Journal of Economic Entomology, 113(1), 2020, 159–171
doi: 10.1093/jee/toz240
Advance Access Publication Date: 10 September 2019
Research

Ecology and Behavior

Season-Long Monitoring of the Brown Marmorated Stink Bug (Hemiptera: Pentatomidae) Throughout the United States Using Commercially Available Traps and Lures

Angelita L. Acebes-Doria,[1,27] Arthur M. Agnello,[2] Diane G. Alston,[3] Heather Andrews,[4] Elizabeth H. Beers,[5] J. Christopher Bergh,[6] Ric Bessin,[7] Brett R. Blaauw,[8] G. David Buntin,[9] Eric C. Burkness,[10] Shi Chen,[11] Ted E. Cottrell,[12] Kent M. Daane,[13] Lauren E. Fann,[7] Shelby J. Fleischer,[14] Christelle Guédot,[15] Larry J. Gut,[16] George C. Hamilton,[17] Richard Hilton,[18] Kim A. Hoelmer,[19] William D. Hutchison,[10] Peter Jentsch,[20] Greg Krawczyk,[21] Thomas P. Kuhar,[22] Jana C. Lee,[23] Joshua M. Milnes,[5] Anne L. Nielsen,[17] Dilani K. Patel,[8] Brent D. Short,[24] Ashfaq A. Sial,[8] Lori R. Spears,[3] Kathy Tatman,[19] Michael D. Toews,[1] James D. Walgenbach,[25] Celeste Welty,[26] Nik G. Wiman,[4] Janet van Zoeren,[15] and Tracy C. Leskey[24]

[1]Department of Entomology, University of Georgia, 2360 Rainwater Road, Tifton, GA 31793, [2]Department of Entomology, Cornell AgriTech, Cornell University, Geneva, NY, [3]Department of Biology, Utah State University, Logan, UT, [4]North Willamette Research and Extension Center, Oregon State University, Aurora, OR, [5]Department of Entomology, Tree Fruit Research and Extension Center, Washington State University, Wenatchee, WA, [6]Alson H. Smith, Jr. Agricultural Research and Extension Center, Virginia Tech, Winchester, VA, [7]Department of Entomology, University of Kentucky, Agricultural Science Center, Lexington, KY, [8]Department of Entomology, University of Georgia, Athens, GA, [9]Department of Entomology, University of Georgia, Griffin, GA, [10]Department of Entomology, University of Minnesota, St. Paul, MN, [11]Department of Population Health and Pathobiology, North Carolina State University, Raleigh, NC, [12]USDA-ARS, Southeastern Fruit and Tree Nut Research Laboratory, Byron, GA, [13]Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA, [14]Department of Entomology, Pennsylvania State University, University Park, PA, [15]Department of Entomology, University of Wisconsin, Madison, WI, [16]Department of Entomology, Michigan State University, Center for Integrated Plant Systems, East Lansing, MI, [17]Rutgers University, Department of Entomology, New Brunswick, NJ, [18]Southern Oregon Research and Extension Center, Oregon State University, Medford, OR, [19]USDA-ARS, Beneficial Insects Introduction Research, Newark, DE, [20]Department of Entomology, Cornell University, Hudson Valley Research Lab, Highland, NY, [21]Fruit Research and Extension Center, Pennsylvania State University, Biglerville, PA, [22]Department of Entomology, Virginia Tech, Blacksburg, VA, [23]USDA-ARS, Horticultural Crops Research Unit, Corvallis, OR, [24]USDA-ARS, Appalachian Fruit Research Station, Kearneysville, WV, [25]Department of Entomology and Plant Pathology, North Carolina State University, MHCREC, Mills River, NC, [26]Department of Entomology, Ohio State University, Columbus, OH, and [27]Corresponding author, e-mail: aacebes@uga.eduSubject Editor: Joseph Munyaneza

Received 3 June 2019; Editorial decision 7 August 2019

Abstract

Reliable monitoring of the invasive *Halyomorpha halys* abundance, phenology and geographic distribution is critical for its management. *Halyomorpha halys* adult and nymphal captures on clear sticky traps and in black pyramid traps were compared in 18 states across the Great Lakes, Mid-Atlantic, Southeast, Pacific Northwest and Western regions of the United States. Traps were baited with commercial lures containing the *H. halys* pheromone and synergist, and deployed at field sites bordering agricultural or urban locations with *H. halys* host plants. Nymphal and adult captures in pyramid traps were greater than those on sticky traps, but captures were positively correlated between the two trap types within each region and during the early-, mid- and late season across all sites. Sites were further classified as having a low, moderate or high relative *H. halys* density and again showed positive correlations between captures for the two trap types for nymphs and adults. Among regions, the greatest adult captures were recorded in the Southeast and Mid-Atlantic on pyramid and sticky traps, respectively, with lowest captures recorded in the West. Nymphal captures, while lower than adult captures, were greatest in the Southeast and lowest in the West. Nymphal and adult captures were, generally, greatest during July–August and September–October, respectively. Trapping data were compared with available phenological models showing comparable population peaks at most locations. Results demonstrated that sticky traps offer a simpler alternative to pyramid traps, but both can be reliable tools to monitor *H. halys* in different geographical locations with varying population densities throughout the season.

Key words: pheromone trap, sticky trap, pyramid trap, invasive species

Halyomorpha halys (Stål), or the brown marmorated stink bug, is an invasive species from Asia that has become a serious agricultural pest of many economically important commodities in the United States, including tree fruit, nut crops, field crops, vegetables, and ornamentals (Rice et al. 2014). It was first detected in the Eastern United States in the 1990s and in 2010, populations increased to outbreak levels resulting in severe losses in tree fruit and other crops in the Mid-Atlantic region (Leskey et al. 2012a). Currently, it has been found in 44 states, threatening agricultural production in at least 10 states and causing nuisance problems in another 21 states in the United States (stopBMSB.org). In addition, *H. halys* has invaded and caused economic injury in several European countries (Leskey and Nielsen 2018).

Since the beginning of the Mid-Atlantic outbreak, monitoring for *H. halys* has been a top research priority (BSMB Working Group Report, 2010). Previous studies have focused on comparing different trapping designs (Leskey et al. 2012b, Joseph et al. 2013, Nielsen et al. 2013, Morrison et al. 2015, Rice et al. 2018) and testing stink bug pheromone lures for attraction to *H. halys* (Aldrich et al. 2007, Khrimian et al. 2008, Nielsen et al. 2011, Rice et al. 2017). The critical discovery of the *H. halys* two-component male aggregation pheromone, (3*S*, 6*S*, 7*R*, 10*S*)-10,11-epoxy-1-bisabolen-3-ol and (3*R*, 6*S*, 7*R*, 10*S*)-10,11-epoxy-1-bisabolen-3-ol (Khrimian et al. 2014), which in combination with a pheromone synergist, methyl (2*E*, 4*E*, 6*Z*)-decatrienoate (MDT), has offered reliable season-long attraction of both nymphs and adults to baited traps (Weber et al. 2014), and paved the way to more *H. halys*-specific trapping programs. The black coroplast pyramid trap baited with the *H. halys* aggregation pheromone and synergist became the standard trap for monitoring (Morrison et al. 2015, Rice et al. 2018). These traps have been used in developing threshold-based management programs in apple orchards (Short et al. 2017). However, the large pyramid traps are bulky, cumbersome to install, and expensive, making them less adaptable for agricultural use (Rice et al. 2018). Acebes-Doria et al. (2018) found that transparent clear sticky traps affixed atop wooden posts and baited with commercially formulated lures containing *H. halys* pheromone and pheromone synergist were a simple, easy-to-use and reliable alternative to pyramid traps for both adults and nymphs.

However, it was unknown if this new trap design would work well in other parts of the United States with differing climatic conditions and *H. halys* populations (Valentin et al. 2017). Differences in the seasonal abundance and phenology of *H. halys* populations in various regions of the United States were recorded using black pyramid traps (Leskey et al. 2015). However, clear sticky traps are quite different than black pyramid traps, using an adhesive glue on the trap surface, rather than a collection jar and killing agent, as a retention mechanism. To date, published trials using clear sticky traps and standard pyramid traps were limited to the Mid-Atlantic region (Acebes-Doria et al. 2018).

To further investigate the reliability and effectiveness of these sticky traps under a range of different *H. halys* densities and climatic conditions, we deployed these two trap types at 115 sites in 18 states encompassing five geographic regions in the continental United States (Mid-Atlantic, Southeast, Great Lakes, Pacific Northwest, and West). Moreover, results from a phenology model for *H. halys* (Nielsen et al. 2016, 2017), were compared with trap captures across different regions of the United States.

Materials and Methods

Trap Designs and Trapping Protocol

The standard Dead-Inn black pyramid trap (1.2 m height, AgBio Inc., Westminster, CO) was compared with a transparent double-sided sticky trap (15.2 × 30.5 cm, STKY Dual Panel Adhesive Trap, Trécé, Inc., Adair, OK) (Supp Fig. 1 [online only]). A clear collection jar (16 × 10 × 10 cm H:L:W; AgBio Inc.) was placed atop each pyramid trap that contained deltamethrin-incorporated netting (Vestergaard-Frandsen Inc., Lausanne, Switzerland) secured flatly to the surface of the interior funnel (1.6 cm internal opening) by a paper clip to prevent captured stink bugs from escaping (Kuhar et al. 2017, Acebes-Doria et al. 2018). Clear sticky traps were secured horizontally to the top of wooden stakes at a height of ~1.2 m from the ground, using 2″ black steel binder clips and by stapling the top and bottom of cards to the wooden stake.

Each trap was baited with 5 mg of the *H. halys* aggregation pheromone and 50 mg of the MDT synergist (Trécé, Inc.). This pheromone loading rate is as reliable as the 4× greater biosurveillance loading rate in areas with low, moderate and high relative population densities in the Mid-Atlantic (Acebes-Doria et al. 2018). Lures were placed outside the collection jar on pyramid traps, and secured by binder clips above the sticky traps. Lures were replaced every 12 wk.

There were 115 sites across 18 states, with states grouped into five geographic regions (Mid-Atlantic, Great Lakes, Southeast, Pacific Northwest, and West; Fig. 1; Supp Table 1 [online only]). This regional grouping was based on regional work groups designated considering geographical proximity, comparable cropping systems and relatively similar climatic conditions. Traps at most sites were deployed mostly along the perimeter of *H. halys*-susceptible cultivated crops and woodlots containing wild *H. halys* hosts (Supp Table 1 [online only]). In Washington State, traps were deployed in residential areas and public parks with known *H. halys* host plants (Supp Table 1 [online only]). At most sites, there were at least three pyramid and three sticky traps alternately arranged at 50-m intervals (Supp Table 1 [online only]). Some sites in California had only one of either trap. Data collected from residential sites in Washington and from non-replicated sites in California were not included in the main comparative statistical analyses, but were used in the graphical presentation of *H. halys* phenology, i.e., season-long captures (Supp Table 1 [online only]). Traps were checked weekly from April to November 2017 at the majority of the sites (Supp Table 1 [online only]) and numbers of *H. halys* nymphs and adults were recorded.

Seasonal Phenology Comparisons Between Phenology Model and Trapping Data

We used a phenological model developed and validated by Nielsen et al. (2016, 2017) for *H. halys* to obtain simulated phenological trends for selected sites in each region, then compared the

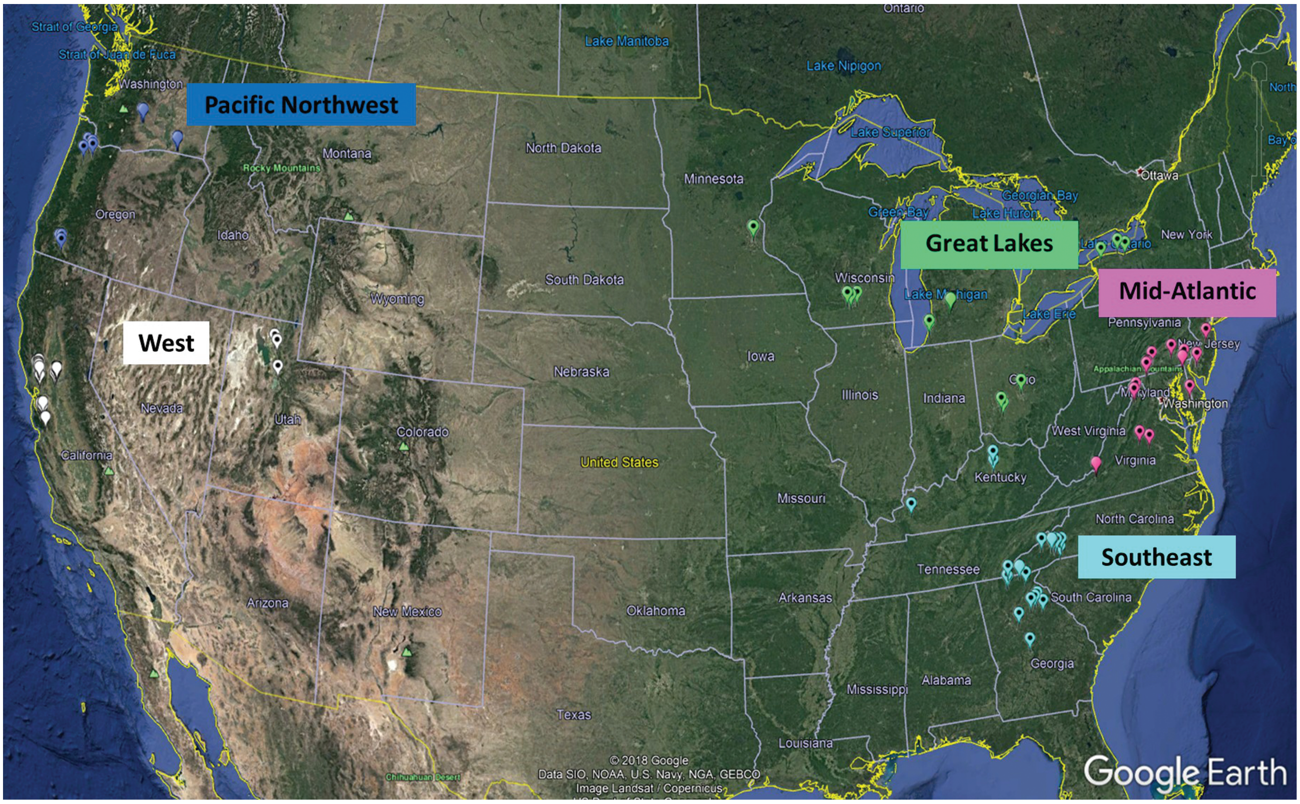

Fig. 1. Locations of the trapping sites across the United States grouped by geographical region (blue: Pacific Northwest, white: West, green: Great Lakes, Pink: Mid-Atlantic and light blue: Southeast). Points with dots were sites used for both statistical analyses and phenology comparison; while points without dots were sites used only for the phenology comparison.

model-generated trends with the trapping data for each selected site (see Data Analyses section). The sites were selected based on high *H. halys* abundance and length of the trapping period. The following sites were chosen from each region: Michigan's SW1 (Great Lakes), Maryland's Durgin and Rinehart (Mid-Atlantic), Georgia's One (Southeast), Oregon's Willamette Valley 2 (Pacific Northwest). No site was chosen from the Western region due to low captures. Two sites were chosen in Maryland due to their proximity and comparable *H. halys* abundance; and captures from the two sites were averaged. We ran 100 simulations for each selected location. For each simulation, we used 1,000 adults as the starting parental population. We ran the simulations on 12 December using the 2017 minimum and maximum temperatures up to that date obtained from the Unrestricted Mesoscale Analysis (URMA) at the National Center for Environmental Prediction (NCEP, at www.ncep.noaa.gov), through a gridded interface at the Center for Environmental Informatics at Penn State (http://www.pestwatch.psu.edu/minmax/index.html). Only data from 1 April 2017 to 1 November 2017 were presented from the phenological simulations to match the trapping period.

Data Analyses

Relative Population Density Grouping

Mean weekly adult trap captures from the week of 29 May 2017 to the week of 8 October 2017 across 65 sites were compared using one-way analysis of variance. Due to the unequal sampling periods among sites (Supp Table 1 [online only]), we only analyzed captures during these periods to ensure a balanced model. Subsequent results from Tukey Kramer's post hoc tests were used to group the sites according to high, moderate, and low relative population densities. To confirm that the mean adult captures in each population group were statistically distinct, we employed a zero-inflated generalized linear Poisson model (GLM ZI), and a multiple mean comparison procedure designed for generalized linear models based on χ^2 statistics, with a Bonferroni correction, in analyzing mean adult captures among each population group. Analyses were conducted using JMP, Version 14 (SAS Institute Inc., Cary, NC).

Trap Comparisons

We compared captures between the two trap designs separately for high, moderate, and low relative density sites ($n = 65$ sites) from the week of 29 May 2017 to the week of 2 October 2017 using the GLM ZI Poisson model, and the same analysis was conducted to compare captures between the two traps during early (week of 17 April – 12 June, 27 sites), mid-season (week of 19 June – week of 7 August, 65 sites), and late season (14 August – 9 October, 59 sites; Supp Table 1 [online only]). The seasonal categories were based on previous *H. halys* trapping studies (Leskey et al. 2015, Morrison et al. 2015) and *H. halys* phenology in the United States. Overwintered adults are present in early season (Bergh et al. 2017) while first-generation nymphal population are common during mid-season (Acebes-Doria et al. 2017), and summer generation nymphs and adults are present late in the season (Nielsen et al. 2009, Leskey et al 2015, Morrison et al. 2015). Pearson correlations were calculated for adult and nymphal captures in pyramid traps and clear sticky traps on each trapping date within each different population density and within the different points in the season.

Comparison Across the Different Regions

We compared *H. halys* adult and nymphal captures across the five geographical regions for the two trap designs between the weeks of 29 May to 2 October using the GLM ZI Poisson model (Great Lakes: 16 sites, Mid-Atlantic: 15 sites, Southeast: 19 sites, Pacific: 8 sites, West: 3 sites; Supp Table 1 [online only]). Multiple mean comparisons were conducted using χ^2 statistics, with Bonferroni correction. Pearson correlations were calculated for adult and nymphal captures in pyramid traps and clear sticky traps at each trapping date for each region.

Comparison of Phenological Model and Trap Counts

Three dates with the highest trap captures in pyramid and in sticky traps, and three dates (start, mid, and end dates) within the period of the highest projected populations from the model were used in the subsequent analysis. The Julian dates corresponding to the dates with the highest captures were compared using a *t*-test. Analyses were done separately for nymphs and adults. Significant differences indicate *H. halys* abundance as predicted by the phenological model and trapping data do not coincide. JMP, Version 14 (SAS Institute Inc., Cary, NC) was used for all analyses.

Results

Trap Comparisons

Numbers of *H. halys* adults and nymphs captured in pyramid traps were significantly greater than on sticky traps during early, mid-, and late-season across all sites (Fig. 2). Adult captures in pyramid traps were 3× greater than on sticky traps early in the season and

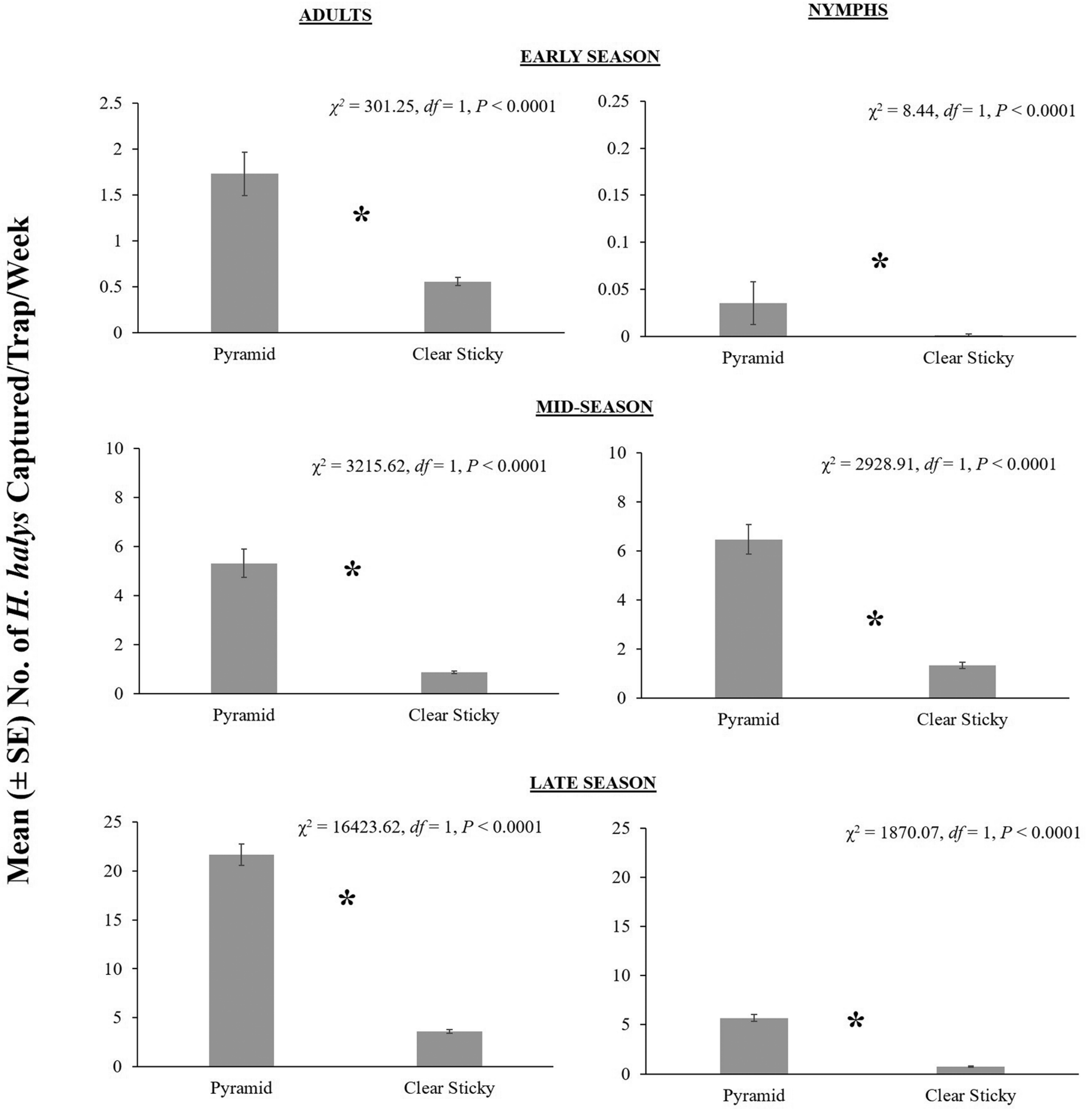

Fig. 2. *Halyomorpha halys* adult and nymphal captures in pyramid and clear sticky traps during early, mid and late periods of the season. (*) indicates significant difference between the treatments at $\alpha = 0.05$.

6× greater during mid to late season (Fig. 2). Captures of nymphs in pyramid traps were 28×, 5×, and 8× greater than on clear sticky traps during early, mid- and late season, respectively (Fig. 2). Captures between pyramid and sticky traps during early, mid- and late season were significantly and strongly correlated, with the exception of the early season nymphal captures, though nymphs were rarely captured in the early season (Table 1). In addition, 47% and 29% of the sites had the first captures of *H. halys* adults and nymphs, respectively, occurring on the same week for both trap types.

Relative Population Density Comparisons

Mean *H. halys* adult captures across the 65 sites selected from throughout the United States were significantly different ($F_{64,\,8152} = 14.85$, $P < 0.0001$; Table 2). Using the results of post hoc tests, three distinct population groups were identified with low, moderate, and high relative population densities having averages of 1.07 ± 0.06, 5.58 ± 0.32 and 20.21 ± 1.11 *H. halys* adults per trap/week, respectively ($\chi^2 = 20215.85$, df = 2, $P < 0.0001$; Table 2). Using this classification as the basis for comparison, captures in pyramid traps were significantly greater than on sticky traps for both *H. halys* adults and nymphs at each relative population density designation (Fig. 3). Adult captures in pyramid traps were 2×, 3×, and 9× greater than on sticky traps in low, moderate, and high population densities, respectively. Nymphal captures were 3–7.8× greater in pyramid traps than on sticky traps across the different population densities. Despite these differences in total captures, *H. halys* adult and nymphal captures in pyramid traps and on sticky traps were strongly and positively correlated regardless of the population density (Table 3).

Geographic Region Comparisons

There was a significant effect of region on adult captures in pyramid traps; greatest captures were recorded in the Southeast, followed by the Mid-Atlantic, Pacific Northwest, Great Lakes, and the West, respectively (Fig. 4). Captures of nymphs in pyramid traps were significantly different among the five geographic regions, with greatest captures also being recorded in the Southeast (Fig. 4). Captures of *H. halys* adults on sticky traps showed a significant effect of region, with significantly greatest captures in the Mid-Atlantic, followed by the Southeast, Great Lakes, Pacific Northwest, and West (Fig. 4). Nymphal captures on sticky traps were also significantly different among the regions, with the highest numbers in the Southeast and lowest in the West (Fig. 4). Correlation analyses of *H. halys* adults and nymphs showed positive relationships between pyramid and sticky traps across all geographical regions (Table 4). In the Southeast, Mid-Atlantic, Great Lakes, and Pacific Northwest, greatest adult captures were generally recorded in late September and/or early October for both trap types (Figs. 5 and 6). However, in the Western region, captures of *H. halys* adults in both trap types, while low, were greatest in May and June in Utah (Fig. 5 and 6), and in September in California for sticky traps (Fig. 6). In the Great Lakes, Pacific Northwest, and Mid-Atlantic, nymphs were captured in pyramid and sticky traps from early May to early October. In the Southeast, nymphal captures begin earlier, in May, for both trap types and extended into fall (October). In Utah, nymphs were only captured in pyramid traps in late May and in sticky traps from late May through early September (Figs. 5 and 6). In California, nymphs were captured from early May to early fall in sticky traps (Fig. 6).

Comparisons Between Phenology Model and Trapping Data

Figure 7 shows that the simulation model enabled an estimate of the timing of each generation (as measured by eclosion of the adult stage). However, overlapping generations result in captures reflecting the combination of individuals present from multiple generations. Across all selected sites for each region, two generations were predicted by the model, with the F1 eggs beginning mid- to late May and the F2 eggs starting mid- to late July (Nielsen et al. 2016, 2017).

The timing of abundance in adult populations, as indicated by peak captures in both traps, was highest late in the season, which aligned with or within a few weeks of the projected peaks in the simulation model (Fig. 7; Table 5). The differences between peak captures of adults and simulated population predictions were not significantly different for each region for both trap types (Table 5). In Michigan, highest adult captures in both trap types occurred in September and October, which coincided with peak adult abundance predicted by the model. Similarly, in Maryland and Oregon, highest captures of adults in both traps occurred from mid-September to early October, which coincided with the model prediction. In Georgia, highest adult captures in pyramid and sticky traps occurred in late September, while the model predicted peak adult abundance a few weeks earlier, but the difference was not significant for either trap type (Fig. 7; Table 5).

In Michigan, Maryland, and Oregon, nymphal captures in pyramid traps did not coincide with the simulated nymphal population predictions, with high nymphal captures recorded more than a month later than the simulation (Fig. 7; Table 5). In Georgia, however, peak nymphal captures in pyramid traps occurred in late July and early August, which closely aligned with the model. Interestingly, seasonal peaks of nymphal captures in sticky traps closely reflected the trends predicted by simulated populations for Michigan, Maryland, Georgia, and Oregon (Fig. 7; Table 5).

Discussion

In response to the *H. halys* invasion in the United States, research efforts were initially focused on identification of its host plants and seasonality (Nielsen and Hamilton 2009). As populations spread and damage intensified, identifying trap designs and effective deployment strategies to accurately detect and monitor field populations of *H. halys* in agroecosystems became a primary focus. The ground-deployed black pyramid trap became the standard trap for monitoring *H. halys* populations, but due to its size and cost, alternatives were sought. Rice et al. (2018)

Table 1. Pearson correlation coefficients ($\alpha = 0.05$) between captures of *H. halys* in pyramid and sticky traps baited with commercially formulated lures during early, mid and late periods of the season

	Adults			Nymphs		
Period in the season	*r*	df	*P*	*r*	df	*P*
Early season	0.51	238	<0.0001	–0.01	238	0.9219
Mid-season	0.65	510	<0.0001	0.77	510	<0.0001
Late season	0.63	568	<0.0001	0.56	568	<0.0001

Table 2. Seasonal captures of *H. halys* adults at 65 field sites from late May to early October 2017

State and location	Mean ± SEM adult captures/trap/week		Relative population densities (mean ± SE adult captures/trap/week)
MD Durgin	39.8 ± 8.2	A	High (20.2 ± 1.1)a
GA One	32.1 ± 3.5	AB	
NC KJ	28.9 ± 6.2	ABC	
GA GAY	25.3 ± 4.7	BCD	
MD Rinehart	23.9 ± 7.5	BCDE	
GA SCPH	20.5 ± 2.9	BCDEF	
GA Two	19.6 ± 2.1	CDEF	
NJ Cream Ridge 1	16.5 ± 4.0	CDEFG	
VA Minebank	14.2 ± 3.1	DEFGHI	
GA GAM	13.7 ± 2.3	EFGH	
VA Homeplace	12.6 ± 2.9	EFGHIJK	
GA Four	12.0 ± 1.5	EFGHIJK	
OR Molalla Holly	11.7 ± 3.1	EFGHIJK	
MI SW2	11.2 ± 4.4	EFGHIJK	
NC HEND	9.1 ± 1.5	FGHIJK	Moderate (5.6 ± 0.3)b
OR Canby Hazelnut	8.9 ± 1.6	FGHIJK	
MI SW1	8.2 ± 3.1	FGHIJK	
GA GARA	7.2 ± 1.0	GHIJK	
NY Schutt	6.9 ± 2.3	GHIJK	
DE Milburns	6.8 ± 1.6	GHIJK	
OR Keizer Hazelnut	6.5 ± 2.1	GHIJK	
OR OSU Veg Farm	6.1 ± 2.6	GHIJK	
MI SW3	6.0 ± 1.9	GHIJK	
NC MRS	5.8 ± 1.9	GHIJK	
NJ Cream Ridge 2	5.7 ± 1.6	GHIJK	
VA Fluvanna	5.4 ± 1.2	GHIJK	
NC LYNCH	5.1 ± 0.8	GHIJK	
MD Ghour	5.1 ± 1.6	GHIJK	
GA GACC	4.5 ± 0.9	GHIJK	
NJ Cream Ridge 3	4.3 ± 0.8	GHIJK	
OH B-hill	4.0 ± 0.8	GHIJK	
DE White Clay	3.9 ± 1.3	GHIJK	
VA Goochland	3.9 ± 0.7	GHIJK	
GA McDonough	3.8 ± 0.5	GHIJK	
KY South Farm	3.3 ± 0.6	GHIJK	
NJ Bridgeton (C)	3.1 ± 0.6	GHIJK	
GA Byron	2.5 ± 0.3	HIJK	Low (1.1 ± 0.1)c
NJ Bridgeton (A)	2.2 ± 0.4	HIJK	
KY North Farm	2.2 ± 0.6	HIJK	
NY Dobbins	2.1 ± 0.8	HIJK	
NJ Bridgeton (B)	2.1 ± 0.5	HIJK	
OR Neilsen	2.0 ± 0.8	HIJK	
GA Three	1.8 ± 0.2	HIJK	
OH Stokes	1.8 ± 0.3	HIJK	
PA Adams	1.5 ± 0.3	HIJK	
OR Vineyards	1.3 ± 0.2	HIJK	
OR Bear Creek	1.2 ± 0.3	IJK	
NY Burch	1.2 ± 0.3	IJK	
NY Windmill	1.1 ± 0.4	IJK	
OH Wman	1.1 ± 0.2	IJK	
PA Lancaster 1	0.6 ± 0.2	IJK	
NC NIX	0.6 ± 0.1	IJK	
OR Vaughn	0.5 ± 0.1	IJK	
WI DC	0.4 ± 0.1	IJK	
PA Lancaster 3	0.3 ± 0.1	IJK	
PA Lancaster 2	0.2 ± 0.1	IJK	
UT 19	0.2 ± 0.0	IJK	
UT 13	0.1 ± 0.1	IJK	
WI EG	0.1 ± 0.0	JK	
WI AB	0.1 ± 0.0	JK	
MN 2	0.1 ± 0.0	JK	
MN 1	0.0 ± 0.0	JK	
MN 3	0.0 ± 0.0	JK	
UT 17	0.0 ± 0.0	JK	
KY Princeton	0.0 ± 0.0	JK	

Means with shared letters are not significantly different from each other at $\alpha = 0.05$ for the analyses comparing captures across all sites and relative population densities. Sites were classified according to relative population densities found at each site and grouping was based on the results of the post hoc test. Data were pooled across both trap types.

demonstrated that canopy-deployed traps, including small pyramid traps, delta traps, and yellow sticky traps were promising alternatives for *H. halys* trapping, but also exhibited limitations. Namely, traps deployed in tree canopies generally captured far fewer *H. halys* nymphs and adults than ground-deployed traps, and captures were not always correlated between the two locations (Rice et al. 2018). These results were likely due to the fact that *H. halys* adults (Lee et al. 2013, 2014) and nymphs (Lee et al. 2014, Acebes-Doria et al. 2016a) have the propensity to walk upwards, and the surface complexity and overall surface area within a tree canopy provided many sites where foraging *H. halys* could arrest (Leskey and Nielsen 2018), whereas for ground-deployed traps there was only a single upright pathway for dispersing *H. halys* nymphs and adults to traverse. Moreover, Quinn et al. (2018) found that captures of adults and nymphs in small baited pyramid traps deployed in host tree canopies at different canopy heights were greater in the upper portions of the canopy compared with those near the tree base. Deploying traps on the ground, therefore, allows for a more uniform and less complex environment to capture foraging *H. halys*, likely leading to less variation in captures based on deployment location. It also provides a more accessible location for traps to be serviced. While captures of *H. halys* were greater in pyramid traps, they were strongly correlated with those on sticky traps at low, moderate, and high population densities across the United States, similar to the results of Acebes-Doria et al. (2018) in the Mid-Atlantic. Thus, sticky traps do provide a simpler and cheaper alternative to pyramid traps, but there still are potential improvements that can be made to this system. In this study, some researchers observed that sticky traps became quickly saturated under high population densities, thereby requiring more frequent servicing. In addition, under cool, wet conditions, nymphs and adults were observed walking across the sticky surface itself, indicating that adhesives may require further refinement to increase overall trapping efficiency.

This study provided additional confirmation on the phenology of *H. halys* in the United States. Adults were captured as early as late March and early April across all regions; at that time their access to suitable host plants may be limited as *H. halys* host utilization follows the plant fruiting phenology (Martinson et al. 2015, Acebes-Doria et al. 2016b). By mid-May to mid-June, crops susceptible to nymphal and adult feeding may include berry crops and peach (Basnet et al. 2014, Wiman et al. 2015, Acebes-Doria et al. 2016c). Peach, in particular, is known to be a vulnerable crop throughout the growing season (Nielsen and Hamilton 2009, Acebes-Doria 2016b).

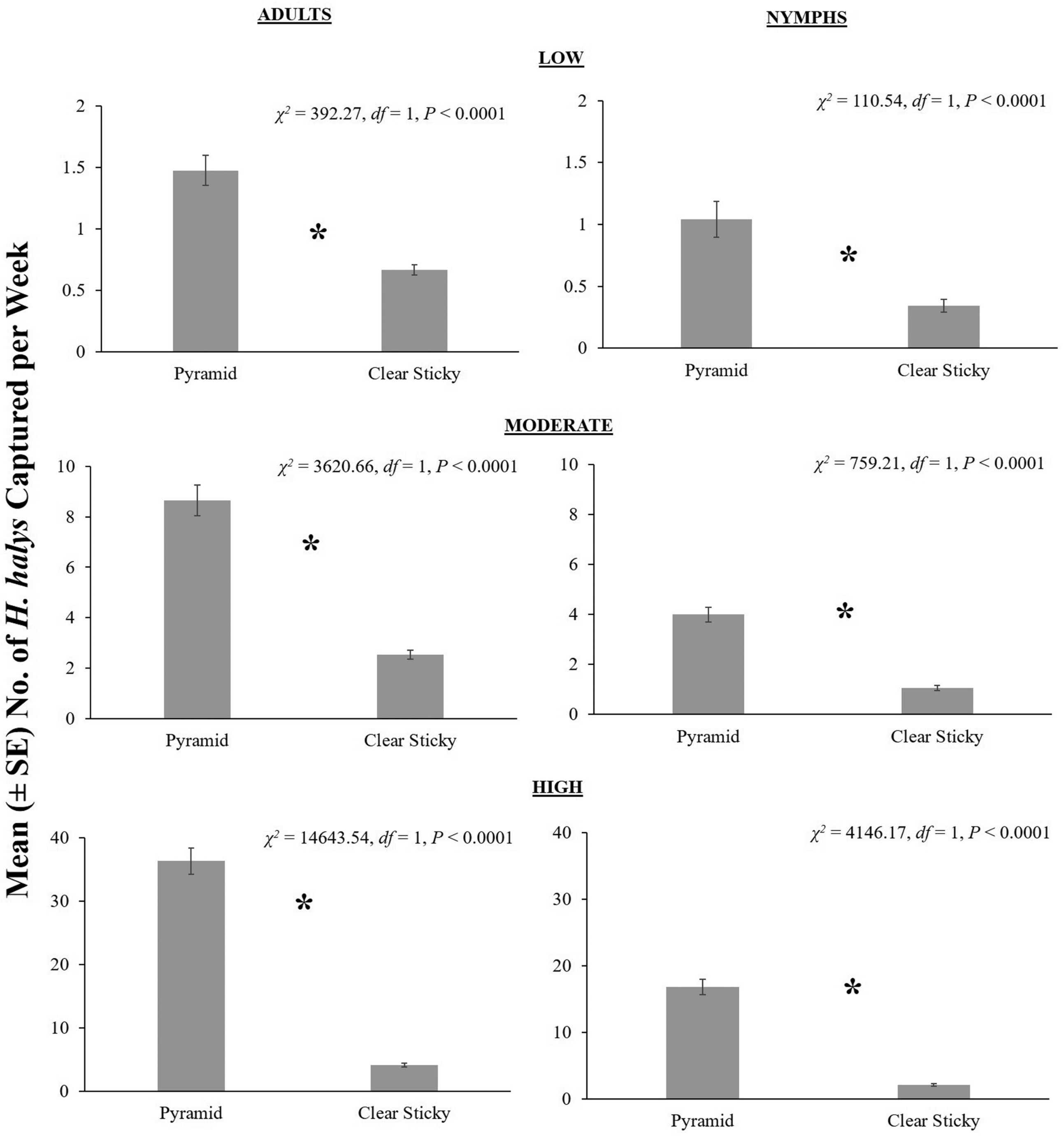

Fig. 3. *Halyomorpha halys* adult and nymphal captures in pyramid and clear sticky traps under low, moderate and high *H. halys* relative densities. Data pooled across selected sites from week of 29 May to week of 2 October 2017. (*) indicates significant difference between the treatments at $\alpha = 0.05$.

Table 3. Pearson correlation coefficients ($\alpha = 0.05$) between captures of *H. halys* in pyramid and sticky traps baited with commercially formulated lures at low, moderate, and high relative population densities

	Adults			Nymphs		
Relative population density	*r*	df	*P*	*r*	df	*P*
Low	0.64	545	<0.0001	0.60	545	<0.0001
Moderate	0.49	410	<0.0001	0.42	410	<0.0001
High	0.68	255	<0.0001	0.76	255	<0.0001

Captures across 65 sites from week of 29 May to week of 2 October 2017 were used in the analyses.

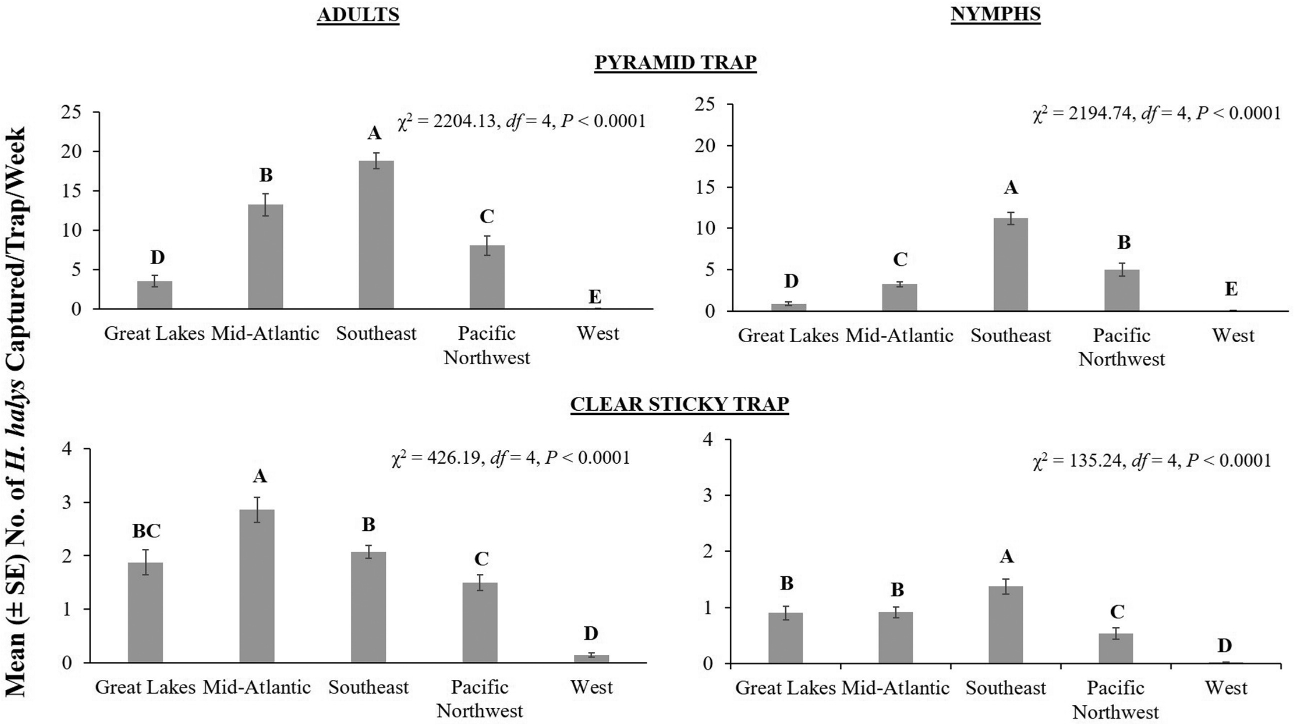

Fig. 4. Comparison of captures of *H. halys* adults and nymphs in clear sticky traps and pyramid traps across the five geographical regions in the United States from week of 29 May to week of 6 October 2017. Data pooled across selected sites within each region. Means with the same letters on each graph are not significantly different (Tukey's α = 0.05).

Table 4. Pearson correlation coefficients (α = 0.05) between captures of *H. halys* in pyramid and sticky traps baited with commercially formulated lures across five geographical regions in the United States

	Adults			Nymphs		
Geographical Region	*r*	*df*	*P*	*r*	*df*	*P*
Great Lakes	0.76	301	<0.0001	0.26	301	<0.0001
Mid-Atlantic	0.84	355	<0.0001	0.61	355	<0.0001
Southeast	0.51	346	<0.0001	0.79	346	<0.0001
Pacific Northwest	0.43	152	<0.0001	0.46	152	<0.0001
West	0.31	56	0.02	0.43	56	0.0008

Captures across 65 sites from week of 29 May to week of 6 October 2017 were used in the analyses.

In August and September, when highest populations of nymphs and adults occurred, crops with maturing fruiting structures such as apples, fruiting vegetables and soybeans would presumably be at greatest risk (Joseph et al. 2015, Venugopal and Dively 2015, Zobel et al. 2016). Knowing when peak populations are expected in each region and which cropping systems are vulnerable to attack, can be useful in conducting timely management decisions.

We found significant differences in captures of *H. halys* adults and nymphs in different regions of the country. In general, trends across the five different regions followed predictions from the niche and climate models proposed by Zhu et al. (2012) and Kriticos et al. (2017), with highest populations in the Southeast and Mid-Atlantic, both areas considered to be highly suitable for *H. halys*. When comparisons were made between season-long adult captures and predictions from the phenological model developed by Nielsen et al. (2016, 2017), we observed similar phenological patterns. Across all selected sites, two generations were predicted by the model with higher populations occurring later in the season (August, September until early October). The Eastern locations (e.g., Mid-Atlantic: Maryland and Southeast: Georgia) generally had the highest predicted adult populations, and these simulated populations closely coincided with peak captures in both pyramid and sticky traps. In Michigan (Great Lakes), overall *H. halys* populations were predicted to be less than populations in Eastern sites, possibly due to colder temperatures affecting *H. halys* population densities, but peak adult captures in both traps did align with the model. Nymphal population peaks predicted by the model did not closely align with pyramid trap captures in Maryland, Oregon or Michigan, with peak captures predicted to peak a month earlier, although they did align in Georgia. Interestingly, captures on sticky traps and model predictions did align for all locations. Whereas the model predicted nymphal counts to be higher than adult counts that followed, the trap data did not follow this pattern. This suggests that the processes differ for these different methods of estimating populations or that the presence of nymphs in traps is more strongly related to a site-specific trap location versus a landscape-level prediction from the model. Further, Kirkpatrick et al. (2019) documented that while baited traps sample *H. halys* adults in open areas over a ~5 ha total area, nymphal sampling is reduced to 0.67 ha. Thus, the likelihood of greater adult captures in traps based on their strong flight capacity (Wiman et al.

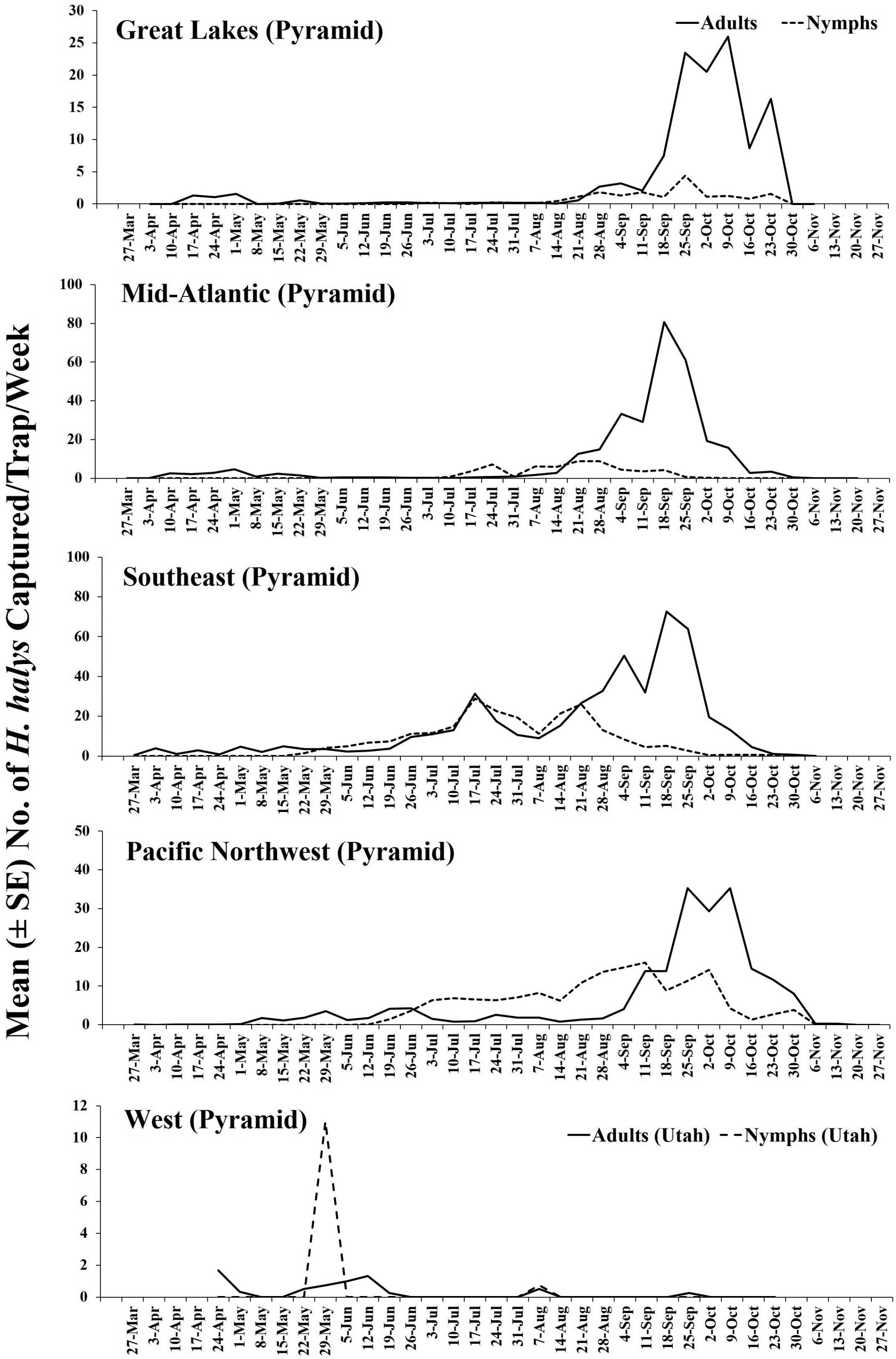

Fig. 5. Season-long captures of *H. halys* adults and nymphal in pheromone-baited pyramid traps across five geographical regions in the United States. Data pooled across all sites within each region. There was a total of 79 sites. Due to unreplicated number of pyramid traps deployed in California, no data from the state were presented above.

2014, Lee et al. 2014) and capacity to reach baited traps compared with nymphs also could explain these differences in captures. Thus, lower nymphal captures, while possibly reflecting reduced trapping efficiency, may also be reflecting relative populations, but over a smaller total area compared with adults. The differences between the simulated populations and trap captures also may be due to the limitations in the model, as it is mainly based on temperature and photoperiod and does not account for other abiotic or biotic factors

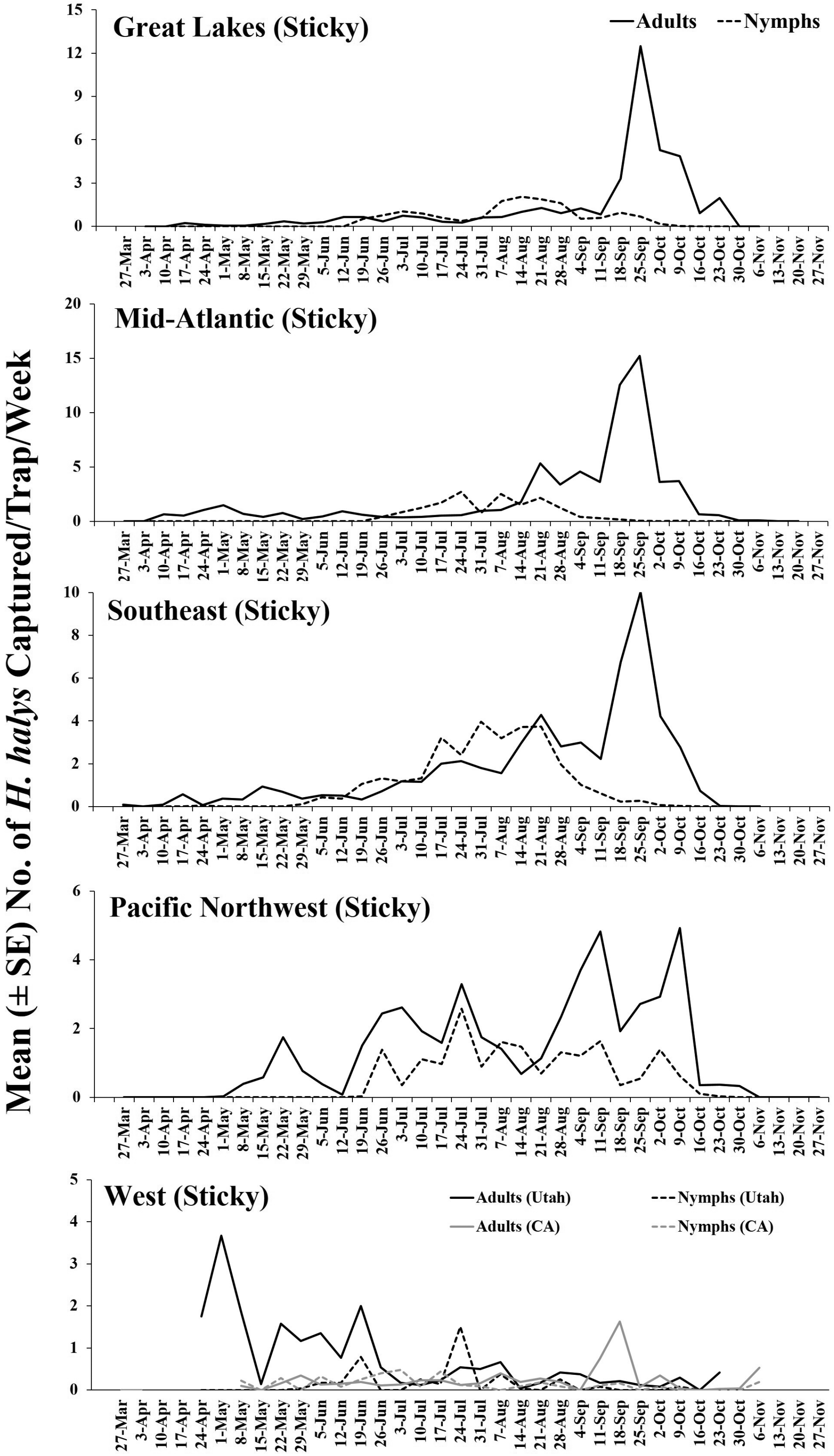

Fig. 6. Season-long captures of *H. halys* adults and nymphal in pheromone-baited clear sticky traps across five geographical regions in the United States. Data pooled across all sites within each region. There was a total of 115 sites.

affecting *H. halys* population phenology and dynamics (e.g., host plant availability, parasitism, predators) (Nielsen et al. 2008). These data documenting differences in the population densities of *H. halys* across multiple locations in the United States provided baseline information on the potential factors affecting its establishment, including parasitism. Recently, adventive populations of the Asian egg parasitoid, *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), were detected in the United States (Talamas et al. 2015,

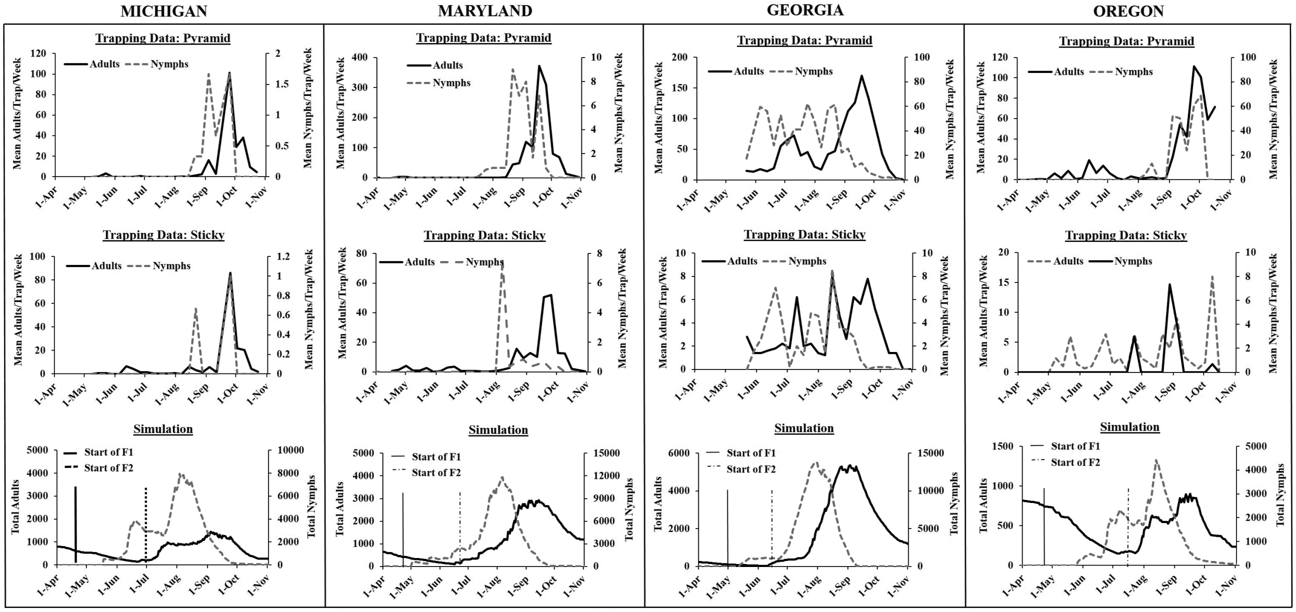

Fig. 7. Comparisons between captures of *H. halys* in pheromone-baited traps and phenological model predictions using 2017 temperature and photoperiod data, at select sites in each region. The onset of the F^1 and F^2 generations in the simulation were based on the egg stage.

Table 5. *T*-test statistics comparing the peak population periods between captures in the two trap types and phenological model simulations

State	Adults *t*	Adults *P*	Days between population peak dates (vs. phenology models)	Nymphs *t*	Nymphs *P*	Days between population peak dates (vs. phenology models)
Pyramid trap						
Michigan	2.14	0.1131	16.67	4.88	0.0099	37.67
Maryland	−0.53	0.6301	7	3.02	0.0422	31
Georgia	2.46	0.072	15.67	−0.86	0.4667	20
Oregon	0.92	0.4382	12.33	4.33	0.0444	37
Clear sticky trap						
Michigan	2.14	0.1131	16.67	1.76	0.3051	31.83
Maryland	−0.09	3.9894	1.33	1.66	0.1731	14.67
Georgia	−0.93	0.4417	18	−1.01	0.3937	19.33
Oregon	−1.97	0.1638	27.67	1.89	0.1970	27

The negative *t* values signify that population peak periods based on model predictions were later than those observed from trap captures.

Milnes et al. 2016, Hedstrom et al. 2017) and in Europe (Sabbatini et al. 2018, Stahl et al. 2019). This parasitoid has been reported to average 50–80% *H. halys* egg parasitism in its native range (Yang et al. 2009, Zhang et al. 2017), and is likely the primary natural enemy keeping *H. halys* populations below damaging levels in Asia. Following the discoveries in the United States and Europe, the use of baited traps may provide longer-term data on relative population densities in response to abiotic or biotic factors, such as *T. japonicus* presence and establishment.

With respect to pest management, captures in traps must be relatable to biological activity of the insect in order to support effective pest management decisions. Using the baited pyramid traps, a management threshold was established for *H. halys* in apple orchards that reduced insecticide applications by 40%, but with statistically identical levels of injury to blocks sprayed weekly (Short et al. 2017). A similar approach in peppers decreased insecticidal applications by 50% in one location (Bush 2018). Comparable studies in other crops vulnerable to *H. halys* injury are warranted and would need to be adapted for sticky traps. However, our results demonstrated that sticky traps baited with *H. halys* pheromone and pheromone synergist can reliably detect and monitor *H. halys* adult and nymphal populations at different population densities and geographical locations. Indeed, this simpler and less expensive trap, integrated with the pyramid trap when appropriate, may promote greater adoption by pest management specialists and growers and provide the means for long-term monitoring of *H. halys* populations, particularly as *T. japonicus* continues to spread and establish across the United States.

Supplementary Data

Supplementary data are available at *Journal of Economic Entomology* online.

Acknowledgments

We are tremendously grateful for the excellent technical assistance provided by the numerous technicians and student research assistants involved in this study. This research was supported by USDA-NIFA-SCRI 2016-51181-25409. Mention of trade names or commercial

products in this publication is solely for the purpose of providing scientific information and does not constitute recommendation or endorsement by the United States Department of Agriculture. USDA is an equal opportunity provider and employer.

References Cited

Acebes-Doria, A. L., T. C. Leskey, and J. C. Bergh. 2016a. Development and comparison of trunk traps to monitor movement of *Halyomorpha halys* nymphs on host trees. Entomol. Exp. Appl. 158: 44–53.

Acebes-Doria, A. L., T. C. Leskey, and J. C. Bergh. 2016b. Host plant effects on *Halyomorpha halys* (Hemiptera: Pentatomidae) nymphal development and survivorship. Environ. Entomol. 45: 663–670.

Acebes-Doria, A. L., T. C. Leskey, and J. C. Bergh. 2016c. Injury to apples and peaches at harvest from feeding by *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) nymphs early and late in the season. Crop Prot. 89: 58–65.

Acebes-Doria, A. L., T. C. Leskey, and J. C. Bergh. 2017. Temporal and Directional Patterns of Nymphal *Halyomorpha halys* (Hemiptera: Pentatomidae) Movement on the Trunk of Selected Wild and Fruit Tree Hosts in the Mid-Atlantic Region. Environ. Entomol. 46: 258–267.

Acebes-Doria, A., W. Morrison, B. Short, K. Rice, H. Bush, T. Kuhar, C. Duthie, and T. Leskey. 2018. Monitoring and biosurveillance tools for the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). Insects. 9: 82.

Aldrich, J. R., A. Khrimian, and M. J. Camp. 2007. Methyl 2,4,6-decatrienoates attract Stink bugs and tachinid parasitoids. J. Chem. Ecol. 33: 801–815.

Basnet, S., L. M. Maxey, C. A. Laub, T. P. Kuhar, and D. G. Pfeiffer. 2014. Stink bugs (Hemiptera: Pentatomidae) in primocane-bearing raspberries in southwestern Virginia. J. Entomol. Sci. 49: 304–312.

Bergh, J. C., W. R. Morrison III, S. V. Joseph, and T. C. Leskey. 2017. Characterizing spring emergence of adult *Halyomorpha halys* using experimental overwintering shelters and commercial pheromone traps. Entomol. Exp. Appl. 162: 336–345.

Bush, H. 2018. Using pheromone lures, insecticide netting, and a novel food-grade repellent to develop IPM strategies for the brown marmorated stink bug. MS Thesis. Virginia Tech Blacksburg, Blacksburg, VA.

Hedstrom, C., D. Lowenstein, H. Andrews, B. Bai, and N. Wiman. 2017. Pentatomid host suitability and the discovery of introduced populations of *Trissolcus japonicus* in Oregon. J. Pest Sci. 90: 1169–1179.

Joseph, S. V., J. C. Bergh, S. E. Wright, and T. C. Leskey. 2013. Factors affecting captures of brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), in baited pyramid traps. J. Entomol. Sci. 48: 43–51.

Joseph, S. V., M. Nita, T. C. Leskey, and J. C. Bergh. 2015. Temporal effects on the incidence and severity of brown marmorated stink bug (Hemiptera: Pentatomidae) feeding injury to peaches and apples during the fruiting period in Virginia. J. Econ. Entomol. 108: 592–599.

Khrimian, A., P. W. Shearer, A. Zhang, G. C. Hamilton, and J. R. Aldrich. 2008. Field trapping of the invasive brown marmorated stink bug, *Halyomorpha halys*, with geometric isomers of methyl 2,4,6-decatrienoate. J. Agric. Food Chem. 56: 197–203.

Khrimian, A., A. Zhang, D. C. Weber, H. Y. Ho, J. R. Aldrich, K. E. Vermillion, M. A. Siegler, S. Shirali, F. Guzman, and T. C. Leskey. 2014. Discovery of the aggregation pheromone of the brown marmorated stink bug (*Halyomorpha halys*) through the creation of stereoisomeric libraries of 1-bisabolen-3-ols. J. Nat. Prod. 77: 1708–1717.

Kirkpatrick, D. M., A. L. Acebes-Doria, K. B. Rice, B. D. Short, C. G. Adams, L. J. Gut, and T. C. Leskey. 2019. Estimating monitoring trap plume reach and trapping area for nymphal and adult *Halyomorpha halys* (Hemiptera: Pentatomidae) in crop and non-crop habitats. Env Ent. doi:10.1093/ee/nvz093

Kriticos, D. J., J. M. Kean, C. B. Phillips, S. D. Senay, H. Acosta, and T. Haye. 2017. The potential global distribution of the brown marmorated stink bug, *Halyomorpha halys*, a critical threat to plant biosecurity. J. Pest Sci. 90: 1033–1043.

Kuhar, T. P., B. D. Short, G. Krawczyk, and T. C. Leskey. 2017. Deltamethrin-incorporated nets as an integrated pest management tool for the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae). J. Econ. Entomol. 110: 543–545.

Lee, D. H., S. E. Wright, and T. C. Leskey. 2013. Impact of insecticide residue exposure on the invasive pest, *Halyomorpha halys* (Hemiptera: Pentatomidae): analysis of adult mobility. J. Econ. Entomol. 106: 150–158.

Lee, D.-H., A. L. Nielsen, and T. C. Leskey. 2014. Dispersal capacity and behavior of nymphal stages of *Halyomorpha halys* (Hemiptera: Pentatomidae) evaluated under laboratory and field conditions. J. Insect Behav. 27: 639–651.

Leskey, T. C., and A. L. Nielsen. 2018. Impact of the invasive brown marmorated stink bug in North America and Europe: history, biology, ecology, and management. Annu. Rev. Entomol. 63: 599–618.

Leskey, T. C., G. C. Hamilton, A. L. Nielsen, D. F. Polk, C. Rodriguez-Saona, J. C. Bergh, D. A. Herbert, T. P. Kuhar, D. Pfeiffer, G. P. Dively, *et al*. 2012a. Pest status of the brown marmorated stink bug, *Halyomorpha halys* in the USA. Outlooks Pest Manag. 23: 218–226.

Leskey, T. C., S. E. Wright, B. D. Short, and A. Khrimian. 2012b. Development of behaviorally based monitoring tools for the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae) in commercial tree fruit orchards. J. Entomol. Sci. 47: 76–85.

Leskey, T. C., A. Agnello, J. C. Bergh, G. P. Dively, G. C. Hamilton, P. Jentsch, A. Khrimian, G. Krawczyk, T. P. Kuhar, D. H. Lee, *et al*. 2015. Attraction of the Invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) to Traps Baited with Semiochemical Stimuli Across the United States. Environ. Entomol. 44: 746–756.

Martinson, H. M., P. D. Venugopal, E. J. Bergmann, P. M. Shrewsbury, and M. J. Raupp. 2015. Fruit availability influences the seasonal abundance of invasive stink bugs in ornamental tree nurseries. J. Pest Sci. 88: 461–468.

Milnes, J. M., N. G. Wiman, E. J. Talamas, J. F. Brunner, K. A. Hoelmer, M. L. Buffington, and E. H. Beers. 2016. Discovery of an exotic egg parasitoid of the brown marmorated stink bug, *Halyomorpha halys* (Stål) in the Pacific Northwest. Proc. Entomol. Soc. Washington. 118: 466–470.

Morrison, W. R., III, J. P. Cullum, and T. C. Leskey. 2015. Evaluation of Trap Designs and Deployment Strategies for Capturing *Halyomorpha halys* (Hemiptera: Pentatomidae). J. Econ. Entomol. 108: 1683–1692.

Nielsen, A. L., and G. C. Hamilton. 2009. Seasonal occurrence and impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) in tree fruit. J. Econ. Entomol. 102: 1133–1140.

Nielsen, A. L., G. C. Hamilton, and D. Matadha. 2008. Developmental rate estimation and life table analysis for *Halyomorpha halys* (Hemiptera: Pentatomidae). Environ. Entomol. 37: 348–355.

Nielsen, A. L., G. C. Hamilton, and P. W. Shearer. 2011. Seasonal phenology and monitoring of the non-native *Halyomorpha halys* (Hemiptera: Pentatomidae) in soybean. Environ. Entomol. 40: 231–238.

Nielsen, A. L., K. Holmstrom, G. C. Hamilton, J. Cambridge, and J. Ingerson-Mahar. 2013. Use of black light traps to monitor the abundance, spread, and flight behavior of *Halyomorpha halys* (Hemiptera: Pentatomidae). J. Econ. Entomol. 106: 1495–1502.

Nielsen, A. L., S. Chen, and S. J. Fleischer. 2016. Coupling Developmental Physiology, Photoperiod, and Temperature to Model Phenology and Dynamics of an Invasive Heteropteran, *Halyomorpha halys*. Front. Physiol. 7: 165.

Nielsen, A. L., S. Chen, and S. J. Fleischer. 2017. Corrigendum to Nielsen *et al*. 2016 published in 2017. Front. Physiol. 8: 568.

Quinn, N. F., E. J. Talamas, A. L. Acebes-Doria, T. C. Leskey, and J. C. Bergh. 2018. Vertical sampling in tree canopies for *Halyomorpha halys* (Hemiptera: Pentatomidae) life stages and its egg parasitoid, *Trissolcus japonicus* (Hymenoptera: Scelionidae). Environ. Entomol. 48: 173–180.

Rice, K. B., C. J. Bergh, E. J. Bergmann, D. J. Biddinger, C. Dieckhoff, G. Dively, H. Fraser, T. Gariepy, G. Hamilton, T. Haye, *et al*. 2014. Biology, ecology, and management of brown marmorated stink bug (Hemiptera: Pentatomidae). J. Integr. Pest Manag. 5: A1–A13.

Rice, K. B., R. H. Bedoukian, G. C. Hamilton, P. Jentsch, A. Khrimian, P. MacLean, W. R. Morrison, III, B. D. Short, P. Shrewsbury, D. C. Weber, *et al*. 2017. Enhanced response of *Halyomorpha halys* (Hemiptera: Pentatomidae) to its aggregation pheromone with ethyl decatrienoate. J. Econ. Entomol. 111: 495–499.

Rice, K. B., W. R. Morrison, III, B. D. Short, A. Acebes-Doria, J. C. Bergh, and T. C. Leskey. 2018. Improved trap designs and retention mechanisms for *Halyomorpha halys* (Hemiptera: Pentatomidae). J. Econ. Entomol. 111: 2136–2142.

Sabbatini Peverieri, G., E. Talamas, M. C. Bon, L. Marianelli, I. Bernardinelli, G. Malossini, L. Benvenuto, P. F. Roversi, and K. Hoelmer. 2018. Two Asian egg parasitoids of *Halyomorpha halys* (Stål) (Hemiptera, Pentatomidae) emerge in northern Italy: *Trissolcus mitsukurii* (Ashmead) and *Trissolcus japonicus* (Ashmead) (Hymenoptera, Scelionidae). J. Hymen. Res. 37: 57–63.

Short, B. D., A. Khrimian, and T. C. Leskey. 2017. Pheromone-based decision support tools for management of *Halyomorpha halys* in apple orchards: development of a trap-based treatment threshold. J. Pest Sci. 90: 1191–1204.

Stahl, J., F. Tortorici, M. Pontini, M.-C. Bon, K. Hoelmer, C. Marazzi, L. Tavella, and T. Haye. 2019. First discovery of adventive populations of *Trissolcus japonicus* in Europe. J. Pest Sci. 92: 371–379.

Talamas, E. J., M. V. Herlihy, C. Dieckhoff, K. A. Hoelmer, M. L. Buffington, M.-C. Bon, and D. C. Weber. 2015. *Trissolcus japonicus* (Ashmead) (Hymenoptera, Scelionidae) emerges in North America. J. Hymenopt. Res. 43: 119–128.

Valentin, R. E., A. L. Nielsen, N. G. Wiman, D. H. Lee, and D. M. Fonseca. 2017. Global invasion network of the brown marmorated stink bug, *Halyomorpha halys*. Sci. Rep. 7: 9866.

Venugopal, P. D., G. P. Dively, and W. O. Lamp. 2015. Spatiotemporal Dynamics of the Invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) in and Between Adjacent Corn and Soybean Fields. J. Econ. Entomol. 108: 2231–2241.

Weber, D. C., T. C. Leskey, G. C. Walsh, and A. Khrimian. 2014. Synergy of aggregation pheromone with methyl (E,E,Z) -2,4,6-decatrienoate in attraction of *Halyomorpha halys* (Hemiptera: Pentatomidae). J. Econ. Entomol. 107: 1061–1068.

Wiman, N. G., J. E. Parker, C. Rodriguez-Saona, and V. M. Walton. 2015. Characterizing Damage of Brown Marmorated Stink Bug (Hemiptera: Pentatomidae) in Blueberries. J. Econ. Entomol. 108: 1156–1163.

Wiman, N. G., V. M. Walton, P. W. Shearer, S. I. Rondon, and J. C. Lee. 2014. Factors affecting flight capacity of brown marmorated stink bug, Halyomorpha halys (Hemiptera: Pentatomidae). J. Pest Sci. 88: 37–47.

Yang, Z.-Q., Y.-X. Yao, L.-F. Qiu, and Z.-X. Li. 2009. A new species of *Trissolcus* (Hymenoptera: Scelionidae) parasitizing eggs of *Halyomorpha halys* (Heteroptera: Pentatomidae) in China with comments on its biology. Ann. Entomol. Soc. Am. 102: 39–47.

Zhang, J., F. Zhang, T. Gariepy, P. Mason, D. Gillespie, E. Talamas, and T. Haye. 2017. Seasonal parasitism and host specificity of *Trissolcus japonicus* in northern China. J. Pest Sci. (2004). 90: 1127–1141.

Zhu, G., W. Bu, Y. Gao, and G. Liu. 2012. Potential geographic distribution of brown marmorated stink bug invasion (*Halyomorpha halys*). Plos One. 7: e31246.

Zobel, E., C. Hooks, and G. Dively. 2016. Seasonal abundance, host suitability, and feeding injury of the brown marmorated stink bug, *Halyomorpha halys* (Heteroptera: Penatomidae), in selected vegetables. J. Econ. Entomol. 109: 1289–1302.