Halyomorpha halys (Hemiptera: Pentatomidae) Response to Pyramid Traps Baited with Attractive Light and Pheromonal Stimuli

Authors: Rice, Kevin B., Cullum, John P., Wiman, Nik G., Hilton, Richard, and Leskey, Tracy C.

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Halyomorpha halys (Hemiptera: Pentatomidae) response to pyramid traps baited with attractive light and pheromonal stimuli

Kevin B. Rice[1,*], *John P. Cullum*[2], *Nik G. Wiman*[3], *Richard Hilton*[4], *and Tracy C. Leskey*[1]

Abstract

Halyomorpha halys Stål (Hemiptera: Pentatomidae) is an invasive insect that causes severe economic damage to multiple agricultural commodities. Several monitoring tools, including pheromone and light-baited black pyramid traps, have been developed to monitor *H. halys*. Here, we evaluated the attractiveness of these traps baited with only light, only pheromone, or the combination in comparison with unbaited traps throughout the growing season in regions with high and low *H. halys* population densities. In regions with high population densities in the Mid-Atlantic, all traps baited with pheromone or lights performed better than control traps. During mid-season, traps containing lights captured more *H. halys* adults, whereas pheromone-baited traps captured greater numbers during the late season. In low density regions in the Pacific Northwest, traps with lights or pheromone captured more *H. halys* adults than control traps. In addition, we evaluated the influence of competing light sources associated with anthropogenic structures. When light traps were deployed next to these additional light sources, *H. halys* captures in pyramid traps baited with light were not significantly reduced. Overall, our results indicate that both light and pheromone traps can be used to detect *H. halys* activity in low and high density populations.

Key Words: brown marmorated stink bug; invasive; light trap; aggregation pheromone

Resumen

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) es un insecto invasor que causa graves daños económicos a múltiples productos agrícolas. Se han desarrollado varias herramientas de monitoreo, incluyendo feromonas y trampas negras de pirámide cebadas con luz, para monitorear *H. halys*. Aqui, evaluamos el atractivo de estas trampas cebadas con solamente luz, solamente feromona, o la combinación en comparación con las trampas no cebadas a lo largo de la temporada de crecimiento en las regiones con densidades altas y bajas de población de *H. halys*. En las regiones del Atlántico Medio con altas densidades de población, todas las trampas cebadas con feromona o luces funcionaron mejor que las trampas de control. Durante la mitad de la temporada, las trampas que contenían luces capturaron más adultos de *H. halys*, mientras que las trampas con cebo de feromonas capturaron un mayor número durante el final de la temporada. En regiones de baja densidad en el noroeste del Pacífico, las trampas con luces o feromonas capturaron más adultos de *H. halys* que las trampas de control. Además, se evaluó la influencia de la competencia de otras fuentes de luz asociadas con las estructuras antropogénicas. Cuando se pusieron las trampas de luz junto a estas fuentes de luz adicionales, las capturas de *H. halys* en las trampas de pirámide cebadas con luz no se redujeron significativamente. En general, nuestros resultados indican que tanto la luz y las trampas de feromonas se pueden utilizar para detectar la actividad de *H. halys* en poblaciones en densidades bajas y altas.

Palabras Clave: chinche hedionda de color café marmorado; invasor; trampa de luz; feromona de agregación

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) is an invasive stink bug that was accidently introduced to the United States from Asia (Hoebeke & Carter 2003). First discovered in Allentown, Pennsylvania, in 2001, *H. halys* has been detected in 42 US states, the District of Columbia, and 2 Canadian provinces (Hoebeke & Carter 2003; Leskey et al. 2015a). *Halyomorpha halys* is a generalist herbivore capable of feeding on hundreds of host plant species and often causes substantial economic damage to fruits, vegetables, field crops, and ornamental plants (Rice et al. 2014). However, *H. halys* population abundance is highly variable among years and localities (Rice et al. 2016), perhaps due to abiotic factors such as temperature that influence overwintering survival (Cira et al. 2016) or to biotic factors such as generalist predators (Morrison et al. 2016).

Stink bugs, including *H. halys,* have a strong dispersal ability (Wiman et al. 2015; Lee et al. 2014; Lee & Leskey 2015), and often move among multiple host plant species (Martinson et al. 2015) making traditional surveying methods such as visual identification and beat and sweep sampling unreliable (McPherson & McPherson 2000). As a result, growers have relied on preventive calendar-based insecticide applications to manage *H. halys* (Leskey et al. 2012a; Lee et al. 2013). Although broad-spectrum insecticides provide effective control, they disrupt established integrated pest management programs (Kuhar 2012a,b,c; Leskey et al. 2012a,b), resulting in increased secondary pest outbreaks (Leskey et al. 2012a). The development of effective monitoring tools to support management decisions and document *H. halys*

[1]United States Department of Agriculture (USDA), Agricultural Research Service (ARS), Appalachian Fruit Research Station, Kearneysville, WV, USA; E-mail: kevin.rice@ars.usda.gov (K. B. R.), tracy.leskey@ars.usda.gov (T. C. L.)
[2]Alson H. Smith Jr. Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, Winchester, VA, USA; E-mail: john29@vt.edu (J. P. C.)
[3]Department of Horticulture, Oregon State University, Corvallis, OR, USA; E-mail: Nik.Wiman@oregonstate.edu (N. G. W.)
[4]Southern Oregon Research and Extension Center, Oregon State University, Central Point, OR, USA; E-mail: richard.hilton@oregonstate.edu (R. H.)
*Corresponding author; E-mail: kevin.rice@ars.usda.gov (K. B. R.)

population establishment and spread remains a high priority among stakeholders (Leskey & Hamilton 2013).

In Asia, traps captured *H. halys* when baited with the aggregation pheromone methyl (*E,E,Z*)-2,4,6-decatrienoate (MDT) of the oriental stink bug, *Plautia stali* Scott (Hemiptera: Pentatomidae) (Moriya et al. 1987; Tada et al. 2001; Lee et al. 2002), leading to speculation that MDT could be used to monitor *H. halys* (Khrimian 2005). In North America, traps baited with MDT captured *H. halys* nymphs and male and female adults (Aldrich et al. 2007), and when combined with visually attractive black pyramid traps, capture rates increased (Leskey et al. 2012c). However, *H. halys* adults do not respond to MDT until late in the growing season, making early season monitoring and detection difficult (Nielsen et al. 2011; Leskey et al. 2012b,c).

Recently, the aggregation pheromone (PHER) of *H. halys* was identified and synthesized (Khrimian et al. 2014). This 2-component pheromone, (3S,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol and (3R,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol, is attractive to *H. halys* throughout the entire season and produces a synergistic response when deployed in combination with MDT (Khrimian et al. 2014; Weber et al. 2014; Leskey et al. 2015b). In apple orchards, pyramid traps baited with a combination of PHER and MDT have been used successfully to monitor *H. halys* populations and make management decisions (Short et al. 2016). However, these traps may not be as reliable when placed in highly preferred crops such as peaches (Nielsen & Leskey unpublished data), because semiochemicals produced by host plants influence insect responsiveness to pheromones (Landolt & Phillips 1997), and thus additional monitoring methods are still needed.

Black light traps can be used to detect and monitor stink bugs (Chatterjee 1989; Kim & Lee 2008; Kamminga et al. 2009), including *H. halys*, throughout the growing season (Nielsen et al. 2013). However, these traps are not species specific, and capture numerous non-targets, making detection laborious (Harding et al. 1966). Light intensity and wavelength can be narrowed to optimize capturing of target pests while reducing non-target captures. For example, pyramid traps augmented with compact fluorescent blue lights captured *H. halys* throughout the growing season, but also captured fewer non-target species compared with pyramid traps baited with compact fluorescent black or white lights (Leskey et al. 2015c).

Combining light traps with restricted light wavelengths and PHER lures may provide increased *H. halys* capture rates and trap sensitivity. Here, we compared *H. halys* captures in pyramid traps baited with only PHER lures, only narrow wavelength blue lights, and the combination of the two with unbaited control traps in regions with high and low *H. halys* population densities. Additionally, we compared *H. halys* captures in traps baited with blue lights deployed with and without artificial light competition from anthropogenic structures to establish whether deployment location influenced trap captures.

Materials and Methods

TRAPS

Black pyramid traps (AgBio Inc., Westminster, Colorado) were constructed from 2 plywood panels (107 cm H × 52 cm W at base and 8.2 cm W at top) and topped with a plastic collection jar (16 cm H × 10 cm L × 10 cm W) with an inverted funnel cone lid (1.6 cm internal opening) (AgBio, Westminster, Colorado) (Fig. 1A). Collection jars were vented on all 4 sides with 3 cm openings covered with vinyl-coated polyester screen (mesh size: 1×3 mm^2). Each pyramid trap contained one of the following treatments: 1) Light, 2) PHER, 3) Light + PHER, and 4) unbaited control. Light treatments (Fig. 1B) consisted of a modified jar

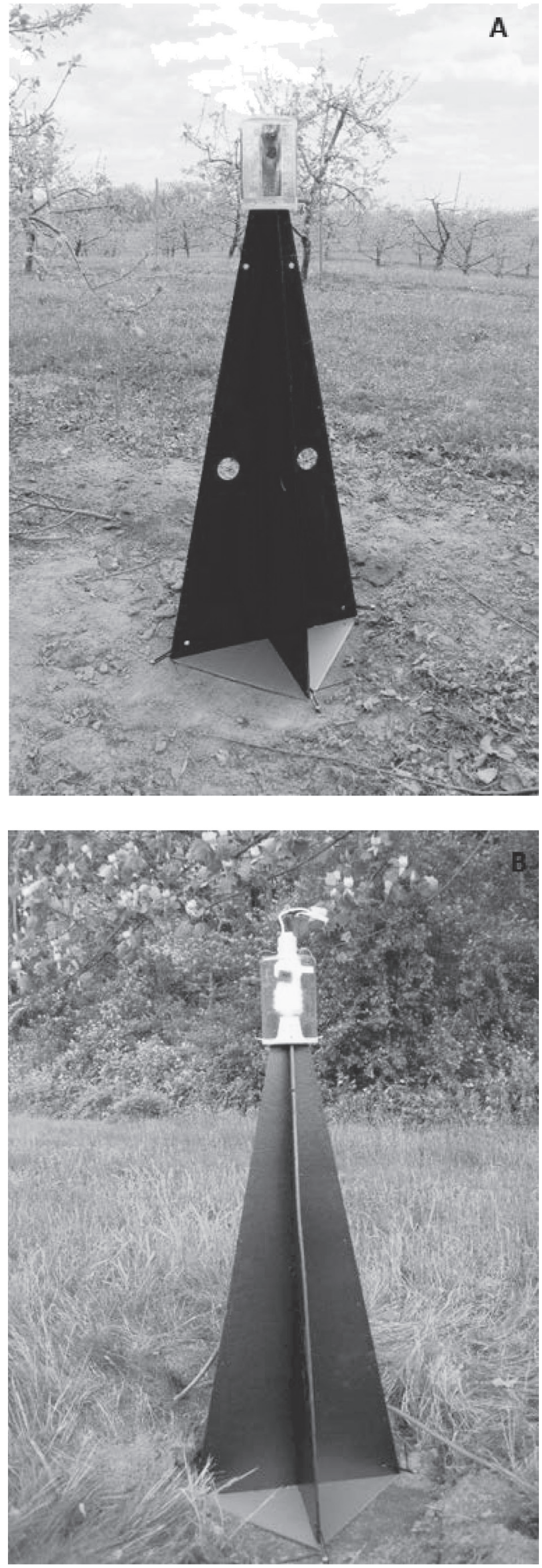

Fig. 1. Standard black pyramid trap with PHER lure (A) and modified pyramid trap with narrow blue fluorescent light (B).

top with a blue compact fluorescent bulb (435 nm, Sunlite Manufacturing, Brooklyn, New York). PHER treatments consisted of a gray rubber septum (1-F SS 1888 GRY, West Pharmaceutical Services, Lititz, Pennsylvania) impregnated with PHER at a 10 mg loading rated for over 30 d in the field (see Leskey et al. 2015b for details). PHER septa were attached to the top inside roof of collection jars. To prevent escape, each jar contained a Vaportape kill strip (Hercon Environmental, Emigsville, Pennsylvania).

FIELD TRIALS

Light and Pheromone Trapping

During 2012, traps were deployed at 3 sites in the Mid-Atlantic (see Table 1 for locations) with historically high population densities (Leskey et al. 2015a). Four traps (1 of each treatment) were placed in transects along wood lines (approx. 2 m from border) and spaced 50 m apart. Each site contained 3 transects with a total of 12 traps. To determine seasonal variation in trap captures, data were classified as early season (15 May to 20 Jun), mid-season (21 Jun to 15 Aug), or late season (16 Aug to 11 Oct) similar to periods reported by Leskey et al. (2015a). During 2014, the experiment was repeated at 4 sites in the Pacific Northwest (see Table 2 for locations) from mid-Aug until mid-Oct with 2 transects per site, therefore only a late season designation was possible. These sites historically have had lower populations compared with the Mid-Atlantic (Leskey et al. 2015a). Traps were emptied weekly, and the numbers of *H. halys* adults were recorded. Kill strips and PHER lures were replaced every 2 wk. Jar tops containing treatments were randomized and moved each week to control for location. Trap capture data violated normality assumptions, and all attempted transformations failed to normalize the data. Therefore, *H. halys* captures among each trap type were compared using the Kruskal–Wallis test followed by Dwass-Steel-Critchlow-Fligner mean separation test. Each season was analyzed separately, and seasonal trap captures were compared using the Kruskal–Wallis test followed by an all-pairwise comparison Dwass-Steel-Critchlow-Fligner test (SAS® software version 9.1, α = 0.05; SAS Institute 2004).

Competing Light Sources

To establish if competing light sources reduced captures in light traps, we deployed pyramid traps with blue fluorescent bulbs within approximately 2 m of anthropogenic structures (outbuildings and barns) with artificial lights that remained on throughout the night in 2013. A 2nd deployment of traps with blue lights was located in an area that contained no additional artificial light sources nearby (>50 m away) and served as the control site. To prevent escape, each trap contained a Vaportape kill strip that was replaced every other week. Each week, the number of *H. halys* adults in each trap was recorded. Traps were deployed from 9 Apr until 30 Sep at 3 sites in Maryland (see Table 3 for locations), with each site and trapping location containing 3 replicates. Data were classified into early season (18 Apr to 19 Jun), mid-season (20 Jun to 14 Aug), and late season (15 Aug to 30 Sep). Trap captures were compared between traps deployed next to competing light sources and traps that did not have additional light using a Wilcoxon test (SAS® software version 9.1, α = 0.05; SAS Institute 2004).

Table 1. Locations and GPS coordinates of 2012 field sites where *Halyomorpha halys* captures in black pyramid traps were compared across 3 treatments (with light, pheromone, and light + pheromone) and an unbaited control.

Site	Latitude	Longitude
Smithsburg, MD	39.6545611°N	77.5580972°W
Catoctin, MD	39.6560972°N	77.4011667°W
Woodbine, MD	39.3085306°N	77.1007833°W

Table 2. Locations and GPS coordinates of field sites in the Pacific Northwest where *Halyomorpha halys* captures in black pyramid traps were compared across 3 treatments (with light, pheromone, and light + pheromone) and an unbaited control.

Site	Latitude	Longitude
Vancouver, WA	45.6349889°N	122.5552222°W
Corvallis, OR	44.5592611°N	123.2881083°W
Talent, OR	42.2393694°N	122.7984056°W
Wilsonville, OR	45.2793500°N	122.7533583°W

Results

LIGHT AND PHEROMONE TRAPPING

In high density locations in the Mid-Atlantic, overall trap captures were lower during early season compared with mid-season and late season captures ($\chi^2 = 23.3$; $P < 0.0001$). During the early season, traps with lights, PHER, and lights + PHER captured greater numbers of *H. halys* adults than control traps ($\chi^2 = 18.0$; $P = 0.0004$) (Table 4). During the mid-season, traps with lights and lights + PHER captured more *H. halys* adults than PHER and control traps, but PHER traps captured significantly more than control traps ($\chi^2 = 70.8$; $P < 0.0001$) (Table 4). During the late season, PHER traps captured significantly more *H. halys* adults than all other traps, and light + PHER traps captured more than controls ($\chi^2 = 44.43$; $P < 0.0001$) (Table 4). In the Pacific Northwest at low density locations, pyramid traps baited with light, PHER, and light + PHER captured significantly more *H. halys* adults than control traps during late season ($\chi^2 = 21.9$; $P < 0.001$) (Fig. 2).

COMPETING LIGHT SOURCES

When light traps were deployed next to competing light sources, *H. halys* captures were not reduced significantly compared with traps placed without competing light in the early season ($Z = -0.3$; $P = 0.77$) (Fig. 2A), mid-season ($Z = 0.29$; $P = 0.77$) (Fig. 2B), and late season ($Z = 1.3$; $P = 0.19$) (Fig. 2C). However, during the mid- and late seasons, traps without light competition captured 68 and 128% more *H. halys* adults, respectively, than traps placed near competing light sources.

Discussion

Early season *H. halys* trap captures were lower than mid-season and late season captures in the Mid-Atlantic. This pattern is similar to that reported by Leskey et al. (2015c) and Weber et al. (2014) for cap-

Table 3. Field site locations and GPS coordinates for black pyramid traps that compare captures with traps baited with PHER and light placed next to competing light sources and placed in areas without competing light sources.

	Competing Light Source		No Competing Light Source	
Site	Latitude	Longitude	Latitude	Longitude
Catoctin, MD	39.6485667°N	77.3952250°W	39.6560972°N	77.4011667°W
Woodbine, MD	39.3135722°N	77.1030333°W	39.3085306°N	77.1007833°W
MT Weather, MD	39.0644917°N	77.8891167°W	39.0612889°N	77.8812194°W
Edgemont, MD	39.6714028°N	77.5443472°W	39.6715278°N	77.5412056°W

Table 4. Median number of *Halyomorpha halys* adults in seasonal trap captures from Mid-Atlantic and Pacific Northwest sites.

	Mid-Atlantic Sites			Pacific Northwest Sites
Treatment	Early Season	Mid-Season	Late Season	Late Season
Light	1.0a	11.5a	4.5ac	0.0a
Pheromone	2.0a	1.0b	16.5b	1.0a
Light + Pheromone	4.0a	20.0a	6.5a	0.5a
Control	0.0b	0.0c	1.0c	0.0b

Different letters indicate significant differences between median trap captures (Kruskal–Wallis test followed by an all-pairwise comparison Dwass-Steel-Critchlow-Fligner test, α = 0.05).

tures in pyramid traps baited with PHER or MDT, indicating that patterns reported in this study correspond to other reported patterns of seasonal populations of *H. halys*, with the largest populations detected in the late season.

During the mid-season in the Mid-Atlantic, *H. halys* captures were greatest in traps with lights, whereas during the late season, trap captures were greatest in PHER traps. Differences in captures may be due to two specific reasons. First, light traps can attract insects from multiple directions, whereas pheromone-baited traps will attract insects downwind of traps only. Thus, light traps can potentially attract insects from a larger area. However, light traps attract *H. halys* only at night, and this species does not fly when temperatures are below approximately 15 °C (Lee & Leskey 2015). This places abiotic constraints on light traps for *H. halys,* particularly when nighttime temperatures fall below 15 °C, which happens routinely in Sep in the Mid-Atlantic (NOAA 2017). PHER traps, on the other hand, are attractive season-long and can continue to attract adults later into the season as daytime temperatures are likely warm enough to allow *H. halys* movement. In the Pacific Northwest, where *H. halys* population densities were significantly lower when trials were conducted (Leskey et al. 2012c, 2015d), no differences were observed in captures in traps baited with PHER or light + PHER. However, captures in traps with only lights were significantly lower, again indicating that nighttime temperatures likely influenced captures. Indeed, PHER traps may be more reliable overall, because they do continue to capture *H. halys* when night temperatures decrease, and they do not require electrical power sources allowing them to be deployed in various landscapes.

When combined, PHER and MDT have a synergistic effect on *H. halys* trap captures (Khrimian et al. 2014; Weber et al. 2014; Leskey et al. 2015a). Traps in this study were not baited with MDT, and *H. halys* response to traps baited with MDT, PHER, and lights have not been quantified in the field. The synergistic effect of PHER and MDT may be increased with the addition of light and should be evaluated. Moreover, although we did not observe a significant effect from competing light sources on trap captures, we did see a decline in captures in the mid- and late seasons. A previous study observed reduced noctuid moth captures in light traps with increased moon light, perhaps due to light competition (Yela & Holyoak 1997). The addition of MDT may be able to offset this effect by increasing attraction through including additional olfactory stimuli in the trap, which may allow more flexibility in trapping location.

Overall, we have found that pyramid traps baited with light + PHER proved to be reliable stimuli for capture of *H. halys* adults. Increasing the understanding of the influences of abiotic and biotic factors on *H. halys* population dynamics enables richer interpretation of trap capture data.

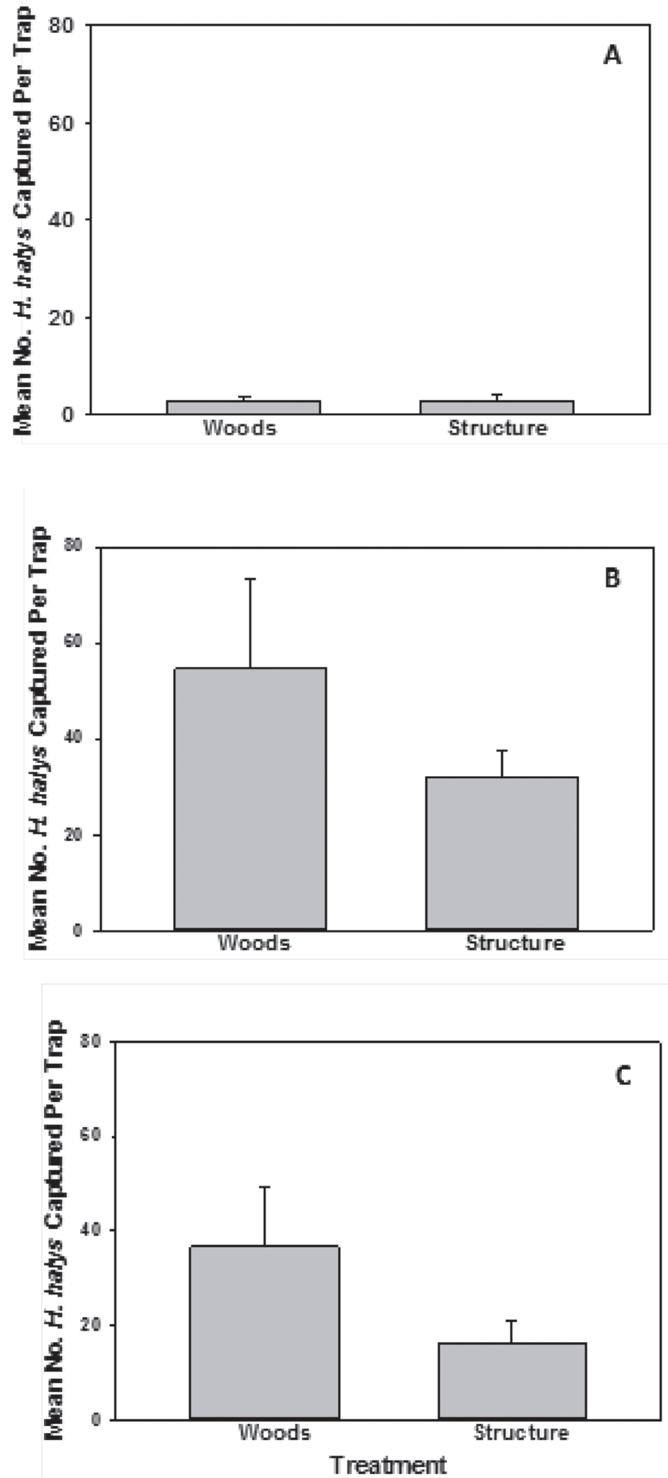

Fig. 2. Mean capture rates of *Halyomorpha halys* in black pyramid traps with fluorescent blue lights placed next to structures with competing light sources or next to wood line without competing lights, during early season (A), mid-season (B), and late season (C).

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