps (peak reflectance: 530 nm, 57%, described by Francese et al. 2011) that were custom color matched to Sabic green (originally manufactured by Chemtica Internacional, San Jose, Costa Rica; distributed by Synergy Semiochemicals, Inc., Burnaby, BC, Canada). Multifunnel traps consisted of seven funnels each, and were coated with Fluon PTFE (AGC Chemicals Americas, Inc., Exton, PA) to make it more difficult for landing insects to cling to the trap surface and possibly escape (Lyons et al. 2012, Francese et al. 2013a). Collection cups were filled with a salt water solution to kill and preserve insects that fell into the traps. Sticky traps were two-sided with each side measuring 21 cm × 61 cm to represent a similar-sized silhouette as the funnel traps. Sticky traps were coated with Pestick™. All traps were suspended from metal rebar poles with the bottom of each rebar pole inserted in the ground and the trap attached to a 90º bend (approximately 0.3-m long) at the top of each rebar pole. The top of each trap was suspended approximately 2 m above the ground. Traps were spaced 5 m apart from each other and at least 5 m from any tree. Four replicates were placed around the perimeter of a black locust planting, 3 replicates placed around the perimeter of a honeylocust planting, and 3 replicates placed around a white oak, *Quercus alba* L., and English oak, *Quercus robur* L., planting, with a grand total of 10 replicates. Traps were placed in the field on 8 June 2012 and removed on 24 July 2012. Buprestids were collected from traps once every week.

Specimen preparation. For all studies, after the insects were removed from the traps they were frozen until prepared for identification. Specimens were soaked in hexane for 24 hours to remove Pestick™ and then preserved in 70% ethyl alcohol or pinned and labeled when prepared for identification. All buprestids were sexed and identified to species using the keys in Fisher (1928), Wellso et al. (1976), MacRae (2003), and Wellso and Manley (2007). Voucher specimens were confirmed by Stanley G. Wellso (USDA ARS-retired, now lives in College Station, TX) and Jason A. Hansen (North Carolina State University, stationed at Cape Cod, MA) and are currently stored at Michigan State University, Department of Entomology, Insect Collection, East Lansing, MI.

Statistical analysis. Mean numbers of buprestids captured per trap were compared among trap types and colors using PROC Mixed (SAS 2008). When adequate numbers of specimens were collected for an individual buprestid taxon (usually >20), we compared the number captured for each genus, species and sex. Replicates where no individuals were captured for the particular group being analyzed were deleted. The Bonferroni multiple comparison test was used to separate means that were significantly different at the $P < 0.05$ level.

Results

For all studies combined, we collected 2,535 individuals representing 8 genera of Buprestidae, including *Acmaeodera* (1 species; 1 individual), *Agrilaxia* (1; 1), *Agrilus* (21; 2,475), *Anthaxia* (3; 13), *Brachys* (2; 8), *Chrysobothris* (1; 35), *Dicerca* (1; 1), and *Xenorhipis* (1; 1). All species of Buprestidae that we collected from 2009–2012 were previously reported from Michigan (Wellso et al. 1976, Nelson et al. 2008)

2009 trapping study on ash. A total of 146 *A. subcinctus* adults was captured in 2009. Significantly more *A. subcinctus* adults were captured on Coroplast™ green and yellow sticky card traps compared to Coroplast™ purple and Coroplast™ white traps (Fig. 4). The captured adults were not sexed. No *A. planipennis* were captured, likely because the only living ash that remained at the site were small sprouts, and also, traps were removed prior to *A. planipennis* peak flight.

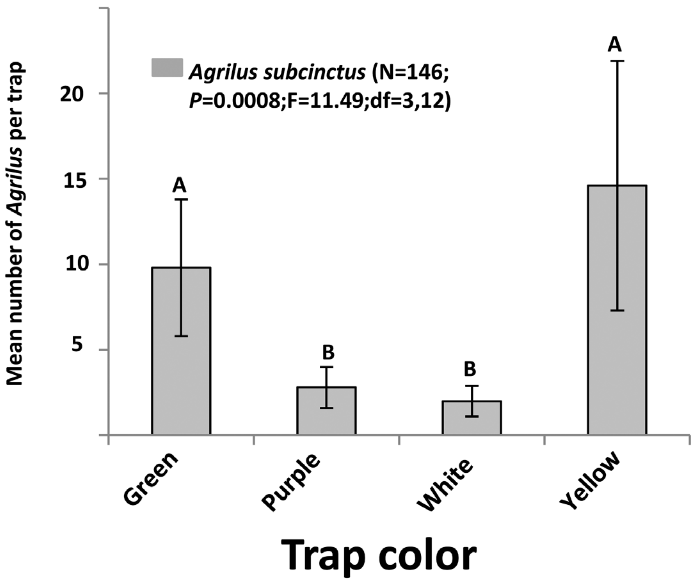

Figure 4. Mean number of *Agrilus subcinctus* captured on different colored sticky traps suspended from branches of *Fraxinus pennsylvanica* trees near Webberville, Ingham County, MI (Lat 42.66 N, Long -84.20 W) on 15 May 2009. Means followed by a different letter are significantly different at the $P < 0.05$ level (Bonferroni multiple comparison test).

2011 trapping study on hybrid poplars. A total of 293 (138 males; 155 females) *Agrilus* specimens was captured on traps placed in hybrid poplars trees in 2011. Significantly more males and females were captured on Coroplast™ green and yellow sticky card traps compared to Coroplast™ purple and Coroplast™ white (Fig. 5A). A total of 13 *Agrilus* species was captured on the traps (Table 1). Significantly more *Agrilus* species were captured on Coroplast™ green traps, followed by yellow sticky cards, Coroplast™ white, and Coroplast™ purple traps, respectively (Fig. 5B). In addition to *Agrilus* species, other buprestids captured included two species of *Anthaxia* (one individual of each species), one species of *Brachys* (two individuals), and one species of *Chrysobothris* (three individuals) (Table 1).

The most common species captured on traps placed on hybrid poplar trees were *Agrilus egenus* Gory (216 individuals) and members and relatives of the *A. otiosus* species-group (33 individuals; Table 1). Females of the *A. otiosus* species-group and a few related species currently cannot be distinguished from one another using morphological characters (Fisher 1928, MacRae 2003), so they were combined for our analyses and we will refer to them as *A. otiosus*-relatives for the remainder of this paper. Significantly more *A. egenus* were captured on Coroplast™ green and yellow sticky card traps compared to Coroplast™ purple and Coroplast™ white traps (Fig. 5C). Coroplast™ green traps caught significantly more *A. otiosus* relatives than the other traps, while Coroplast™ white and Coroplast™ purple traps caught the least. There were no other significant differences among traps (Fig. 5C).

2011 trapping study on honeylocust. A total of 444 (178 males; 266 females) *Agrilus* adults was captured on sticky traps placed on honeylocust trees in 2011. Significantly more male and female *Agrilus* were captured on Coroplast™ green traps followed by yellow, then Coroplast™ white, and Coroplast™ purple

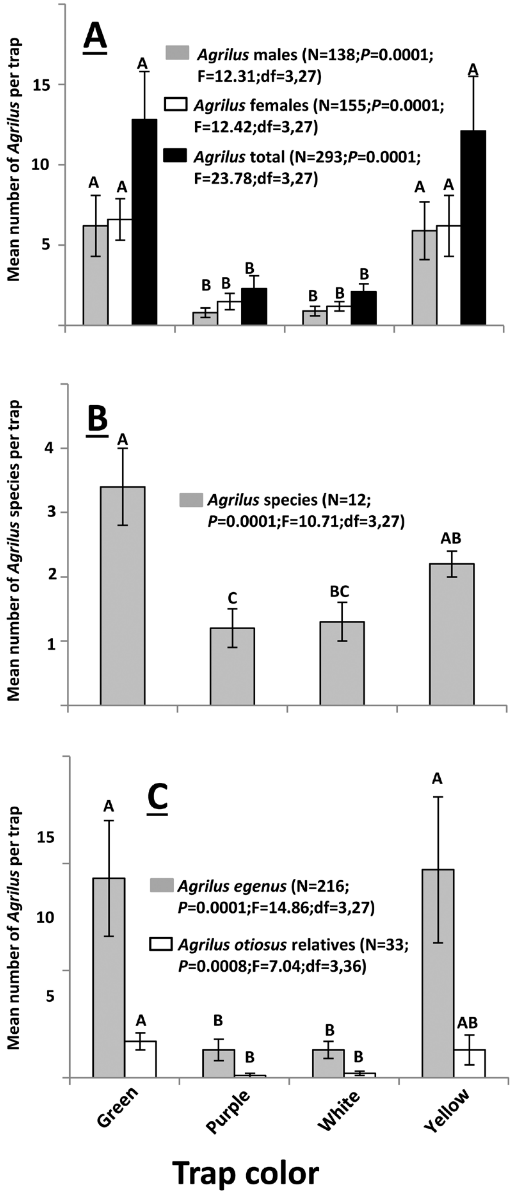

Figure 5. Mean number of A) *Agrilus* males, females and total; B) *Agrilus* species; and C) the two most common *Agrilus* species captured on different colored sticky traps suspended from branches of hybrid poplar trees that were also bordering black locust trees at Michigan State University Tree Research Center, Ingham County, MI (Lat 42.67 N, Long -84.47) from 31 May–27 July 2011. Means within each *Agrilus* group, sex and species followed by a different letter are significantly different at the $P < 0.05$ level (Bonferroni multiple comparison test).

Table 1. Total number of male and female individuals for each buprestid species captured on sticky traps suspended from the limbs of hybrid poplar, *Populus* spp., trees that bordered a black locust, *Robinia pseudoacacia*, plantation in Michigan in 2011 by trap color.

	Trap color and type[3]			
Species	Green Coroplast™ ♂(♀)	Purple Coroplast™ ♂(♀)	White Coroplast™ ♂(♀)	Yellow card ♂(♀)
Agrilus arcuatus (Say)[1]	0(0)	0(0)	0(0)	1(0)
A. bilineatus (Weber)	0(0)	0(1)	0(0)	0(0)
A. egenus Gory	54(41)	5(8)	8(5)	50(47)
A. fallax Say	2(0)	0(0)	0(0)	0(0)
A. granulatus liragus Barter&Brown	1(1)	2(4)	1(3)	0(0)
A. lecontei lecontei Saunders	1(4)	0(0)	0(0)	0(0)
A. masculinus Horn[1]	2(0)	0(0)	0(0)	4(0)
A. obsolettoguttatus Gory	0(2)	1(0)	0(0)	0(1)
A. otiosus relatives[2] (females)	0(14)	0(1)	0(2)	0(8)
A. pseudofallax Frost	1(0)	0(0)	0(0)	0(0)
A. planipennis Fairmaire	0(1)	0(0)	0(0)	0(0)
A. putillus putillus Say	1(1)	0(0)	0(0)	3(3)
A. subcinctus Gory	1(0)	0(0)	0(1)	1(1)
A. sulcicollis Lacordaire	0(1)	0(0)	0(1)	0(1)
A. transimpressus Fall[1]	1(0)	0(0)	0(0)	0(0)
Anthaxia quercata (Fabricius)	0(1)	0(0)	0(0)	0(0)
An. viridifrons Gory	0(1)	0(0)	0(0)	0(0)
Brachys aerosus (Melsheimer)	0(1)	0(1)	0(0)	0(0)
Chrysobothris sexsignata Say	0(0)	0(2)	0(1)	0(0)

[1]Includes members of the *Agrilus otiosus* species group and close relatives.
[2]Females of the *Agrilus otiosus* species group and close relatives cannot be distinguished from one another.
[3]A total of 10 traps of each color and type was deployed. See text for trap dimensions and details.

traps (Fig. 6A). Ten species of *Agrilus* were captured on these traps, and the number of species captured did not vary significantly among trap colors (Table 2; Fig. 6B). No other buprestid species were captured.

The three most common *Agrilus* species captured were *A. egeniformis* Champlain & Knull (305 individuals), *A. fallax* Say (89), and *A. pseudofallax* Frost (35; Table 2). Significantly more *A. egeniformis* were captured on Coroplast™ green and yellow sticky card traps compared to Coroplast™ purple and Coroplast™ white (Fig. 6C). Significantly more *A. fallax* were captured on Coroplast™ green traps, compared to Coroplast™ purple and Coroplast™ white traps, and the number captured on yellow sticky card traps did not vary significantly (Fig. 6C). Coroplast™ green traps captured significantly more *A. pseudofallax* than Coroplast™ purple traps. There were no other significant differences found among the remaining trap colors.

2011 purple- and green sticky trap comparison study. A total of 259 (92 males; 167 females) *Agrilus* adults was captured on the purple and green traps in 2011 (Table 3). The number of male *Agrilus* captured did not vary significantly among trap colors (Fig. 7A). Significantly more female *Agrilus* were captured on Coroplast™ purple with Pestick™ compared to Alpha Scents purple, Alpha Scents light green, and Coroplast™ purple covered with clear sticky sheet (Fig. 7A). There were no other significant differences in the number

Table 2. Total number of male and female individuals for each buprestid species captured on sticky traps that were suspended from the limbs of honeylocust, *Gleditsia triacanthos*, trees in Michigan in 2011 by trap color.

	Trap color and type[2]			
Species	Green Coroplast™ ♂(♀)	Purple Coroplast™ ♂(♀)	White Coroplast™ ♂(♀)	Yellow card ♂(♀)
Agrilus bilineatus (Weber)	0(1)	0(0)	0(0)	0(0)
A. cyanescens Ratzeburg	0(1)	0(0)	0(1)	1(0)
A. egeniformis Champlain&Knull	82(88)	4(19)	9(13)	30(60)
A. egenus Gory	0(1)	0(0)	0(0)	0(1)
A. fallax Say	36(39)	2(2)	1(1)	2(6)
A. lecontei lecontei Saunders	0(1)	0(0)	0(0)	0(0)
A. masculinus Horn	0(0)	0(0)	0(0)	1(0)
A. otiosus relatives[1] (females)	0(0)	0(0)	0(1)	0(1)
A. pseudofallax Frost	9(22)	0(1)	1(1)	0(1)
A. sulcicollis Lacordaire	0(0)	0(0)	0(1)	0(0)

[1]Females of the *Agrilus otiosus* species group and close relatives cannot be distinguished from one another.

[2]A total of 10 traps of each color and type was deployed. See text for trap dimensions and details.

of females captured among the other trap types (Fig. 7A). Nine species of *Agrilus* were captured (Table 3). Significantly more *Agrilus* species were captured on Coroplast™ green with Pestick™ traps compared to Alpha Scents light green traps. The number of species captured on Alpha Scents dark green, Coroplast™ purple with Pestick™, and Coroplast™ purple covered with clear sticky sheet did not vary significantly (Fig 7B). *Agrilus planipennis* represented 223 (80 males; 143 females) of the total *Agrilus* individuals captured. Significantly more total *A. planipennis* were captured on Coroplast™ purple with Pestick™ traps compared to Alpha Scents light green and Coroplast™ purple covered with clear sticky sheet (Fig. 7C). There were no other significant differences in the number of total *A. planipennis* captured among the other trap types. The number of *A. planipennis* males captured did not vary significantly among trap types (Fig. 7C). However, the number of female *A. planipennis* captured was significantly higher on Coroplast™ purple with Pestick™ compared to Alpha Scents light green and Coroplast™ purple covered with clear sticky sheet traps. The number of *A. planipennis* females captured did not vary significantly among the other trap types. Other buprestids captured included two species of *Anthaxia*, one species of *Brachys* and one species of *Chrysobothris* (Table 3). Alpha Scents purple traps captured significantly more *Chrysobothris* compared to Alpha Scents light green, Alpha Scents dark green and Coroplast™ green traps. There were no other significant differences for the number of *Chrysobothris* captured among traps. (Fig. 7D).

2012 sticky trap and funnel trap comparison. In total, 1,333 *Agrilus* individuals were captured in 2012 (Table 4). Significantly more male *Agrilus* were captured on Coroplast™ green and Sabic green sticky traps compared to black multifunnel and Coroplast™ purple traps (Fig. 8A). The number of male *Agrilus* captured in green funnel traps did not vary significantly among the trap types tested. Significantly more female *Agrilus* were captured on Coroplast™ green and Sabic green sticky traps compared to black multifunnel. The number of male *Agrilus* captured in green multifunnel traps or Coroplast™ purple traps did not vary significantly among the trap types tested. A total of 17 *Agrilus* species were captured in 2012, with significantly more captured in

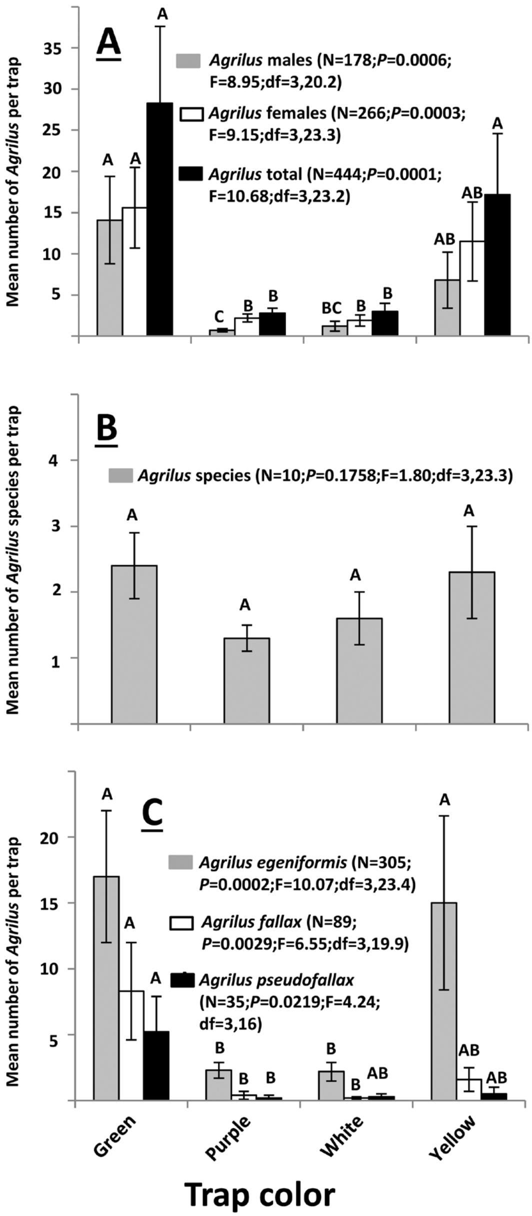

Figure 6. Mean number of A) *Agrilus* males, females and total; B) *Agrilus* species; and C) the three most common *Agrilus* species captured on different colored sticky traps suspended from branches of honeylocust trees at Michigan State University Tree Research Center, Ingham County, MI (Lat 42.67 N, Long -84.47) from 31 May–27 July 2011. Means within each *Agrilus* group, sex and species followed by a different letter are significantly different at the $P < 0.05$ level (Bonferroni multiple comparison test).

Table 3. Total number of male and female individuals for each buprestid species captured on sticky traps suspended from rebar poles in the understory of a green ash, *Fraxinus pennsylvanica*, planting in Michigan in 2011 by trap color and trap type.

	Trap color and type[3]					
Species	**Alpha Scents light green sticky card ♂(♀)**	**Alpha Scents dark green sticky card ♂(♀)**	**Coroplast™ green Pestick™ ♂(♀)**	**Alpha Scents purple sticky card ♂(♀)**	**Coroplast™ purple clear sticky ♂(♀)**	**Coroplast™ purple Pestick™ ♂(♀)**
Agrilus bilineatus (Weber)	0(0)	0(0)	0(0)	0(0)	0(1)	0(2)
A. cephalicus LeConte	0(0)	1(0)	0(0)	0(0)	0(0)	0(0)
A. egenus Gory	0(0)	2(1)	2(5)	0(1)	0(1)	0(0)
A. lecontei lecontei Saunders	0(1)	0(1)	0(1)	0(0)	0(0)	1(1)
A. masculinus Horn[1]	0(0)	0(0)	1(0)	1(0)	0(0)	2(0)
A. otiosus relatives[2] (females)	0(0)	0(1)	0(4)	0(0)	0(0)	0(1)
A. obsolettoguttatus Gory	0(0)	0(0)	1(1)	0(0)	0(0)	0(0)
A. planipennis Fairmaire	16(7)	15(18)	21(42)	8(13)	7(2)	13(61)
A. ruficollis (Fabricius)	0(0)	1(0)	0(0)	0(0)	0(0)	0(0)
A. subcinctus Gory	0(0)	0(1)	0(1)	0(0)	0(0)	0(0)
Anthaxia quercata (Fabricius)	0(1)	0(0)	0(1)	0(0)	0(0)	0(0)
An. viridifrons Gory	0(0)	0(0)	0(1)	0(0)	0(0)	0(0)
Brachys aerosus (Melsheimer)	0(0)	0(1)	0(0)	0(0)	0(0)	0(0)
Chrysobothris sexsignata Say	0(0)	0(0)	0(0)	0(10)	1(4)	1(7)

[1]Members of the *Agrilus otiosus* species group and close relatives.
[2]Females of the *Agrilus otiosus* species group and close relatives cannot be distinguished from one another.
[3]A total of 10 traps of each color and type was deployed. See text for trap dimensions and details.

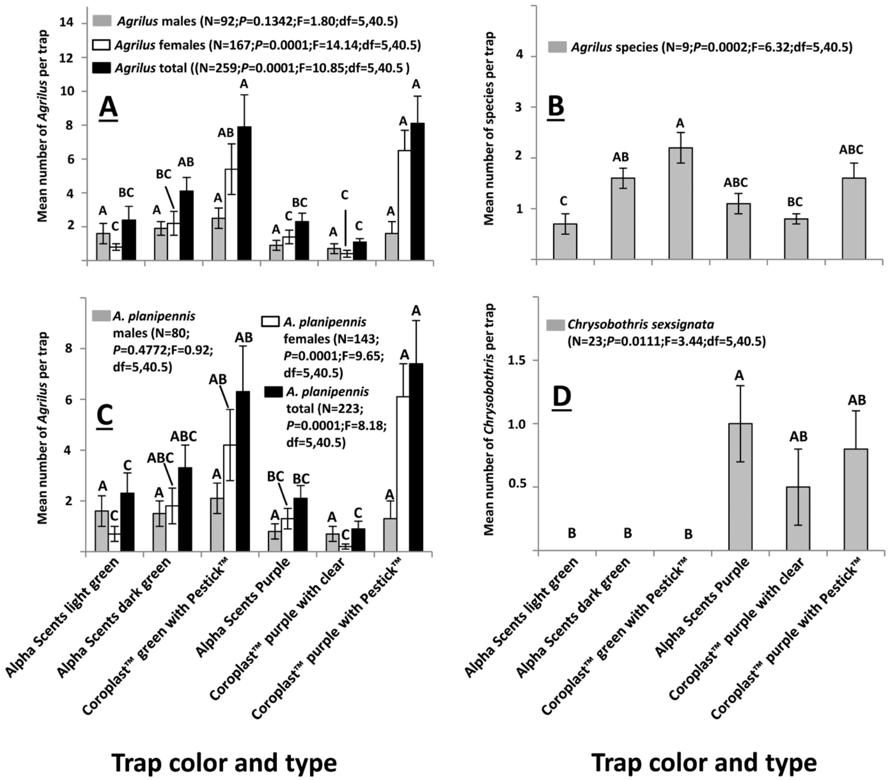

Figure 7. Mean number of A) *Agrilus* males, females and total; B) *Agrilus* species captured; C) *Agrilus planipennis* males, females and total; and D) *Chrysobothris sexsignata* captured on different colored sticky cards suspended from rebar poles placed in a *Fraxinus pennsylvanica* planting at Kellogg Experimental Forest, Kalamazoo County, MI (Lat 42.37 N, Long -85.36) from 17 June –14 July 2011. Means within each *Agrilus* group, sex and species followed by a different letter are significantly different at the $P < 0.05$ level (Bonferroni multiple comparison test).

green multifunnel traps when compared to black multifunnel traps. The number captured for the other trap types did not vary significantly (Table 4; Fig. 8B). In addition, three species of *Anthaxia*, two species of *Brachys*, and one species of *Chrysobothris* were captured in 2012 (Table 4).

Agrilus egenus (1011 individuals) was the most common *Agrilus* captured in 2012, followed by *A. egeniformis* (138) and *A. fallax* (40). Considering only traps around black locust trees, significantly more *A. egenus* were captured on Coroplast™ green compared to black multifunnel traps while catches on Sabic green, green multifunnel traps and Coroplast™ purple traps did not vary significantly compared to the trap types tested (Fig. 8C). Similarly, comparing only traps around honeylocust trees, significantly more *A. egeniformis* were captured on Sabic green compared to Coroplast™ purple, while the number captured on Coroplast™ green, green multifunnel traps, and black multifunnel traps did not vary significantly among the traps tested (Fig. 8C). The number of *A. fallax* captured did not differ significantly among traps types (Fig. 8C).

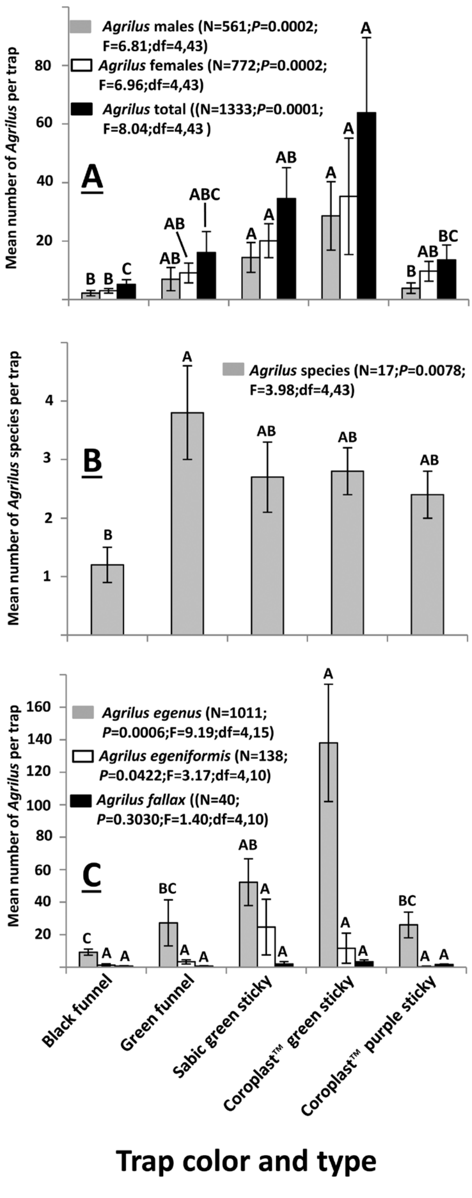

Figure 8. Mean number of A) *Agrilus* males, females and total; B) *Agrilus* species captured on traps placed around the edge of black locust, honeylocust, and English oak/white oak plantings combined; and C) *A. egenus* captured on traps around the black locust planting, and *A. fallax* and *A. egeniformis* captured around the honeylocust planting. Traps weresuspended from rebar poles at Michigan State University Tree Research Center, Ingham County, MI (Lat 42.67 N, Long -84.47) from 8 June–24 July 2012. Means within each *Agrilus* group, sex and species followed by a different letter are significantly different at the $P < 0.05$ level (Bonferroni multiple comparison test).

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Table 4. Total number of male and female individuals of each buprestid species captured on sticky traps suspended from rebar poles near plantings of hybrid poplars, *Populus* sp., black locust, *Robinia pseudoacacia*, and honeylocust, *Gleditsia triancanthos*, plantations in Michigan in 2012 by trap color and trap type.

	Trap color and type[3]				
Species	**Sabic Green ♂(♀)**	**Coroplast™ Green ♂(♀)**	**Coroplast™ Purple ♂(♀)**	**Funnel Black ♂(♀)**	**Funnel Green ♂(♀)**
Acmaeodera tubulus (Fabricius)	0(0)	0(0)	0(1)	0(0)	0(0)
Agrilaxia flavimana (Gory)	0(0)	0(0)	0(0)	0(0)	1(0)
Agrilus bilineatus (Weber)	0(0)	0(0)	3(2)	0(0)	0(1)
A. cephalicus LeConte	0(0)	0(0)	1(0)	0(0)	0(0)
A. cyanescens Ratzeburg	0(0)	0(0)	0(0)	0(0)	1(1)
A. egeniformis Champlain&Knull	29(47)	15(22)	3(6)	2(2)	1(11)
A. egenus Gory	106(145)	255(312)	30(78)	18(25)	54(59)
A. fallax Say	3(5)	7(13)	0(5)	1(2)	2(2)
A. granulatus liragus Barter&Brown	1(0)	3(1)	0(3)	1(0)	2(2)
A. lecontei lecontei Saunders	0(1)	0(1)	0(0)	0(0)	0(6)
A. masculinus Horn[1]	0(0)	1(0)	1(0)	0(0)	0(0)
A. otiosus relatives[2] (females)	0(1)	0(3)	0(1)	0(0)	0(1)
A. obsolettoguttatus Gory	0(0)	1(0)	0(0)	0(0)	1(1)
A. paracelti Knull	0(0)	0(1)	0(0)	0(0)	0(0)
A. planipennis Fairmaire	4(0)	2(0)	1(1)	0(0)	6(5)
A. politus (Say)	0(0)	0(0)	0(0)	0(0)	1(0)
A. pseudofallax Frost	0(0)	0(0)	0(1)	0(0)	0(0)
A. putillus putillus Say	0(0)	0(0)	0(0)	0(0)	1(0)
A. ruficollis (Fabricius)	1(0)	0(0)	0(0)	0(0)	1(2)
Anthaxia fisheri Obenberger	0(0)	0(0)	0(0)	0(1)	0(0)
An. quercata (Fabricius)	0(0)	1(1)	0(0)	0(0)	0(0)
An. viridifrons Gory	0(2)	1(1)	0(1)	0(0)	0(2)
Brachys aeruginosus Gory	0(0)	0(0)	0(0)	0(0)	0(1)
B. aerosus (Melsheimer)	0(0)	0(1)	0(0)	0(0)	0(3)

Table 4. Continued.

	Trap color and type[3]				
Species	Sabic Green ♂(♀)	Coroplast™ Green ♂(♀)	Coroplast™ Purple ♂(♀)	Funnel Black ♂(♀)	Funnel Green ♂(♀)
Chrysobothris sexsignata Say	0(0)	0(0)	0(7)	0(1)	0(1)
Dicerca tenebrica (Kirby)	0(0)	0(0)	0(0)	1(0)	0(0)
Xenorhipis brendeli LeConte	0(0)	0(0)	0(1)	0(0)	0(0)

[1]Members of the *Agrilus otiosus* species group and close relatives.
[2]Females of the *Agrilus otiosus* species group and close relatives cannot be distinguished from one another.
[3]A total of ten traps of each color and type were deployed. See text for trap dimensions and details.

Discussion

Most of the *Agrilus* captured in our studies were relatively small species which attack small twigs and branches in the tree canopy (Hespenheide 1969, 1976; MacRae 1991). The Coroplast™ green and yellow sticky cards were highly attractive to these species. Black locust is the larval host for *A. egenus* (Nelson et al. 2008), but almost 200 *A. egenus* were captured on Coroplast™ green and yellow sticky cards placed on hybrid poplars found adjacent to the black locust trees. Petrice et al. (2013) also found that smaller *Agrilus* species, such as the *A. otiosus*-relatives, were attracted on Coroplast™ green, and hypothesized that it resembled green foliage in the tree canopy where smaller species would be searching for twigs and small branches to oviposit. Four of the five European *Agrilus* species that Domingue et al. (2013) found to be attracted to small green sticky traps that were attached to tree branches at study sites in Hungary oviposit on small, weakened- or dead twigs of trees primarily in the beech family Fagaceae and birch family Betulaceae (Bílý 2002).

The number of *A. planipennis* captured in the 2011 purple- and green-trap comparison varied significantly among some of the trap types, however, the number captured did not vary significantly between Coroplast™ green and Coroplast™ purple traps, both of which were previously found to be attractive to *A. planipennis* (Crook et al. 2009, Francese et al. 2010). Comparing the green traps where Alpha Scents light green captured significantly fewer *A. planipennis* than Coroplast™ green with Pestick™ or Alpha Scents dark green, Alpha Scents light green reflectance in the green wavelength range (495–570 nm) was much lower compared to Coroplast™ green (Fig. 3A). Crook et al. (2009) found that clear insect trapping glue, similar to the glue we used, increased reflectiveness by 2.5%. Given this, reflectance would have been even higher for Coroplast™ green coated with Pestick™ than what was shown by the spectrophotometer readings (Fig. 3B). The wavelength of Alpha Scents dark green trap was also much lower than Coroplast™ green but higher than Alpha Scents light green. The sensitivity of *A. planipennis* to reflectance in the green range is similar to results found in other studies testing the attraction of *A. planipennis* to colors in the green spectrum (Crook et al. 2009, Francese et al. 2010). For example, Francese et al. (2010) found that 525–540 nm was the optimal green wavelength range for *A. planipennis* attraction.

It is possible that Pestick™ enhanced attractiveness of Coroplast™ purple to *A. planipennis*, given that Coroplast™ purple covered with a clear sticky sheet captured significantly fewer *A. planipennis* compared to Coroplast™ purple coated with Pestick™. Reflectance of Coroplast™ purple without insect glue and Coroplast™ purple covered with a clear sticky sheet appeared to be most different in the 400-460 nm spectral range, with Coroplast™ without insect glue showing slightly higher reflectance compared to Coroplast™ purple covered with a clear sticky sheet. As mentioned above, Pestick™ increased reflectiveness by 2.5%, therefore, reflectance in the 400–460 nm range would have been even higher for Coroplast™ purple coated with Pestick™ than what was shown by the spectrophotometer readings (Fig. 3B). Interestingly, the reflectance of Alpha Scents purple in this wavelength range was much higher compared to the two Coroplast™ purples but the number of *A. planipennis* females captured was not significantly different from Alpha Scents purple. It is possible that both types of Coroplast™ purple traps were similarly attractive to *A. planipennis* but beetles were able to escape from the clear sticky film, however, the authors of this paper have found the clear sticky material was very effective in capturing large beetles such as Cerambycidae and even small birds (personal observation). Furthermore, Coroplast™ purple with the clear sticky sheet and Coroplast™ purple with Pestick™ captured similar numbers of *Chrysobothris*, which is a larger and more robust buprestid compared to *A. planipennis*. However, it is possible that the clear sheet may be more susceptible to debris and dust reducing its ability to capture insects over time compared to Pestick™ which is most often applied in a much thicker coat compared to the former.

Difference in color attraction between the sexes of several *Agrilus* species seems to be limited to those *Agrilus* that would normally oviposit on the trunks and larger branches of trees as opposed to small branches and twigs. For example, in most of our studies, where primarily twig-infesting agrilids were captured, attraction of *Agrilus* males and females to the trap colors tested followed similar trends, being attracted predominately to green and yellow traps (Figs. 5A, 6A, and 8A). However, in the 2011 purple- and green-trap comparison study, where mostly *A. planipennis* were captured, the number of females captured varied significantly among treatments, while males did not show a significant color preference. Some studies found the sex ratio of *A. planipennis* captured on Coroplast™ purple traps skewed toward females, and the sex ratio on Coroplast™ green traps skewed toward males (Crook et al. 2009, Francese et al. 2010). Purple is believed to have a similar reflectance as tree bark (Francese et al. 2010), while green most likely mimics foliage (Francese et al. 2010, Petrice et al. 2013). Previous studies have found that *A. planipennis* males are most commonly found hovering near foliage (Lelito et al. 2007, Rodriguez-Saona et al. 2007). In contrast, adult females must spend time both on foliage to conduct maturation feeding and on the bark of trunks and branches to search for oviposition sites and lay eggs. Petrice and Haack (2014) found females of *Agrilus bilineatus* (Weber) were attracted to Coroplast™ purple, and females of *A. sulcicollis* were attracted to Coroplast™ purple and Coroplast™ white, while males of both species showed no significant color preference.

In addition to *Agrilus*, 8 of the 15 *Anthaxia* individuals and 2 of the 8 *Brachys* specimens were captured on Coroplast™ green traps in our study. However, relatively few *Chrysobothris* specimens were captured on Coroplast™ green. *Chrysobothris* adults are known to be strongly attracted to purple (Oliver et al. 2003, Petrice et al. 2013). This preference was most obvious in our 2011 purple vs. green trap comparison in which 23 *Chrysobothris sexsignata* Say were captured on purple traps and none were captured on green traps (Fig. 7D). *Chrysobothris* typically oviposits on stems and larger branches of trees.

Green multifunnel traps were much more effective compared to black multifunnel traps in attracting *Agrilus*. Although the number of *Agrilus* specimens captured by green multifunnel traps was intermediate between Coroplast™ green and black multifunnel traps, green multifunnel traps captured the most *Agrilus* species. Francese et al. (2013b) found green multifunnel traps as effective as purple sticky traps for capturing *A. planipennis*. It is important to note that in their study traps were suspended in the canopy of *Fraxinus* trees, and also the purple sticky traps they used were actually an "improved" version that previous studies had found to be more attractive to *A. planipennis* than Coroplast™ purple.

Both Coroplast™ sticky traps and multifunnel traps have their advantages and disadvantages. Coroplast™ sticky traps are inexpensive, light weight, and if they are to be assembled in the field, they can be stored and transported as flat sheets. However, Coroplast™ sticky traps require application of insect trapping glue. Finding and removing target insects from the trap surface can be difficult which increases risk of overlooking target insects. Also, insect trapping glue must be removed from the insects with a solvent so positive identifications can be made. Due to the difficulty removing the insect trapping glue from the traps, Coroplast™ sticky traps are not conveniently reusable. Conversely, multifunnel traps are reusable, they do not require insect trapping glue, and all insects captured are contained and preserved in the collection cup at the bottom of the trap. Some of the disadvantages of using multifunnel traps include: initial cost is substantially more than Coroplast™ sticky traps; there is an added expense and labor of applying fluon to trap surface every 2–3 yr; and they are more bulky and heavier when compared to Coroplast™ sticky traps.

In conclusion, our studies found Coroplast™ green sticky traps consistently captured the most *Agrilus* individuals, and a variety of *Agrilus* species and the other Buprestidae with the exception of *Chrysobothris* species. Yellow sticky card traps and Sabic green traps also captured a large number of *Agrilus* individuals. Coroplast™ purple sticky traps generally captured fewer *Agrilus* compared to Coroplast™ green, Sabic green, and yellow cards with the exception of *A. planipennis* in 2012, where similar numbers were captured on both Coroplast™ green and Coroplast™ purple. Black multifunnel traps and Coroplast™ white sticky traps were among the least effective traps in our studies. While absolute number of *Agrilus* captured was lower for green multifunnel traps compared to Coroplast™ green, the multifunnel traps appeared to be an effective alternative to using sticky traps. Furthermore, green multifunnel traps captured the most *Agrilus* species and almost all of the buprestid species that were collected from all trap types in the 2012 study.

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