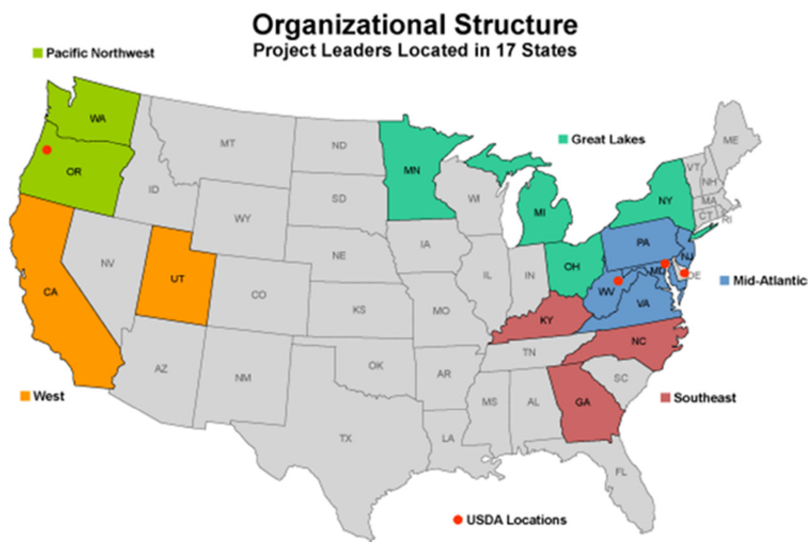
Management of Brown Marmorated Stink Bug in US Specialty Crops

2018

ANNUAL REPORT



The information contained in this report is based upon work that was supported by the USDA National Institute of Food and Agriculture, Specialty Crops Research Initiative under award number 2016-51181-25409.

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BMSB SCRI Stakeholder Advisory Panel Meeting
February 19, 2019, Hyatt Place, Columbus, Ohio

Time	Lead Presenter	Title
8:00 – 8:30	Arrival – coffee, drinks, snacks	
8:30 – 8:45	Jim Walgenbach	Introductions and purpose
Distribution and Pest Status		
8:45 – 9:45	Mike Toews	Southeastern Region
	Larry Gut	Great Lakes Region
	Tom Kuhar	Mid-Atlantic Region
	Betsy Beers	Pacific Northwest Region
	Kent Daane	Western Region
Landscape Ecology		
9:45 – 10:15	Dave Crowder/Javier Illan	Landscape modeling: Abundance, landscape suitability and abiotic factors
10:15 – 10:30	BREAK	
10:30 – 10:45	Frank Zalom/Joanna Fisher	Temperature and humidity effects
10:45 – 11:00	Anne Nielsen	Photoperiod effects on diapause
11:00 – 11:15	Diane Alston	Phenology in Utah
11:15 – 11:30	--	Discussion and preplanning for 2019
Outreach		
11:30 – 11:45	Deb Grantham	Update and plans for StopBMSB.org and evaluations
Economics		
11:45 – 12:00	Jay Harper	Update on and plans for economic survey
12:00 – 1:00	CATERED LUNCH	
Biological Control		
1:00 – 1:20	Kim Hoelmer	*Trissolcus japonicus*: host range, adventive populations, status of petition to release, interstate transport
1:20 – 1:35	Chris Bergh	*T. japonicus* redistribution efforts in the eastern US
1:35 – 1:50	Betsy Beers	*T. japonicus* redistribution efforts in the western US
1:50 – 2:05	Paula Shrewsbury	Native natural enemies: Regional and habitat variation
2:05 – 2:20	Ann Hajek/Art Agnello	Impact of *Nosema maddoxi* on BMSB populations
2:20 – 2:30	–	Discussion and preplanning for 2019
Management Strategies		
2:30 – 2:45	Tom Kuhar	BMSB response to insecticides
2:45 – 3:00	Celeste Welty	Relationship between pheromone traps and damage
3:00 – 3:15	Tracy Leskey	Active space of pheromone traps
3:15 – 3:30	Larry Gut	Attract and kill
3:30 – 3:45	BREAK	
3:45 – 4:00	Jana Lee	Improving habitats for natural enemy populations
4:00 – 4:15	Tracy Leskey	Mid-Atlantic Areawide Program
Discussion and Wrap-up		
4:15 – 4:45	Jim Walgenbach	Discussion and wrap-up

Project Goal and Objectives

The overall goal of this project is to develop environmentally and economically sustainable management programs for the brown marmorated stink bug (BMSB) that focus on biological control and management strategies that are informed by landscape level risk and compatible with biological control. To achieve this goal, the following specific objectives have been set:

(1) Predict risk from BMSB damage through enhanced understanding of agroecology and landscape ecology.

1a. Predict risk from BMSB damage through enhanced understanding of agroecology and landscape ecology.

1b. Assess suitability of landscapes for BMSB based on host distribution.

1c. Integrate landscape-level habitat maps and data on abiotic factors to predict BMSB distribution and risk.

(2) Implement widespread biological control of BMSB, incorporating exotic Asian parasitoids and native natural enemies.

2a. Asian parasitoids
- i. Determine distribution/range of adventive *T. japonicus* in US.
- ii. Complete host range evaluations and petition for field release of quarantine T. japonicus.
- iii. Determine habitat preferences and role of kairomones in host location
- iv. Measure impact on BMSB populations and non-targets

2b. Native parasitoids
- i. Document regional differences in key species of native parasitoids and impacts on BMSB and native stink bugs
- ii. Assess potential adaptation of native parasitoids to BMSB

2c. Document regional and habitat differences in native predators impacts on BMSB populations.

2d. Identify entomopathogens of BMSB that contribute to BMSB population regulation.

(3) Develop management tools and strategies that are compatible with biological control and informed by risk from landscape factors.

3a. Develop decision support tools to assess BMSB abundance and to mitigate damage.
- i. Optimize trap design for monitoring and surveillance.
- ii. Determine the relationship between captures in traps and crop injury.

3b. Identify effective uses of insecticides that minimize impacts on natural enemies.
- i. Evaluate new insecticides and threat of resistance
- ii. Impact of insecticides on natural enemies.

3c. Improve agroecosystem sustainability through spatially focused management or habitat manipulation.
- i. Impact of behaviorally-based management on BMSB and natural enemies.

ii. Refine and expand trap crop utilization within the agroecosystem.
iii. Conserve beneficial insects to enhance biological control of BMSB.

3d. Integrate IPM tools across landscape factors.

(4) Managing the Economic Consequences of BMSB Damage.

4a. Assess economic potential of biological control of BMSB on specialty crops.

4b. Develop estimates of the cost and benefits of specific management practices for BMSB.

4c. Assist with the development of program evaluation tools including survey instruments.

(5) Outreach Plan – Deliver new information on BMSB to stakeholders.

5a. Inspire the next generation of invasive pest experts.

5b. Build upon existing BMSB outreach resources, develop and maintain a knowledge repository that captures lessons, insights, and success stories over time.

5c. Expand relevancy of BMSB outreach resources to all U.S. regions.

5d. Evaluate social benefits of improved conditions resulting from increased awareness and knowledge of sustainable practices and their adoption.

Project Participants[1]

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Objective 1: Predict risk from BMSB damage through enhanced understanding of agroecology and landscape ecology.

Project: National monitoring of BMSB in specialty and alternative hosts across the USA

Background: The main goal of Objective 1 is to develop species distribution models that are able to describe the ecological niche, and invasive spread, of BMSB. Models are aimed to predict where this insect species will become established and also to what extent it will develop into a key pest of specialty crops.

Two key factors anticipated to mediate establishment, as well as variation in population dynamics within established regions, are climate and host plant availability. Host plants include not only specialty crops, but alternative crops (e.g., soybean, corn, cotton) and non-managed or natural habitats (e.g., wooded areas, ditch banks). The first step in developing ecological models to predict BMSB abundance and phenology is to understand its current distribution and environmental and plant fauna associated with population fluctuation across the various ecoregions where BMSB is predicted to be problematic (Fig. 1).

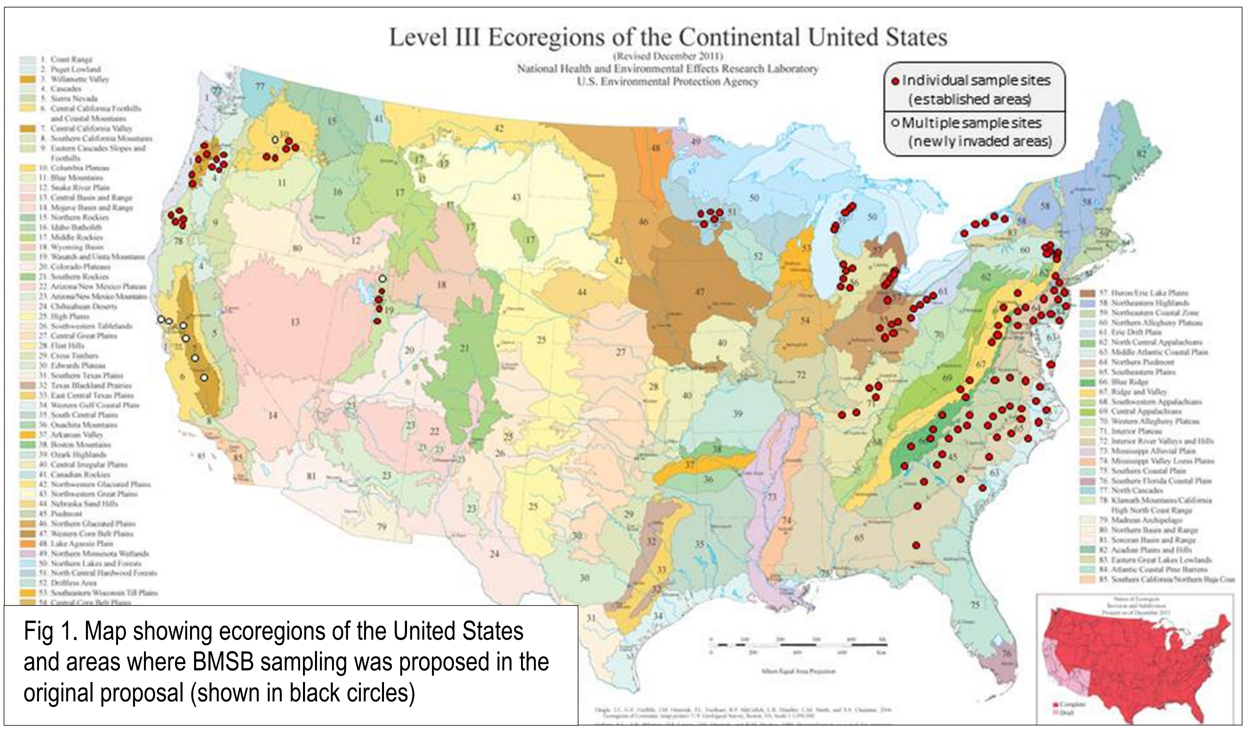


Fig 1. Map showing ecoregions of the United States and areas where BMSB sampling was proposed in the original proposal (shown in black circles)

What was Done: Since 2017 a nationwide network of sticky card traps was established to monitor BMSB abundance and phenology on a regional basis, and to detect expansion of BMSB into new areas. A summary of the trap collection network during these first two years is shown in Fig. 2 below. During 2018, a total of 221* trapping sites were monitored across 15 states and over 25 ecoregions, with a total of 26 PIs participating in the objective. Typically, a trapping site consisted of a unique location with 3 sticky panel traps baited with BMSB pheromone and synergist (MDT) deployed at the interface of wooded habitats and host crops. Each of the nearly 800 traps was monitored from early spring into the fall.

Results: As a continuation of the 2017 sampling, during 2018 we have been highly successful in maintaining the standardized nationwide monitoring effort for BMSB. Our sampling network encompasses both regions where BMSB is already well established (eastern and northeastern US states) as well as regions where BMSB is not yet established but has high potential for invasion (west coast, upper Midwest). Populations on the west coast and in Utah are particularly important since these regions are reported to be actively invaded in recent years.

We will continue the sampling network in the coming years, which will provide a comprehensive dataset showing variation in BMSB abundance across many locations and time points. These data will be incorporated into geographical information systems software to explore ecological and environmental factors affecting BMSB population dynamics and invasion risk. We expect to make progress on these analyses in 2018, but will complete them when all data is collected. Data from 2017/18 shows a high degree of variation in the abundance of BMSB throughout the USA (Fig. 2).

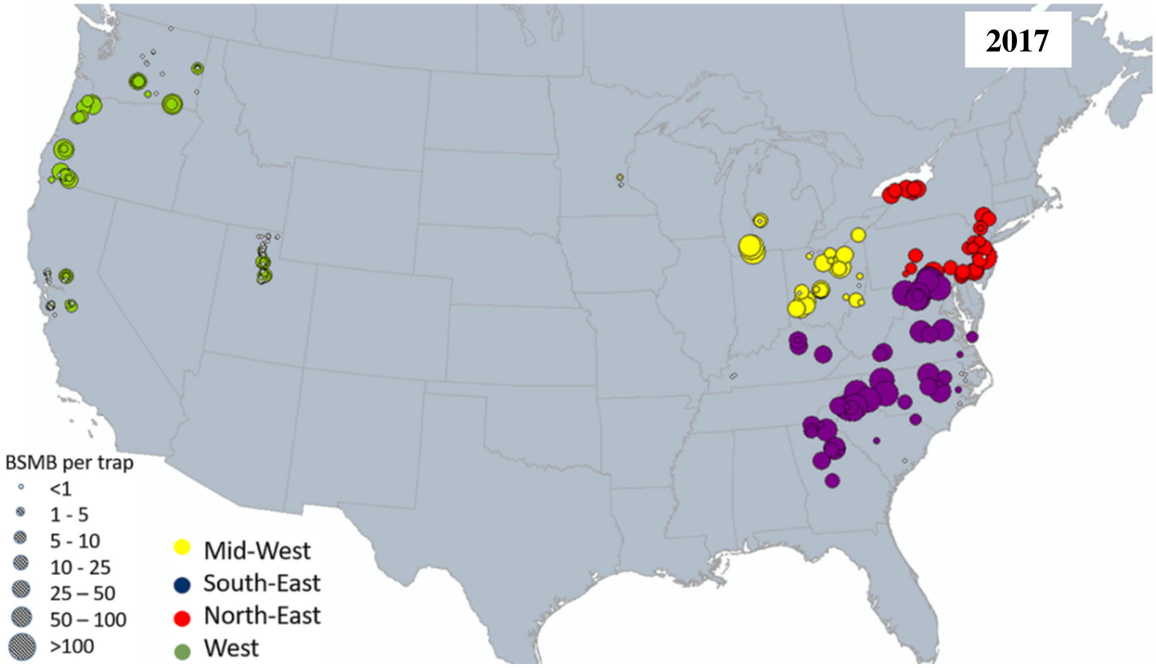
Based on these 2 years of data, during 2019 we will run models that will begin to effectively characterize the ecological niche of BMSB, and will detect the most important factors driving both the establishment and the population dynamics of this pest. We anticipate that the risk of invasion to new regions will be assessed with presence-only models (e.g. MAXENT), whereas the status of already established populations will be analyzed with predictive models based on abundance (e.g. Boosted Regression Models).

Monitoring results summary:

	2017	**2018***
States	15	15
Research groups	26	26
Sampling sites	276	221
BMSB individuals trapped	24476	14605
BMSB/trap by region (#sites):		
MidWest	25.6 (37)	28.4 (39)
NorthEast	56.5 ** (29)	31.9 (26)
SouthEast	60.9 (65)	61.9 (37)
West	10.2 (145)	18.4 ** (164)
Mean tp (ºC)	11.57 (5.07 - 18.26)	*(under development)*
Minimum tp (ºC)	5.26 (-2.88 – 12.03)	
Maximum tp (ºC)	17.87 (12.79 – 24.48)	
Precipitation (mm)	705.50 (190.67 – 1841.45)	
Elevational range (m)	541.63 (3-1845)	
Land-use (within 5K buffer)	15 land-use classes (+82 crop types)	

** Note: Waiting for WA, CA (Sac) and GA*
*** Statistically significant*

Monitoring results by region:



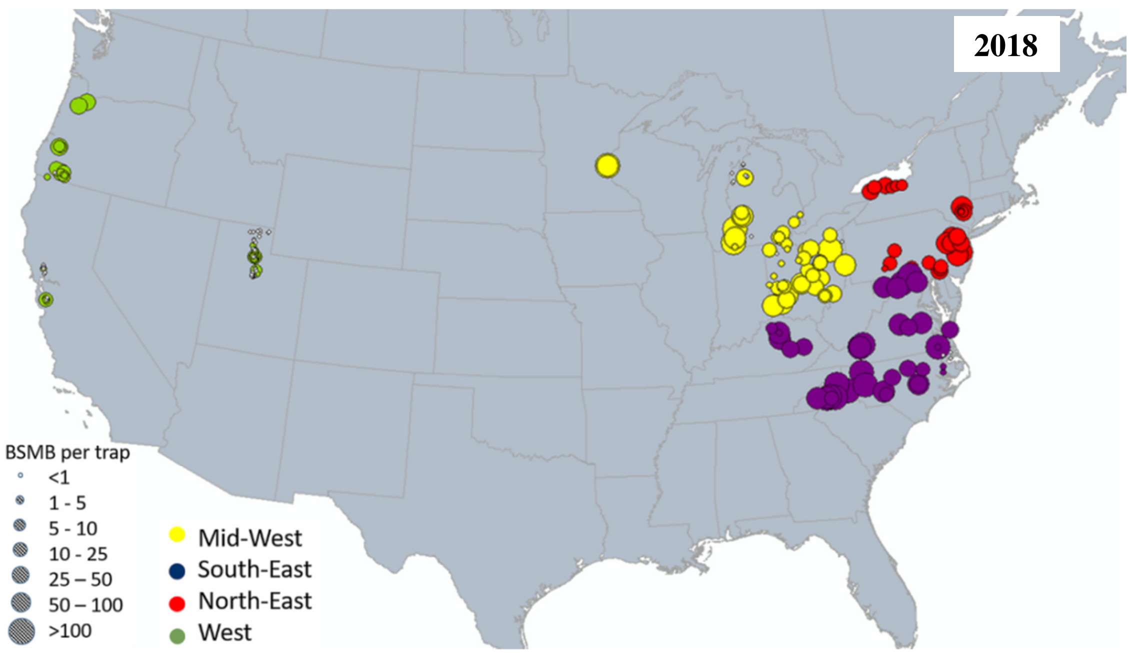


Fig 2. Graphical depiction of the BMSB trap catches from 2017 and 2018. Different colors represent different sampling regions, and size of the circle is proportional to the number of BMSB captured at each sampling location. As can be seen, populations were highest in the eastern states, and generally diminished further inland. During 2018, on average we have observed a decrease in BMSB per trap in the NorthEast, and an increase in the West, whereas populations in the SouthEast and MidWest have maintained similar numbers.

Objective 1: Predict risk from BMSB damage through enhanced understanding of agroecology and landscape ecology.

Project: Phenology and voltinism of BMSB in Utah

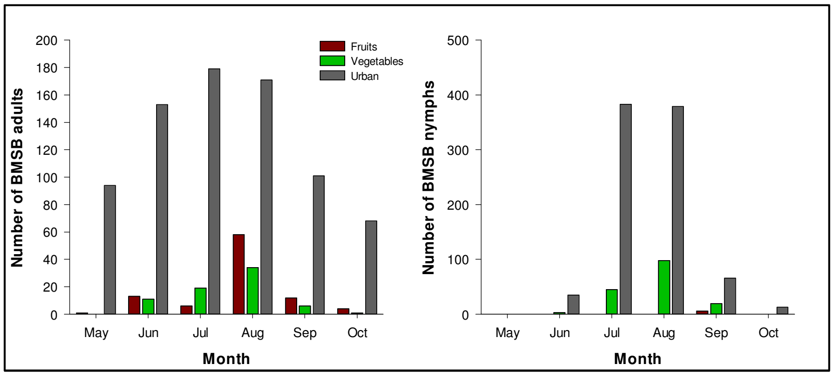
Background: Brown marmorated stink bug (*Halyomopha halys* Stål) was first detected in Utah in 2012 on the exterior of buildings at the University of Utah near downtown Salt Lake City. Subsequent surveys found BMSB on homes in nearby neighborhoods. BMSB is now established (reproducing populations) in six counties; detected in two others. A recent finding of BMSB in Kane County was the first detection in southern Utah; all others have been in the north. The Intermountain West is a novel location for BMSB. The majority of its arable lands are above 4,000 ft elevation, and conditions are arid, 15-20 inches of precipitation annually. Crops are irrigated; water comes from snowmelt and aquifers. Utah has strong agrarian traditions with most farms family-owned and operated. The arable land is adjacent to urban areas, squeezed between the western reach of the Rocky Mountains and the Great Basin (Great Salt Lake). The first damage to agricultural crops was observed in 2017: peach, apple, popcorn, squash, basil and borage. Tree fruits are economically important crops in Utah, especially tart cherry. No information is available on the potential impact of BMSB to tart cherry.

What was done: To determine the phenology and voltinism of BMSB in northern Utah, we 1) monitored populations with traps in suburban and agricultural sites, 2) surveyed host plant utilization and BMSB phenology, and 3) established caged colonies on catalpa and tart cherry trees to assess development and voltinism during the season.

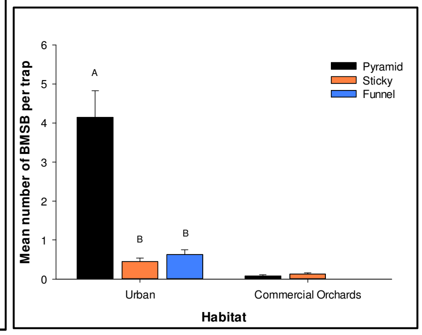
BMSB voltinism study cages on tart cherry.

BMSB feeding damage on borage, corn, peach, apple, squash, and basil (clockwise from upper left).

Results: BMSB was monitored from May through October in 2017 and 2018 in commercial fruits and vegetables (30 sites each year), and urban-suburban landscapes (15 sites each year) in northern Utah. We used three types of traps baited with the Trécé dual lure [AgBio 4 ft Dead-Inn pyramid (not in vegetable sites), Trécé clear dual panel adhesive (sticky), and Trécé dual funnel (urban-suburban sites only)]. In 2017, peak capture was during July in urban sites and during August in orchard and vegetable sites. In ornamental landscapes, the majority of adults and nymphs were caught in pyramid traps; however, in orchards, the majority of adults were caught on sticky traps, and few nymphs were observed. Peak capture in 2018 was similar, except later in agricultural sites (September) and population size was substantially lower, perhaps due to extended hot and dry conditions during summer. In ornamental landscapes and agricultural sites, the majority of adults and nymphs were caught in pyramid traps (differed from 2017 for agricultural sites).

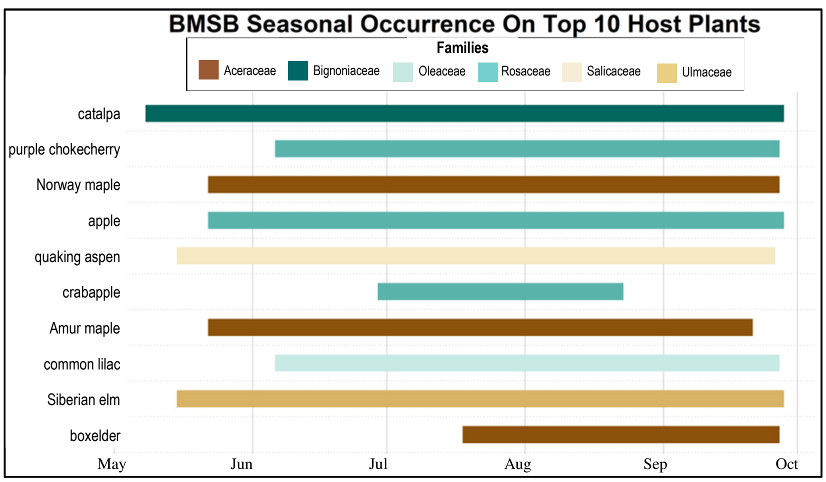


Comparison of BMSB populations among urban, fruit and vegetable sites in 2017. (adults on left, nymphs on right).



Trap efficiency in urban and orchard sites.

Host plant transects in urban-suburban landscapes (including community gardens) near and adjacent to agricultural areas revealed 63 plant species from 24 families with Aceraceae, Bignoniaceae, Fabaceae, and Rosaceae as the most common families, and quaking aspen (Salicaceae) as a novel host. The Utah host plant list is available at https://utahpests.usu.edu/caps/bmsb-host-plants. BMSB adults were found during the entire survey period in each 2017 and 2018 (May to October) with a peak in July; nymphs were detected from June through October, also peaking in July.



Most common host plants for BMSB in Utah.

BMSB were caged on tart cherry to assess bud and fruit injury.

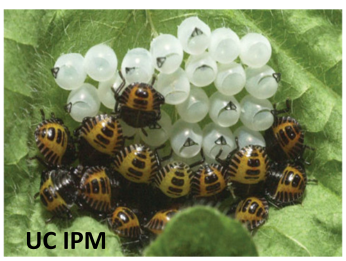
To assess BMSB voltinism in Utah, wild caught spring emerged BMSB adults (F0 Generation) were placed in mesh bags on tart cherry and catalpa trees in early June and their subsequent progeny (F1, F2) monitored once a week until mid-October. The 40 F0 adults placed on tart cherry produced 96 egg masses that resulted in 59 surviving F1 adults by October 8. The F1 adults produced four egg masses from which one nymph survived and reached the third-instar by October 1. On catalpa, the 30 F0 adults produced 84 egg masses resulting in 38 surviving F1 adults by October 8. F1 adults did not successfully oviposit on catalpa. These results are congruent with the current understanding that BMSB is predominantly univoltine (single generation) in the Intermountain West.

Objective 1: Predict risk from BMSB damage through enhanced understanding of agroecology and landscape ecology.

Project: Understanding the role of temperature and humidity on BMSB populations

Background: The brown marmorated stink bug, *Halyomorpha halys*, was first found in CA in 2002, and in Sacramento CA, in 2013. In CA, BMSB has been predominately an urban nuisance pest but recently the insect has moved into orchards in Modesto County and has the potential to establish in agricultural areas throughout California. In 2016, the BMSB population in Sacramento was the largest it had been since trapping began in 2014 (Ingles and Daane, 2018 J. Econ. Entomol). In July and August of 2016, there was a heat wave and temperatures were hotter and drier than normal. Following the heat wave, BMSB trap counts plummeted to near zero. Since 2016, the BMSB population in Sacramento has remained low although BMSB has continued to expand its range in CA.

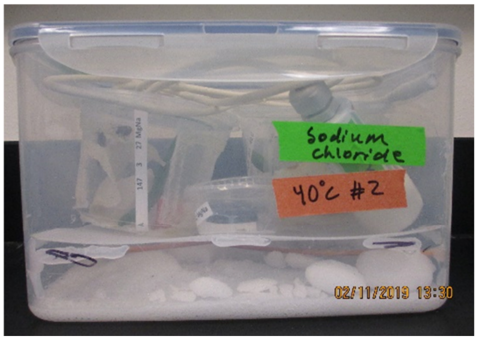
BMSB on tree in Sacramento in 2015 prior to heat wave. (C. Ingles)



Following these observations, we wanted to know if the observed declines in the BMSB population were due to high temperatures and low humidity. We examined the effects of high temperature on BMSB eggs and adults in the field in CA. We also conducted temperature cabinet studies to examine the effects of high temperature and low humidity on BMSB adults, nymphs and eggs. The results of our study will improve our understanding of BMSB's potential to spread and establish in CA and other areas with high temperature events. Additionally, our findings could be used to improve climatic models that predict BMSB spread and establishment.

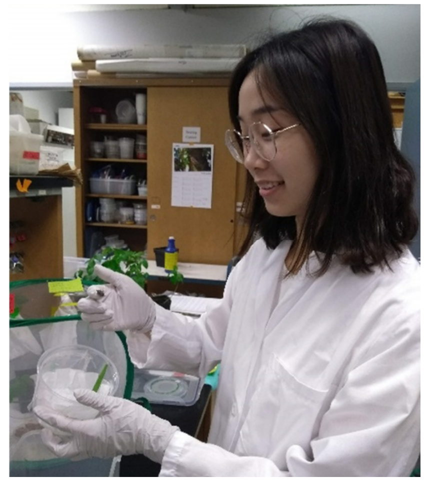
What was done: BMSB egg masses were placed in the field to determine the effects of high temperature on egg viability and development. Over 350 egg masses were placed in the field from July-September 2017. In 2018, adult BMSB were caged weekly in the field from March until August to determine the effects of high temperature on BMSB survival. A temperature cabinet lab study was also conducted to better understand the effect of temperature vs. humidity on BMSB survival and development. Adults, nymphs and eggs were exposed to one of three temperature treatments (27, 39 or 42 °C) for 4hr/day for 2 days and one of four humidity treatments (19,38,54 or 73% RH) after which, they were monitored for survival.

Mesh field cage on tree

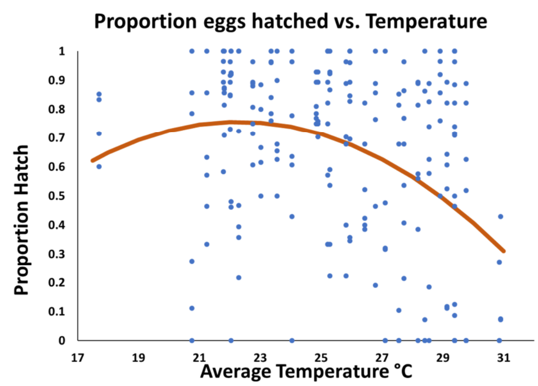


Humidity box with saturated salt solution used for temp cabinet study

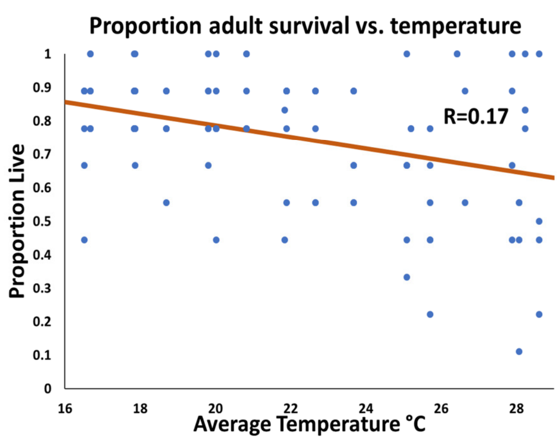
UC Davis student Jiajun Lin working with BMSB in the lab



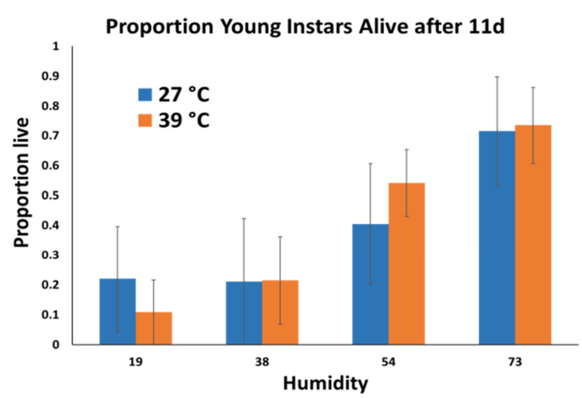
Results: We found that high temperature and low humidity seem to be factors in the observed decline of BMSB populations in CA following high temperature events. Higher temperatures and lower humidity decreased the proportion of eggs that hatched and increased adult mortality in the field. Through our temperature cabinet studies, we found that the impact of temperature on BMSB mortality depended on the relative humidity. We also found that first instars and adult BMSB are more susceptible to high temperatures than older nymphs. Our results suggest that high temperature events can lead to decreases in BMSB populations. The impact of high temperature events on BMSB populations will depend on the relative humidity and what insect life stages are exposed.



Proportion of eggs that hatched after 2 days of exposure to high field temperatures vs. temperature



Proportion of adult BMSB that survived 1 week in the field vs. temperature



Temperature cabinet study: Proportion instars alive 11 days after 2-day exposure to different temperature and humidity treatments

Objective 2. Implement widespread biological control of BMSB, incorporating exotic Asian parasitoids and native natural enemies.

Project: Overview of efforts to establish *Trissolcus japonicus* in the invaded range of BMSB

Background: *Trissolcus japonicus*, commonly referred to as the samurai wasp, is an exotic parasitic wasp that is a key natural enemy of BMSB in its native Asian range. *T. japonicus* deposits its own eggs into the eggs of BMSB, which its progeny then consume and after several weeks emerge as adults. In its native Asian range, *T. japonicus* typically parasitizes a high proportion of BMSB eggs and helps maintain BMSB populations at low levels. This parasitoid was chosen as a candidate for a classical biological control program of BMSB in the US, and has undergone risk analysis studies in quarantine laboratories at the USDA biological control laboratory in Newark, DE, and cooperating labs in Oregon, Michigan, Florida and California. These tests are now largely complete and a petition to release *T. japonicus* in the US is in preparation for submission to USDA-APHIS. A companion petition for its release in Canada was submitted in August 2018 and is in review.

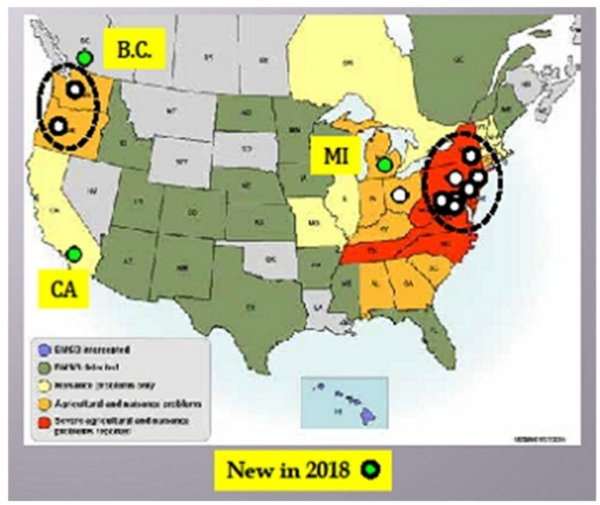
During a 2014 study of native natural enemies attacking BMSB, *T. japonicus* was unexpectedly found in Maryland, and subsequently has also been detected in additional states. Genetic tests conducted by USDA showed that these “adventive” populations were clearly different from those imported from Asia into U.S. quarantine culture for risk evaluations and were not accidental escapees. We do not know how these adventive populations arrived in the US, but their spread and impact on BMSB and native natural enemies is being actively monitored. During 2018, adventive populations of *T. japonicus* and a related Asian species, *T. mitsukurii*, were also detected attacking BMSB in Europe.

What was done: Surveys were continued across the US and Canada to detect new adventive populations of *T. japonicus* and monitor its spread. Survey methods included placing lab-reared sentinel egg masses on BMSB host plants, collection of wild egg masses from managed and non-managed habitats, and yellow sticky cards. Organized efforts to redistribute the adventive populations and enhance their rapid establishment are underway in several states (e.g., New York, Virginia, West Virginia, Delaware, Maryland, Oregon and Washington) by mass-rearing parasitoids in the laboratory and releasing them in different areas of these states. These efforts will be started in other states once local researchers resources will allow. Researchers have also conducted field releases of *T. japonicus* for specific experiments, such as to examine their ability to move between crops and unmanaged habitats.

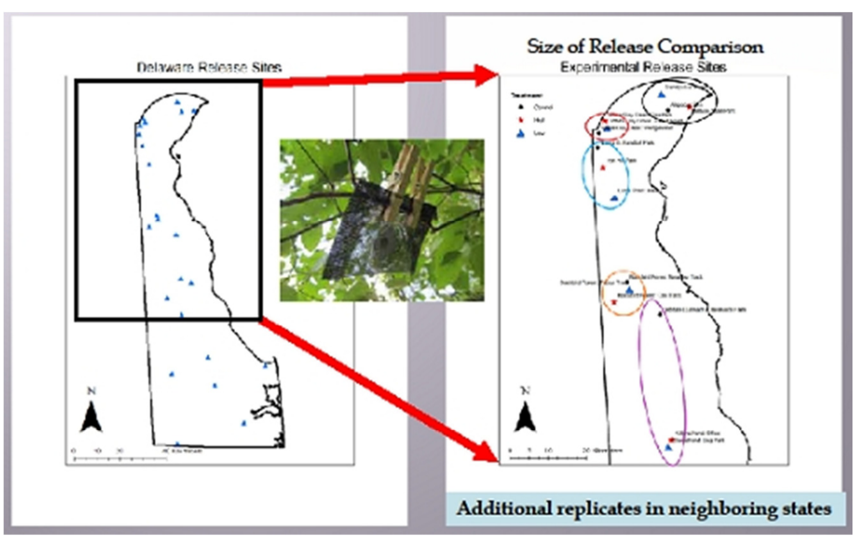
Results: *Trissolcus japonicus* has now been found in a total of twelve states (VA, WV, MD, DE, NJ, NY, PA, OH, MI, OR, WA, and CA), the District of Columbia, and British Columbia (MI, CA and B.C. were the new additions to this list in 2018). Although the newest finds have not yet been characterized by molecular assays, we know that at least three different populations of adventive *T. japonicus* are now present in North America; presumably each arrived independently in separate introductions from Asia. In most areas of discovery the local population of *T. japonicus* is still too low to evaluate their impact on BMSB, but in some areas (such as northwestern VA) where it has been present for several years it is now found increasingly often parasitizing BMSB eggs. Within-season recoveries of *T. japonicus* have been made at some of the sites where releases of lab-reared parasitoids were made in 2018, and recovery surveys will be continued at release sites in 2019. Although most of the recoveries were from unmanaged host plant habitats, detection of *T. japonicus* from sentinel and wild egg masses have also been made in commercial fruit orchards (e.g., peach in the US, apple in Switzerland, peach and various other fruits in Asia), indicating that the parasitoid is able to follow BMSB between managed and unmanaged habitats.

Laboratory studies in Delaware previously demonstrated that *T. japonicus* has a clear preference for BMSB eggs compared with *Podisus maculiventris* (spined soldier bug, SSB), an agriculturally important predatory stink bug. Searching wasps responded to the presence of female BMSB and SSB kairomones on leaf surfaces by searching longer and more intensively for BMSB. BMSB egg masses were discovered and attacked at higher rates, with more progeny produced. Further studies have shown that male and nymphal BMSB kairomones also induce increased searching behavior. Analysis of the kairomone traces have identified two major chemical components, (E)-2-decenal and tridecane, that are being tested to see the behaviors they induce. In the field, studies in Washington using sentinel egg masses of BMSB and three species of native US stink bugs showed that established field populations of *T. japonicus* attack BMSB at significantly higher rates than the native species.

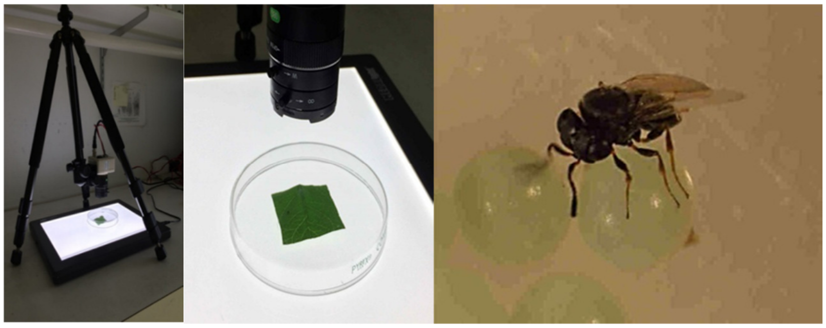
Trissolcus japonicus female emerging from a BMSB egg (credit A. Salzberg/ USDA-ARS)



Current distribution of adventive *Trissolcus japonicus* in North America (field recoveries as of fall 2018)



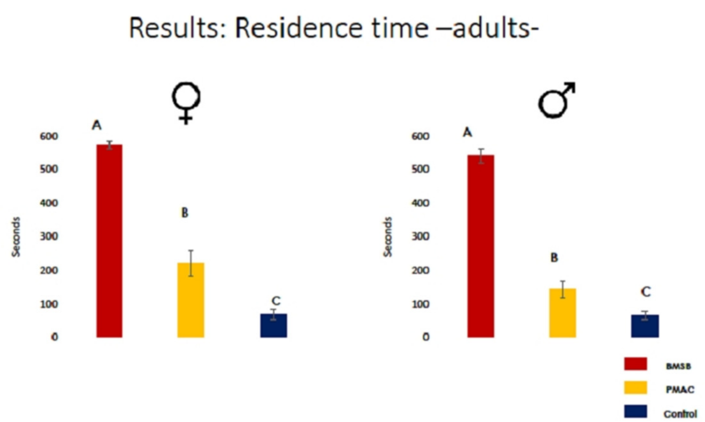
Field releases in participating states (DE shown as an example) were conducted within an experiment to measure establishment success as a function of the numbers of parasitoids released at a site.

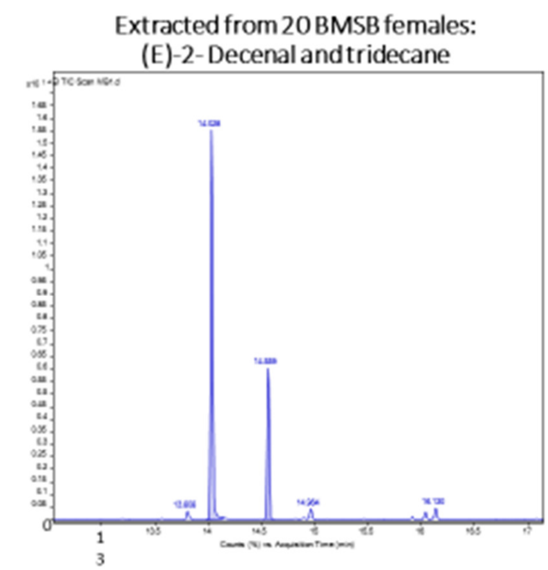


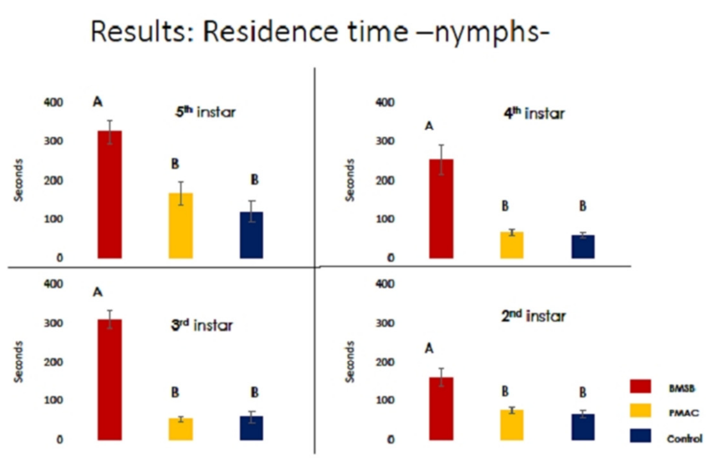
A videocamera with image analysis software is used to record the behavioral response of female *Trissolcus japonicus* to chemical traces deposited by BMSB and native stink bug species by walking on leaf surfaces.

When female wasps detect BMSB kairomones they spend more time in searching than when detecting an alternate host, the spined soldier bug. Wasps respond similarly to kairomones of both female and male BMSB, and to a lesser degree, also to nymphal BMSB.

After extraction of the kairomone traces, parasitoids are exposed to isolated, identified compounds and their behavioral response recorded. These behaviors can be related to host acceptance and attack, and to their potential impact on non-target stink bug species. Two compounds, (E)-2-decenal and tridecane, are the major components of the BMSB kairomone.







Objective 2. Implement widespread biological control of BMSB, incorporating exotic Asian parasitoids and native natural enemies.

Project: Efforts to redistribute *Trissolcus japonicus* in the eastern USA

Background: Following the initial detection of an adventive population of *Trissolcus japonicus* (Hymenoptera: Scelionidae) in Maryland in 2014, populations of this important Asian egg parasitoid of BMSB have been detected in several eastern and western States. In the east, concerted efforts to expand the geographic distribution of *T. japonicus* have occurred in New York, Virginia, and Ohio. In these states, respectively, *T. japonicus* was first detected in 2016, 2015, and 2017, and the State Department of Agriculture in each approved the redistribution of wasps cultured from specimens recovered from sentinel BMSB egg masses in each state. Programs to promote the wider distribution of *T. japonicus* in the eastern US were first initiated in New York, followed by Virginia and Ohio.

What was Done: In New York, *T. japonicus* sampling using sentinel BMSB eggs at 9 sites in summer 2017 yielded wasps only at the original detection site from 2016. From mid-September through early October, 2017, two or three BMSB egg masses parasitized by *T. japonicus* were deployed at each of 32 locations on 25 fruit farms in western NY and the Hudson Valley (majority of sites), including the 9 sites where pre-release sampling had been conducted. All egg masses had been frozen at -80^{o}C for between a few days and a few months prior to being exposed to *T. japonicus*. Parasitized egg masses were sent to citizen scientist volunteers and also deployed by Cornell University personnel. Citizen scientists received eggs attached to the bottom of a Petri dish (Fig. 1) and these were suspended from twigs of BMSB host trees, while Cornell staff deployed eggs by stapling the leaf piece to which they were attached to the of foliage on trees (Fig. 2).


Fig. 1


Fig. 2

In Virginia, sampling *T. japonicus* in Frederick Co. (northwest VA) via yellow sticky traps deployed in mid-canopy of host trees (Fig. 3) yielded an increasing frequency of detections between 2016 and 2017. However, surveillance in multiple counties outside of Frederick Co. in 2016 and 2017 resulted in detections only in Arlington, VA in 2016 (D. Weber, unpublished data). In 2018, 10 sites from northern to southwestern VA were selected for *T. japonicus* releases, based on reports of high BMSB pressure in the area. Pre-release sampling using 3 yellow sticky traps per site per week from early to mid-June resulted in the capture of only 1 *T. japonicus* in Warren Co. (the closest to Frederick Co). Two sequential releases of parasitized egg masses were timed to coincide with the first and second periods of peak BMSB oviposition. In June, eggs from a laboratory colony and from the NJ Dept. of Agriculture were exposed to *T. japonicus* on June 6 and deployed at these sites from June 11-15. A second release of eggs exposed to *T. japonicus* on July 17 was made from July 24-26. For each release, 12


Fig. 3

parasitized egg masses were deployed per site. June releases consisted of fresh (50%) and frozen (50%; frozen at -80^{o}C) eggs, while July releases used frozen eggs exclusively. The parasitized egg masses were affixed to cardstock that was attached to the bottom of a small Petri dish placed within a mesh cage to protect them from predation and that enabled emerged wasps to disperse, and these were affixed to small branches on host trees (Fig. 4)


Fig. 4

In Ohio, *T. japonicus* pre-release sampling using sentinel BMSB egg masses deployed on 12 farms in June 2018 yielded no detections of the parasitoid. In July, 15 egg masses parasitized by *T. japonicus* were released at each of 5 farms, using mesh bags similar to those used in VA (Fig. 5). An additional 5 farms at which eggs were not deployed were used as controls.


Fig. 5

Results: In New York, inspection of egg masses several weeks after deployment revealed that adult wasps had emerged from only 24% of the eggs. Sentinel BMSB eggs placed at 9 release sites after parasitized eggs had been deployed resulted in *T. japonicus* detections at two sites in western NY; the sentinel eggs attacked were approximately 30 m from the point where parasitized eggs had been placed. In 2018, two sentinel BMSB egg masses deployed per week at 9 of the release sites from 2017 yielded no *T. japonicus* detections between late June and mid-September, including at the site where *T. japonicus* had been detected in 2016 and 2017. However, yellow sticky traps deployed weekly in the lower or mid-canopy of host trees at the same sites yielded *T. japonicus* at 4 sites (5 wasps total) in 2018.

In Virginia, post-release inspections revealed that *T. japonicus* had emerged from 59.7% and 60.2% of deployed eggs in June and July, respectively. Post-release sampling was conducted at all sites for two, 1-week intervals between mid- and late August, using 3 yellow sticky traps for parasitoids and 3 pheromone-baited sticky card traps for BMSB. No *T. japonicus* were captured, although relatively large captures of BMSB nymphs and adults at many sites indicated that BMSB egg masses were present during the July and likely the June releases.

In Ohio, post-release sampling using sentinel eggs at the 10 farms (5 release sites and 5 controls) in August and September resulted in 1 egg mass at one release farm yielding *T. japonicus*.

In 2019, investigators in New York, Virginia, and Ohio will continue sampling at the release sites and (in Ohio) also at the control sites. In Ohio, new paired sites may be added, given an adequate supply of BMSB eggs.

Objective 2. Implement widespread biological control of BMSB, incorporating exotic Asian parasitoids and native natural enemies.

Project: Redistribution of *Trissolcus japonicus* in the Pacific Northwest

Background: Adventive populations of the Asian parasitoid *Trissolcus japonicus* were found in the PNW in 2015 (Vancouver, WA) and 2016 (Portland, OR) following the initial discovery in Maryland in 2014. Continuing efforts are being made to determine the spread of these accidental introductions, and re-distribute them to areas where BMSB has become established. Unlike many of the North American species, *Trissolcus japonicus* is a highly efficient parasitoid of BMSB, and will typically parasitize 80-100% of the eggs in a BMSB egg mass. An efficient biological control agent will be helpful in suppressing populations of BMSB in unmanaged habitats, and may prevent outbreaks of BMSB.

What was done: *Trissolcus japonicus* were released in the adult stage in the summer and fall of 2018 in urban and agricultural regions in Washington and Oregon. Multiple releases were made at each site to mitigate Allee effects. Follow-up monitoring was done at the sites using sentinel egg mass (SEM) survey and yellow sticky cards (visual attractant) (Fig. 1).

Fig. 1. Yellow sticky card for monitoring *T. japonicus* in hazelnut.

Washington

Releases were made at a total of 8 sites in 4 areas (2 sites/area). One of the Walla Walla sites (WW1) was the location of the single find in 2017; the other (WW2), was surveyed in 2017, but with no *T. japonicus* found. Two sites in Prosser had increasing populations of *H. halys*, and were targeted for release. The first (PR1) was a private residence, and the second a small park in the same neighborhood (PR2). The Yakima sites were a small suburban park (YK1) (where the October 2017 release was made), and YK2, an arboretum, which was surveyed in 2017 with negative results. The two White Salmon sites were commercial pear orchards across the Columbia River from Hood River, OR in the mid-Columbia area, whose climate is intermediate between the humid, mild-winter coastal climate west of the Cascades, and the semi-arid shrub steppe east of the Cascades. Both release sites (WS1 and WS2) were near wooded areas bordering the orchards. The surrounding woods were reported to support a robust population of *H. halys*, and included some known host plants (wild filberts and big leaf maple).

Oregon

Efforts in 2018 focused on detection of *T. japonicus* at sites where releases were made in the previous two seasons. We also released adults at 7 additional sites in 2018 (Fig. 3). A total of

176 SEM were deployed for monitoring parasitoids in 2018 in three regions of the state: Southern Oregon (91 SEM), southern Willamette Valley (37 SEM) and northern Willamette Valley (48 SEM).

Results:

Fig. 2. Graduate student Josh Milnes releases adult *T. japonicus* while *Good Fruit Grower* Reporter TJ Mullinax looks on.

Washington

Releases began on 25 June at the two White Salmon sites (Fig. 2). Each site received the adults from 2 parasitized egg masses, averaging 3.4 males and 52.0 females per release. Seven of the sites had 4 releases, but one site (YK2) had 5 releases. A total of 1,827 adults were released, with 6% males and 94% females.

A total of 9 egg masses (153 adults) were attacked by *T. japonicus*, with small numbers of *T. euschisti, T. brochymenae,* and *Trissolcus* sp. found. The detections were made in three of the release sites; no releases were made in Vancouver (VC1, VC2), which had well established populations of *T. japonicus* (Fig. 3).

Oregon

In the Portland area, nearly half of the egg masses deployed (20 out of 48) were parasitized by *T. japonicus*. In southern Oregon, none were parasitized by *T. japonicus*, but 24% of the egg masses (13% of eggs) were parasitized by *T. euschisti*. Of 194 yellow sticky cards (Fig. 3) deployed for monitoring parasitoids, 33 had *T. japonicus*. This included positive detections in a broader geographic area than egg masses. Specifically, we detected *T. japonicus* in the northern and southern Willamette Valley, Mid-Columbia, Columbia Plateau, and the Northeast Region. The positive finds in Northeast Oregon are from two redistributions made in 2018, while the rest are attributed to either 2017 releases or naturally occurring adventive populations. We detected four native *Trissolcus* species on cards or egg masses – *T. euschisti, T. utahensis, T. brochymenae,* and *T. strabus*. *T. euschisti* were found on cards or egg masses at 14 sites, while the other species were found a single time at separate sites.

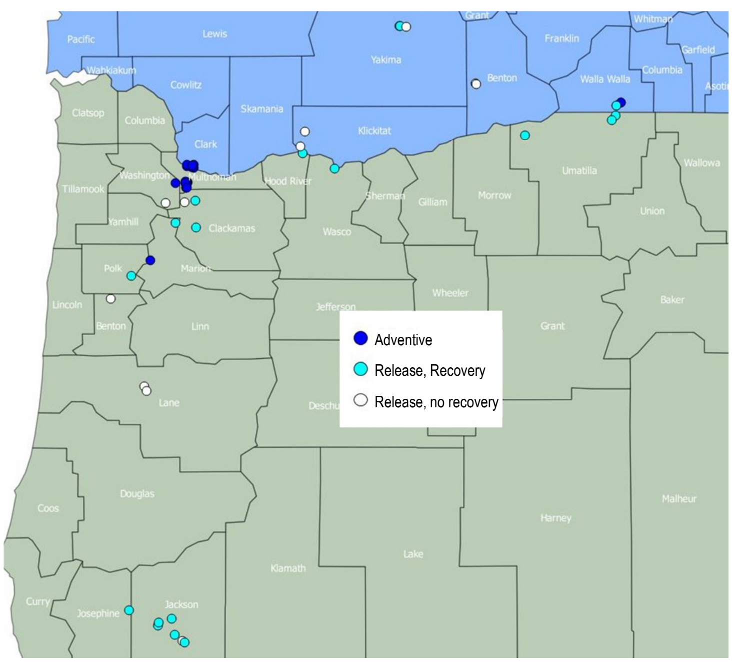


Fig. 3. Adventive populations of *T. japonicus* in the PNW, including release and recovery sites.

Objective 2. Implement widespread biological control of BMSB, incorporating exotic Asian parasitoids and native natural enemies.

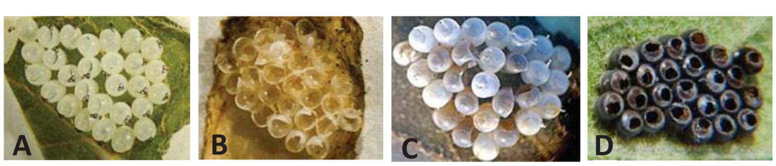
Project: Impact of native (and exotic) natural enemies: Regional complexes and habitat differences

Background: A major goal of this project is to maximize the impact of biological control agents – both exotic egg parasitoids, native parasitoids and predators – on BMSB populations. As a landscape level insect that is highly mobile and utilizes a diversity of managed and non-managed habitats, biological control may be the most powerful population regulatory factor at our disposal. Understanding the identity and impact of complexes of native natural enemies among different locations and habitats is critical to maximizing their impacts across agroecosystems.

What was Done: This research project was to originally focus on native natural enemies. However, with adventive populations of *T. japonicus*, an egg parasitoid of BMSB in its native range in the U.S., these studies include monitoring for both native natural enemies and the exotic *T. japonicus*. In 2017 and 2018, sentinel egg masses (fresh and frozen) that were deployed in the field, collection of naturally laid BMSB eggs, and yellow sticky cards were used to monitor for natural enemies in various regions and habitats in the U.S. Participation included ~15 co-PIs from 13 states representing 5 regions of the country. Not all states provided data for both years or used all sampling methods. Habitats monitored included forests (non-managed wooded edges), orchards (tree fruit, berries), ornamentals (nurseries, urban landscapes), field / vegetable crops (corn, soybean, peppers), and semi-natural (campuses, parks, arboretum). Sentinel and naturally laid eggs were retrieved from the field habitats throughout the season. Eggs were returned to the lab and assessed for parasitism and predation (by both chewing and sucking predators) or for other fate outcomes (ex. BMSB emergence or dead BMSB). Eggs were held to allow parasitoids to emerge for identification and quantification. All non-hatched eggs were then dissected to look for evidence of parasitism (e.g., partially developed parasitoid).

Anastatus reduvii is a generalist egg parasitoid that is commonly collected from BMSB eggs in arboreal habitats.

Telenomus podisi is a parasitoid of native brown stink bugs in vegetables and field crops, but has difficulty completing development in BMSB eggs.



Examples of normal, hatched BMSB eggs (A), eggs attacked by chewing (B) predators, stylet sheaths of sucking predators emerging from eggs (C), and eggs from which parasitoids emerged (D).

Results: Due to differences in data collection and recording methods, the 2017 and 2018 data were not combined for this report. Not all collaborators submitted data, and of those that did, not all sample results have been processed. Results from 2017 were presented at last year's SAP meeting. Here we present results from 2018. In the future 2017 and 2018 data will be combined for more robust interpretation of results.

Data for 2018 have been analyzed by region and habitat category. States that submitted data within each region include: West (Utah), Pacific Northwest (Washington, Oregon), Southeast (Kentucky, North Carolina), Mid-Atlantic (Maryland, Delaware) and the Great Lakes (Ohio, Wisconsin). Habitat categories include: semi-natural (campuses, parks), forests (wooded edges), ornamentals (nurseries and urban landscapes), orchards (cherry, peach, apple, berries, hazelnut), and field/vegetable crops (corn, soybean, peppers). Results presented here are from fresh sentinel egg masses only. Sentinel fresh eggs were relatively the most abundant sampling method. Other sampling methods (frozen sentinel eggs, naturally laid eggs, yellow sticky cards) will be analyzed in the future.

Fig. 1. Species of parasitoids (%) emerged from fresh sentinel BMSB egg masses used in surveys in each of six habitat categories (n = number of emerged parasitoids and infers the rigor of the results). For each category, species are color-coded by parasitoid genus. Dark-blue hashed bars denote the prevalence of *Trissolcus japonicus*, a non-native parasitoid species. All other species are native (solid colors). A subset of parasitoids were quantified but not yet identified (=unidentified).

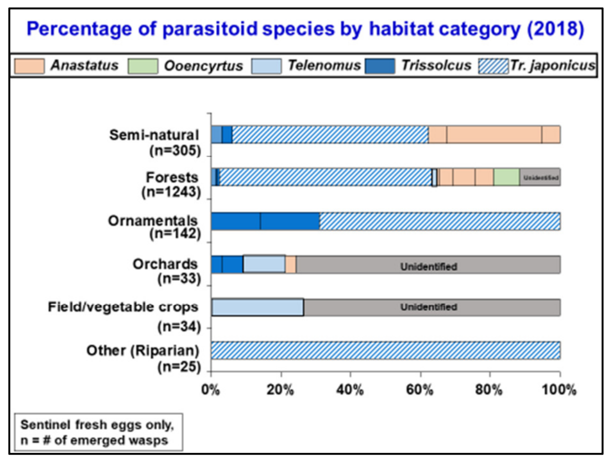


Fig. 1. Summary points

- Parasitoids from three insect families emerged from egg masses in six habitats
- *Anastatus* species were most prevalent in forests and semi-natural habitats
- Native *Trissolcus* species dominated ornamentals
- Non-native *Tr. japonicus* was prevalent in arboreal habitats such as semi-natural, forests, and riparian areas.
- Highest diversity (# of species) emerged from egg masses in forest habitats (wooded edges)

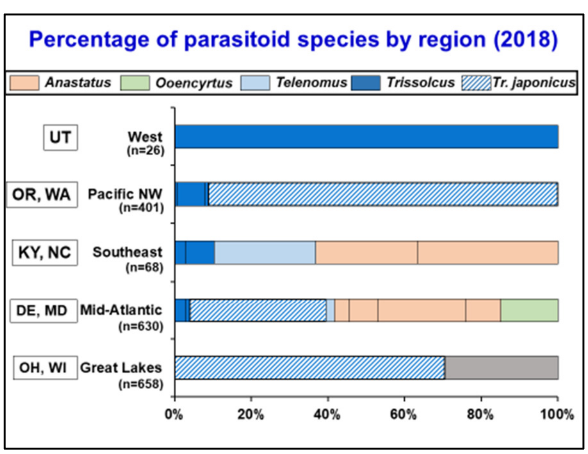


Fig. 2. Species of parasitoids (%) emerged from fresh sentinel BMSB egg masses used in surveys in each of five U.S. regions (n = number of emerged parasitoids and infers the rigor of the results). For each category, species are color-coded by parasitoid genus. Dark-blue hashed bars denote the prevalence of *Trissolcus japonicus*, a non-native parasitoid species. All other species are native (solid colors). A subset of parasitoids were quantified but not yet identified (=unidentified).

Fig. 2. Summary points

- Non-native *Tr. japonicus* was only collected in the Pacific NW, Great Lakes, and Mid-Atlantic regions
- *Anastatus* spp. were most prevalent in the Southeast and Mid-Atlantic regions
- Highest diversity of species in the mid-Atlantic

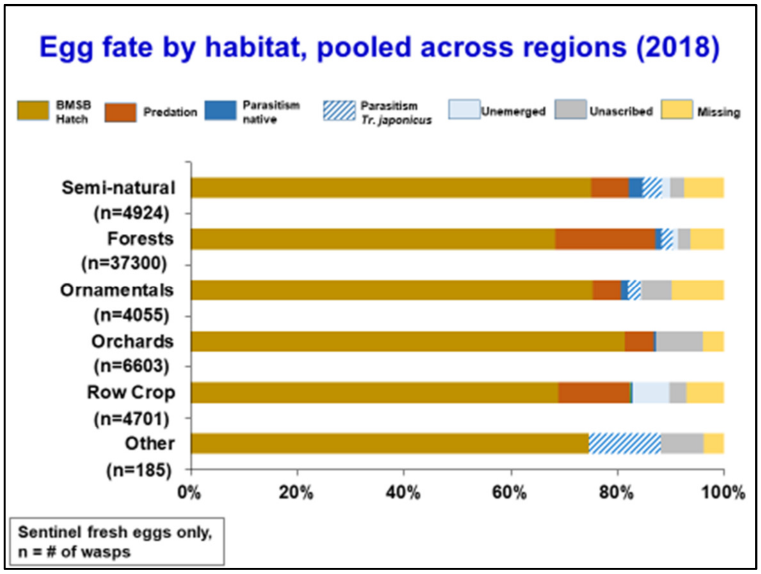


Fig. 3. Egg fate (%) categories of fresh sentinel eggs by 6 habitat categories (pooled across all regions) (n = number of eggs in each habitat and infers the rigor of the results). For each habitat category, species are color-coded by egg fate. Egg fate categories include: BMSB hatch, Predation, Parasitism by native parasitoids, Parasitism by *Tr. japonicus*, a non-native parasitoid, Unemerged eggs, Unascribed (unknown) mortality, and Missing eggs.

Fig. 3. Summary points

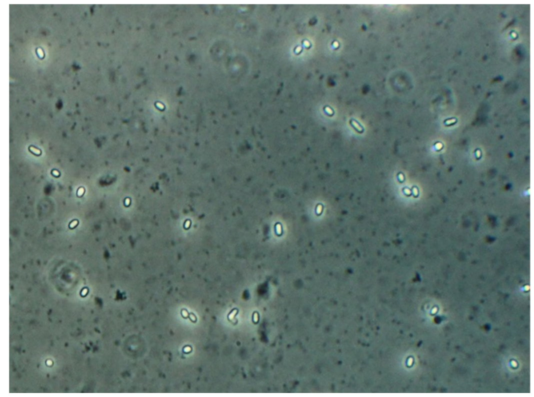
- BMSB survival was high in all habitats (~70-80%)
- Predation was highest in forest habitats
- Parasitism was low overall (about 4% from native and exotic parasitoids). Parasitism was most common in semi-natural, forest, and ornamental habitats, and lowest in orchards and row crops.

Conclusions

- Parasitoid species vary by habitat and by region in 2018. This data supports that of 2017 and other studies testing habitat differences. Certain parasitoid species are more prevalent in specific habitats, though the same species can occur in different habitats. For example, *Anastatus* species were most prevalent in forests and semi-natural habitats, and in the Mid-Atlantic and Southeast regions.
- Predation was highest in forest habitats in 2018 and totaled 13% overall. This supports similar results found in 2017. Mortality by parasitoids was low overall at only 4% by native parasitoids and *Tr. japonicus* combined.
- Additional data need to be incorporated into data sets and more extensive statistical analysis well be conducted to elucidate more robust patterns in natural enemies.

Objective 2. Implement widespread biological control of BMSB, incorporating exotic Asian parasitoids and native natural enemies.

Project: Monitoring the spatial and temporal activity of the microsporidian *Nosema maddoxi* infecting BMSB



Spores of *Nosema maddoxi* seen at 400x, phase contrast. *Nosema maddoxi* cells are very small (around the size of bacteria), developing within host cells.

Background: A microsporidian was first discovered by Dr. James Becnel in 2012 in Florida, where it was creating problems in a declining BMSB colony being used to rear egg parasitoids. Subsequently, this pathogen was detected in BMSB field populations in New Jersey by Dr. Anne Nielsen's lab. Once it was discovered by Dr. Ann Hajek infecting BMSB colonies at the University of Maryland, studies of this previously undescribed species proceeded. Microsporidia are often chronic pathogens that have an impact in insect populations by reducing reproduction and longevity. Few microsporidian species had been known from terrestrial bugs (like BMSB), as it had been assumed that with piercing-sucking mouthparts, bugs were not likely to ingest spores and become infected; microsporidia are known to infect through the gut wall (when not passed within eggs by infected mothers and not all species of these pathogens are known to infect through eggs).

Curiously, a microsporidian had been mentioned in the literature by Dr. Joe Maddox in 1979, who reported high infection levels in green stink bugs, *Chinavia hilaris*, in Illinois. Surprisingly, frozen samples of the microsporidian from green stink bugs that had been stored for decades were found! (suggesting that it's a good idea NOT to clean out your freezer!) This was before BMSB was present in North America but also nowhere near where BMSB was first found in North America (in Allentown, PA) in 1996. We also obtained samples of BMSB from China and South Kora that contained microsporidia. Molecular work demonstrated that all of these samples were the same species, newly described as *Nosema maddoxi* in 2017 (Hajek et al. 2017). While it seems that this microsporidian species has a global distribution, the samples from BMSB in North America were more similar to the green stink bug samples, strongly supporting that this is a native pathogen that has shifted over to infecting invasive BMSB. Now we needed to learn more about *N. maddoxi*.

What was done: Surveys were conducted with samples from 32 sites in 11 states, during 2017 and 2018. We evaluated whether percent infection by *N. maddoxi* was associated with BMSB sex, BMSB population density, presence of native stink bugs, and the length of time that BMSB had been present in that state. To determine whether BMSB were infected by *N. maddoxi* or not, we used phase contrast microscopy; we found that sometimes individual insects contained lots of spores and other times just a few, so we also included infection intensity in our analyses. During 2018, we investigated at the percent infection in BMSB populations across the season and in adults versus nymphs.

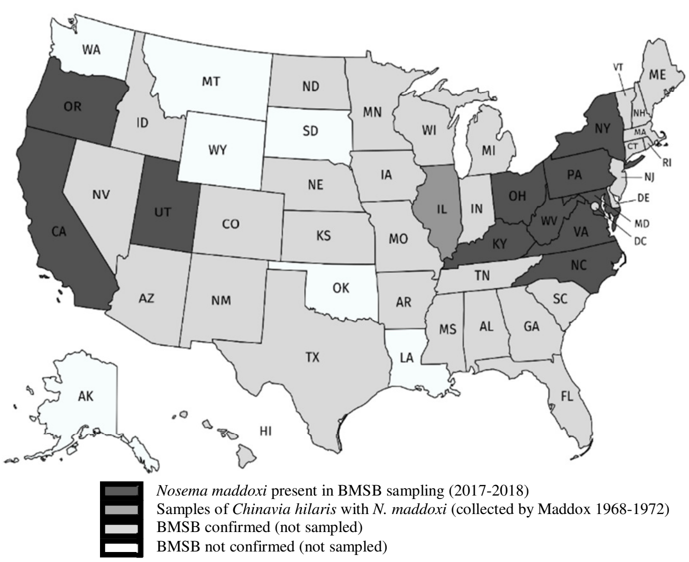
We had also found that sometimes BMSB infected by *N. maddoxi* had some markings on them and we looked into whether these markings could be used to detect infections without the extra steps of phase contrast microscopy (or methods that would be even more complicated and expensive).

Results: Our survey from 2017-2018, detected this newly described pathogen in all states that we had samples from. Percent infection varied from 0-52% in BMSB populations and there was no difference in infection for males versus females. We found that the high intensity infections were found more often at sites where BMSB populations were dense. However, we did not find an association between infection level and 1. The number of years that BMSB had been present in that state of 2. The numbers of native stink bugs found when collections were made.

Relative to the seasonal occurrence of *N. maddoxi* infections, the highest levels of infection were found among BMSB adults collected in the spring that had emerged from overwintering sites. Lower levels of infection were generally found in summer, the period when more nymphs were collected than in spring or fall. However, even in summer, more adults were infected than nymphs.

Carrie Preston collecting BMSB and native stink bugs from foliage.

Finally, we investigated the brown spots on the abdomens of BMSB to see whether these could help with detecting infections. These brown spots were actually darkened cells beneath the cuticle that could be seen through the center of the abdominal cuticle; the darkening was due to the BMSB's immune reaction. However, we found that presence or absence of these spots did not always predict infection of lack of infection. So, while we still consider these an indicator, for more accuracy, analysis of specimens using either microscopy or molecular biology must be undertaken.



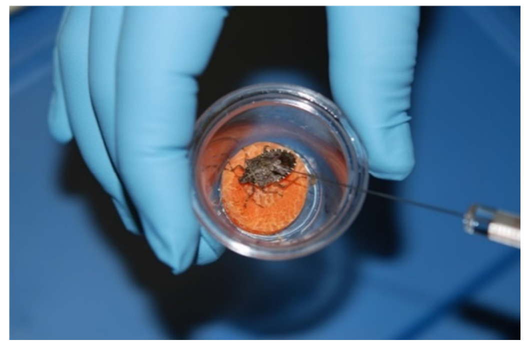
Map of *N. maddoxi*; we sampled 11 states in 2017-18 and found it in all states we sampled. Also, *N. maddoxi* was found in Illinois in green stink bugs in 1968-1972.

These brown spots on the BMSB abdomen are darkened tissues within the abdomen that can be seen through the cuticle. They can help as an indication of *N. maddoxi* infection (although they are not an exact measure).

Objective 3. Develop management tools and strategies that are compatible with biological control and informed by risk from landscape factors.

Project: Monitoring the response of BMSB populations to insecticides

Background: Insecticides, especially pyrethroids, are the most widely used tool for BMSB control in the U.S. Neonicotinoids make up the bulk of other non-pyrethroid insecticides used for this pest. These insecticides have been frequently applied for control of BMSB on various commodities in the mid-Atlantic U.S. for over a decade. Consequently, there has been concern for BMSB populations developing insecticide resistance and great impetus for additional insecticide testing on BMSB, particularly compounds that are less toxic to beneficial arthropods and thus, more compatible in IPM systems and pollinator protection plans.



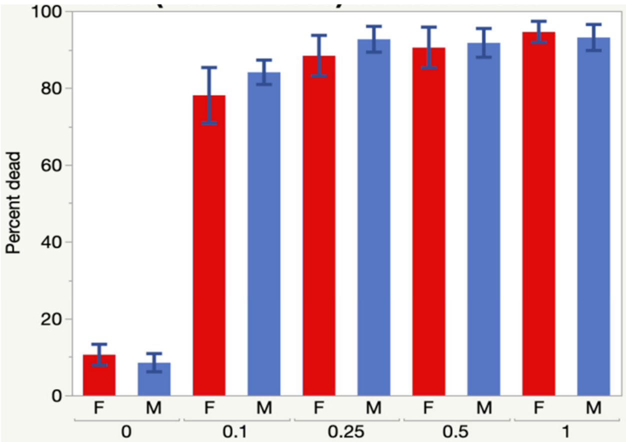
BMSB adult receiving a 2-ul aliquot of insecticide.

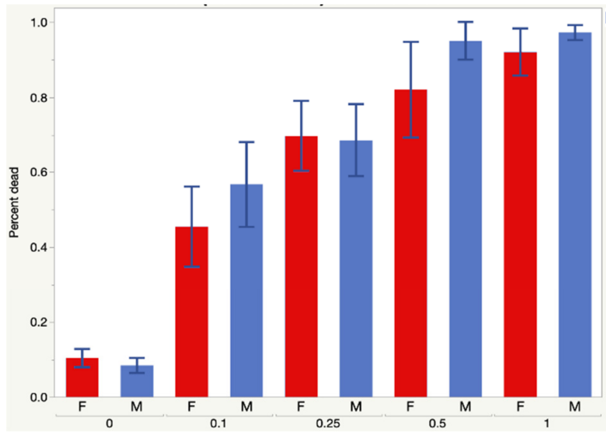
What was Done: Researchers from six states (NC, NJ, NY, OH, PA, and VA) collaborated on a project to determine baseline toxicity levels in BMSB populations to bifenthrin (a widely-used pyrethroid) and thiamethoxam (a standard neonicotinoid). In 2017 and 2018, researchers collected wild populations of BMSB adults from their respective locations and conducted the same topical insecticide bioassays, which involved pipetting serial dilution concentrations of 1X, 0.5X, 0.25X, 0.1X, and 0X concentrations of field rate mixtures of bifenthrin (Brigade 2EC) and thiamethoxam (Actara 50WDG). Approximately 30 males and 30 females were tested per dose per location and bugs were maintained in 1 oz plastic cups with a carrot slice for at least 48 hr and at most 5 to 7 days post treatment to assess mortality.

Insecticide-treated BMSB adults.

Also, in an effort to find more selective insecticides for BMSB control, researchers are annually conducting field efficacy trials in vegetables and tree fruit. Some insecticides that are being closely evaluated include: 1) sulfoxaflor, a Class 4C (sulfoxamine) insecticide introduced in 2013 in the products Closer and Transform; 2) cyclaniliprole, a new broadspectrum diamide (Class 28) insecticide; 3) flupyradifurone, a Class 4D insecticide in the product Sivanto, 4) flonicamid, a chordotonal organ modulator (Class 29); and 5) an extract made from heat-killed cells and fermentation solids of the proteobacteria *Burkholderia* spp. in the commercial product Venerate. These insecticides have demonstrated some efficacy against BMSB in preliminary studies or other hemipteran pests, and thus, warrant further evaluation.

Results: It has been noted that BMSB adults recover after exposure to insecticides. By assessing the percentage of bugs that were moribund at 48 hr after exposure (not dead, but severely impaired and unable to walk) that changed to "alive" and able to walk by five or seven days, we were able to estimate the fate of "moribund" bugs. We found that, across our bioassays, once poisoned, only 6% or less of bugs recovered to a fully functional state regardless of insecticide or concentration. This enabled us to efficiently record dead + moribund bugs at 48 hr as "mortality". It has also been previously noted that female bugs are harder to kill than males. However, we found no statistical difference in response to these insecticides and rates between male and female BMSB. With regards to bifenthrin, a concentration of 25% of the labeled field





Percentage mortality (@ 48 h) of BMSB adults exposed topically to serial dilutions of a field rate (1X) concentration of bifenthrin (left graph) and thiamethoxam (right graph).

rate resulted in ~90% mortality of BMSB adults, and a concentration of 10% of the field rate resulted in ~80% mortality based on pooled data from 12 populations (6 states x 2 years). With regards to thiamethoxam, a concentration of 25% of the labeled field rate resulted in ~70% mortality of BMSB adults, and a concentration of 10% of the field rate resulted in ~50-60% mortality. These values will be useful to assess potential changes in insecticide susceptibility in the future.

In insecticide efficacy trials conducted on tree fruit in New York (Peter Jentsch) and on peppers and tomatoes in Virginia (Tom Kuhar), sulfoxaflor (Closer) provided a significant reduction in stink bug damage to fruit at harvest, including after bugs were artificially caged on fruit following applications, as was done on apples at the Hudson Valley Research Laboratory. Flupyradifurone (Sivanto) and flonicamid (Beleaf) have also performed well in field trials on fruiting vegetables. Other insecticides such as cyclaniliprole (Harvanta) and Venerate were less reliable for BMSB control in field trials.

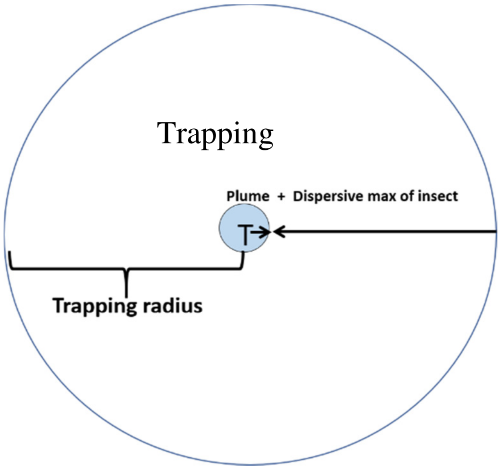
BMSB adult caged on apple after treatment in the field.

BMSB damage to tomatoes after six foliar applications of insecticides in Whitethorne, VA in summer 2018.

		Proportion stink bug damaged fruit	
Treatment	Rate / acre	24-Aug (8 DAT2)	30-Aug (7 DAT4)
Untreated check		0.29 a	0.33 a
Harvanta 50SL	10.9 fl oz	0.24 ab	0.21 ab
Harvanta 50SL	16.4 fl oz	0.22 ab	0.19 bc
Closer SC	4.5 fl oz	0.08 b	0.07 c
Sivanto Prime	4.5 fl oz	0.32 a	0.25 ab
Sivanto HL	7.0 fl oz	0.16 ab	0.2 b
Beleaf 50SG + NIS	2.4 oz	0.16 ab	0.19 bc
Minecto Pro + NIS	6.0 fl oz	0.12 b	0.19 bc
Minecto Pro + NIS	8.0 fl oz	0.09 b	0.17 bc

Objective 3. Develop management tools and strategies that are compatible with biological control and informed by risk from landscape factors.

Project: Estimating pheromone-baited monitoring trap plume reach and trapping area for nymphal and adult BMSB



Background: An important question that remains for pheromone-baited trapping of BMSB is calculating the area a single trap samples BMSB from. This information is critical for assessing how many traps are necessary at farmscape and landscape levels to detect BMSB presence, abundance, and seasonal phenology. Miller et al. (2015)[1] provided a blueprint for estimating this value. The objectives for this study were to evaluate the maximum dispersive distance (furthest distance from which 95% of the population can reach the trap within the given time assisted by a pheromone source) for BMSB adults and nymphs and determine the plume reach (distance where target individuals encounter the plume and elicit a positive behavior towards the source) of a baited, clear sticky panel trap that is commonly used for monitoring of BMSB in crop systems. Once the values for maximum dispersive distance and plume reach are obtained, they are summed to calculate the trapping radius, or the longest distance from the trap that can yield captures of target BMSBs. The trapping radius is then used in the equation for the area of a circle to calculate the trapping area, or the area over which a trap reliably captures the target insect over a given period of time. The population density within the trapping area can also be estimated to estimate how many BMSB are present within the trapping area.

What was Done: For this study, a single clear sticky trap on a wooden post and baited with a Trece dual lure was placed in the center of a plot and BMSB uniquely marked with different colors of fluorescent dusts pertaining to specific distances from the trap were released at each distance in four cardinal directions from the trap (Fig. 1). There were four different experiments conducted for this study: 1) adult BMSB released in an open field without host plants present and the clear sticky trap encircled by 8 unbaited pyramid traps; 2) adult BMSB released in an open field without host plants with a baited, clear sticky trap; 3) adult BMSB released in one cardinal direction outside and apple orchard border row where the baited, clear sticky trap was placed (Fig. 2); and 4) nymphal BMSB released in an open field without host plants present and a baited, clear sticky trap. All BMSB used for the study were wild-collected from host plants, marked with fluorescent dusts the day before the release, and held in 30 cm^3 mesh cages, with each cage having a unique color pertaining to a release distance. Releases were conducted at pre-dawn hours, ~5:30am. Mesh cages were placed in the study site with the tops removed and a small branch of a non-host plant placed

Fig 1.

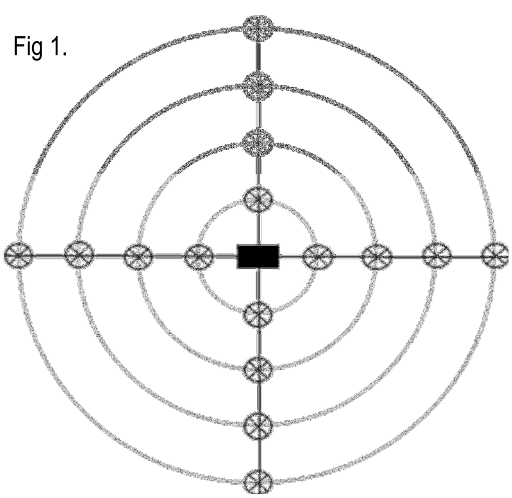


Fig 2.

inside to provide the BMSB cover from the sun and something to crawl up for dispersal from the mesh cage. The trap was checked every day for seven days following the release. Captured BMSB were removed from the trap and taken to the laboratory where they were examined for fluorescent dust markings using UV light.

Results: The estimated maximum dispersive distances for adults released at sites with and without pyramid traps present was 120 and 130m, respectively. Ultimately, trapping area was quite similar for pheromone-baited clear sticky traps deployed with (4.83 ha) or without (5.55 ha) unbaited pyramid traps. Thus, in a landscape devoid of host plants, we can assume that a single pheromone-baited sticky trap can capture BMSB adults over a ~5 ha area. However, the likelihood of BMSB not encountering host plants over such an area is unlikely. Thus, the influence of host plants must be considered when interpreting over what distance BMSB will respond to pheromone-baited traps. In our preliminary studies here, when a pheromone-baited trap was deployed in the border row of an apple block, plume reach was consistent with what we measured in open field experiments at < 3 m, but maximum dispersive distance was reduced to 70 m. The resulting total trapping area in the presence of apple trees was 1.7 ha, less than a third of what the total trapping area was in the open, mowed grass field devoid of host plants, potentially indicating that the presence of the apple trees and pheromonal stimuli in combination provided a more attractive habitat for foraging BMSB. For nymphal BMSB, the maximum dispersive distance in an open, mowed grass field was approximately 40 m, resulting in a total trapping area of about 0.58 ha; considering this is an immature walking-only life stage. More research will be conducted in the future to build on the estimates of maximum dispersive distance, plume reach and trapping area for nymphal and adult BMSB a to further understand the influence of host plants, to refine trapping area, and provide estimates of absolute pest density to understand how captures in baited sticky traps relate to damage at harvest.

Table 1. Trapping Area

Life Stage	Experimental Design	Percent Recaptured	Plume Reach	Maximum Dispersal Distance	Trapping Area
Adults	1. Open Field with Pyramid Trap	3.2%	< 3 m	120 m	4.83 ha
	2. Open Field	0.6%	< 3 m	130 m	5.56 ha
	3. Apple Orchard	1.1%	< 3 m	70 m	1.67 ha
Nymphs	4. Open Field	6.6%	< 3 m	40 m	0.58 ha

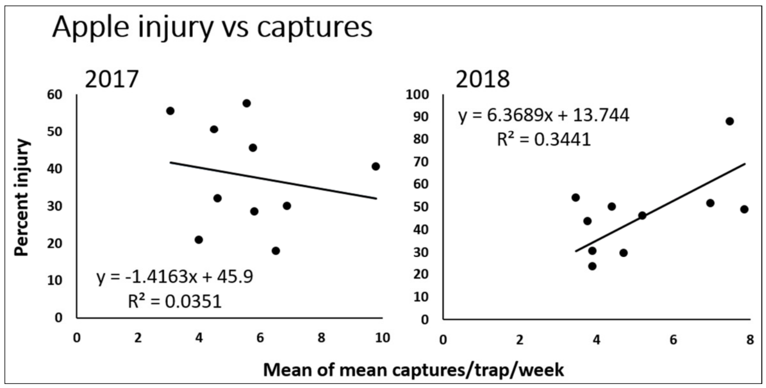
[1]**Miller, J. R., C. G. Adams, P. A. Weston, and J. H. Schenker. 2015.** Trapping of small organisms moving randomly: principles and applications to pest monitoring and management. Springer Briefs in Ecology. New York, NY

Objective 3: Develop management tools and strategies that are compatible with biological control and informed by risk from landscape factors.

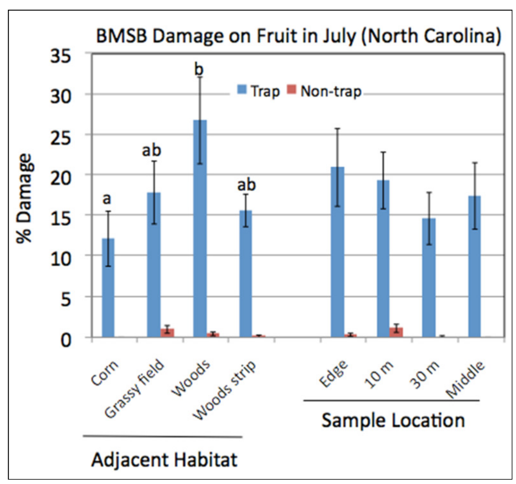
Project: Explore relationships between pheromone trap capture and crop injury

Five fruit projects and two vegetable projects were undertaken in 2018 as summarized below.

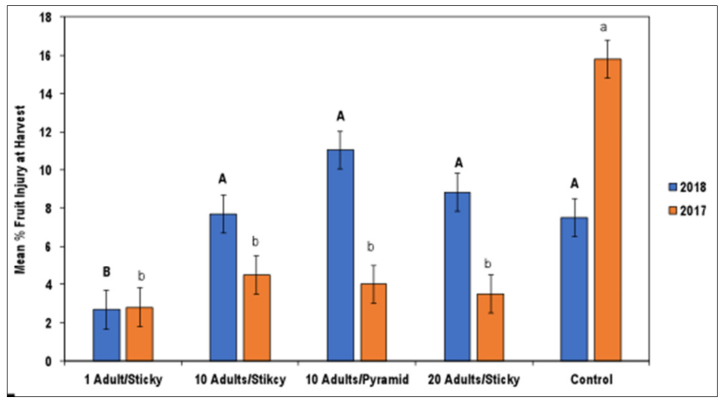
1. Site-specific differences in BMSB captures and apple fruit injury - Virginia Tech. The objective was to examine the relationship between fruit injury at harvest and BMSB captures in pheromone traps at the edge of woods next to apple orchards. The study was done in 10 orchards, each with 3 sticky pheromone traps monitored from April through October 2017 and 2018. Apple injury was assessed at harvest, and analyzed for correlations with BMSB captures. A lack of correlation between BMSB captures and apple injury was found in both years (see graphs below). The study will be repeated in 2019 to determine if site ranking for BMSB captures remains similar among years. Data will be examined for the relationship between site-specific differences in BMSB captures and the composition and size of adjacent woodlots.



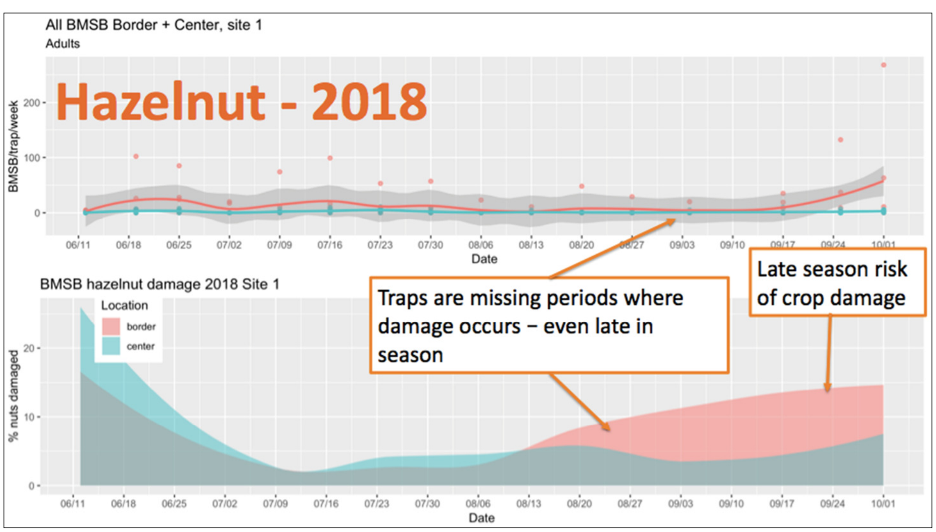
2. Interpretation of Pheromone Trap Captures in North Carolina Apples – NC State. Orchards in NC are dispersed in a diverse habitat, are relatively small, irregularly shaped, and managed by diverse management schemes. A study was done with BMSB traps and damage assessments in 27 orchards. Traps were checked weekly and damage was assessed monthly along transects into orchard along one border per orchard. Results showed that neither adjacent habitat nor spatial location within orchard affected pheromone trap capture, but damage was strongly associated with location of pheromone traps. Damage was affected by adjacent habitat but there was a poor relationship between trap capture and damage. Damage was highly concentrated in trees near traps. A complicating factor in correlating damage and trap captures is the extended time of development of damage from time of bug feeding to symptoms development, which can vary from 1 to 3 weeks.



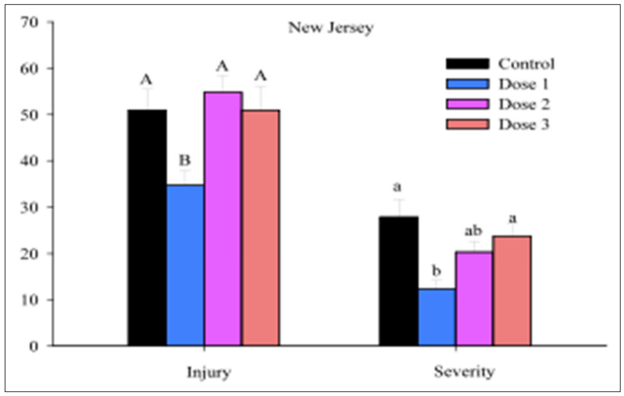
3. Threshold Development for Apple Orchards - USDA/ARS, West Virginia. Threshold studies done in 2013 and 2014 showed that sprays triggered by cumulative captures of ten BMSB in either of two tall black pyramid traps, one at the orchard edge and one in interior, resulted in reduction of fruit injury by BMSB to levels similar to that when trees were sprayed every week. Studies in 2017 and 2018 were done to determine the appropriate threshold when commercially available sticky panel traps and pheromone lures were used. Results showed that sprays triggered by a threshold of 1 adult per sticky trap resulted in significant reductions in injury, but additional commercial trials suggested that an appropriate threshold of four adult BMSB per sticky trap be used. This and several comparison thresholds will be evaluated in 2019.



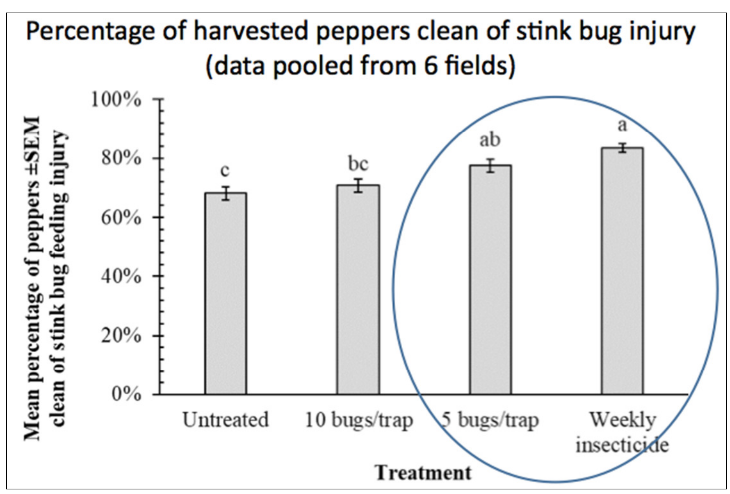
4. BMSB trap thresholds on hazelnuts, cherry, and pear in Oregon - Oregon State University. To determine whether trap captures can be used as a decision aid for spray timing, threshold trials were conducted in 2016-2018 in sweet cherry as an early crop, pear as a mid-season crop, and hazelnut as a late-season crop. Each site included 3 sticky and 3 pyramid traps in border and interior locations; damage was assessed every 2 weeks in the two areas. In cherries in 2018, there were almost no trap captures despite severe damage, and no edge effect was seen in traps or damage. On pears, traps showed higher captures on borders than interior areas. For hazelnuts, traps did not show an increase in catch during periods where damage occurs. It is concluded that current standard trap technology is not sensitive enough for detecting early orchard crop damage. The BMSB being captured may not be the ones causing damage, resulting in poor correlation between damage and captures. Traps can provide information on presence or absence of BMSB, but scouting is a better indicator of feeding damage on nuts or fruit.



5. Trap-based methods for BMSB in peaches - Rutgers University and USDA-ARS. Monitoring for BMSB in peaches is complicated by competitiveness with fruit and lack of a correlative relationship between trap numbers and injury. Previous trials have shown that injury in peaches has a larger spillover area beyond the trap. We evaluated two reduced loading rate lures against the Trécé standard lure. Traps were placed 5 m outside peach orchards in NJ and WV. If traps had two BMSB of any life stage, an insecticide was applied to the block. Fruit was assessed for stink bug injury at harvest. The reduced rate lures tracked seasonality similarly as the Dual standard but caught significantly fewer BMSB. Only the Dual lure had significantly lower injury and severity of injury than the unsprayed control. These results indicate that either a reduced rate lure is ineffective or the threshold is not sensitive enough. The trial will be repeated in 2019.



6. Using pheromone-baited sticky card trap catch to guide BMSB control decisions in peppers - Virginia Tech. A trial was conducted in 6 pepper fields over 2 years in VA. Traps were monitored weekly. Treatments evaluated were: untreated control, thresholds of 10 BMSB/trap/week and 5 BMSB/trap/week, and weekly sprays of bifenthrin. Damage on peppers was assessed at 2-3 harvests. Based on 6 fields over 2 years, there was a significant relationship between BMSB trap catch and visual counts on pepper plants. Following a trap catch threshold of 5 or 10 BMSB/trap significantly reduced the number of bifenthrin spray applications compared with standard weekly sprays. The threshold of 5 BMSB/trap resulted in peppers that were as clean after an average of 1.8 sprays as those sprayed weekly for an average of 7.8 sprays.



7. Stink bug injury in sequential sweet corn plantings - Ohio State University. A trial was done in 2018 to document seasonal trends in BMSB infestation in sweet corn, in the absence of insecticides, as detected by scouting and pheromone trapping. Infestation was compared with kernel injury at harvest. A pheromone trap was placed in the middle of the edge of each of 3 blocked replicates of corn. Each block contained 5 sequential plantings. BMSB was more abundant than in 2017. Kernel injury was found in all sequential plantings. There was a strong spillover effect with heavy infestation and injury concentrated on the first five plants in the two rows closest to a trap but with injury scattered throughout the blocks. A similar trial but with several insecticide options, in blocks with and without an adjacent trap, is planned for 2019.

Students deploying BMSB pheromone trap at corn border.

Objective 3. Develop management tools and strategies that are compatible with biological control and informed by risk from landscape factors.

Project: Improve agroecosystem sustainability through spatially focused management or habitat manipulation – Attract-and-Kill in Orchards

Background: While broad spectrum pyrethroid and neonicotinoid insecticides have been useful tools in mitigating BMSB damage to many specialty crops, their broad spectrum activity has negatively affected biological control systems and led to secondary pest outbreaks in orchard systems. The high degree of attractiveness of the BMSB aggregation pheromone + MDT synergist to both adults and nymphs has provided the opportunity to develop behavioral based management strategies that offer a more sustainable management program, particularly in orchard systems. Initial research focused on deploying pheromone bait stations in trees on the perimeter of orchards and then spraying these and adjacent trees a frequent intervals, and thereby exposing only a small portion of the orchard to broad spectrum insecticides on a regular basis. However, with the recent availability of netting impregnated with pyrethroid insecticides, and documentation that these nets are highly toxic to BMSB that come into contact with the nets, research is now focusing on deploying this long-lasting insecticide netting (LLIN, sold as Permanet) in combination with pheromones + MDT synergist. This Attract & Kill approach offers the potential of even further reducing insecticide sprays for BMSB, and allowing biological control systems to become re-established in orchard systems.

Michigan Studies – Larry Gut lab.

Optimizing LLIN traps: LLIN traps were constructed using deltamethrin-impregnated netting zip-tied to shepherd's crook style posts (Fig. 1). Catch at two heights was compared by draping the fabric over tall (84") or short (48") posts. Weed barrier cloth was secured into the ground directly under the netting to provide a vegetation-free zone for nymphs to crawl onto the trap and for dead individuals to be readily visible. To investigate the potential effect of attractant potency, traps were baited with either one or three BMSB dual-component lures. Traps were checked for BMSB adults and nymphs, as well as native stink bugs and non-target insects, and lures were replaced after 12 weeks. A total of 3,693 stink bugs were released during the course of this experiment. There was no significant difference in weekly BMSB capture between tall (8.54 ± 0.95) vs short (7.24 ± 0.80) traps. Traps baited with three lures caught significantly more BMSB than those baited with only one lure (9.78 ± 1.03 vs 6.00 ± 0.69). The study revealed that height of trap did not impact capture of BMSB, while higher lure potency increased catch. However, the increase in catch likely does not justify the added cost of using multiple lures. A better approach may be to use multiple traps baited with a single lure.

Figure 1: LLIN trap

Effectiveness and optimum placement of LLIN traps: We directly compared the performance of pyramid, panel and LLIN traps, and the effect of trap placement in relation to the crop-wood edge interface on captures of BMSB in the three trap types. Trap placement location was the wood edge, orchard edge, and in the middle (between wood and orchard edge). All traps were baited with a high dose BMSB dual-component lure. A total of 11,885 BMSB were killed and counted in all treatments. Across all farms and crops, the most BMSB per assessment were trapped in LLIN traps deployed in middle locations (Fig. 2). Catch was significantly impacted by trap type and trap placement. Stink bug catches in traps deployed in middle locations were significantly higher than those in at the orchard edge ($P = 0.001$). Catch in LLIN traps was significantly higher than catch in panel traps ($P = 0.002$), but catch in pyramid traps was not significantly different from that in LLIN traps ($P = 0.17$) or panel traps ($P = 0.23$). However, middle-placed LLIN traps captured nearly twice as many stink bugs as the next best trap-placement combination, middle placed pyramid traps. As in the previous study, LLIN and pyramid traps were substantially more effective than the panel trap (Fig. 2). Female BMSB captures were especially low in the panel trap.

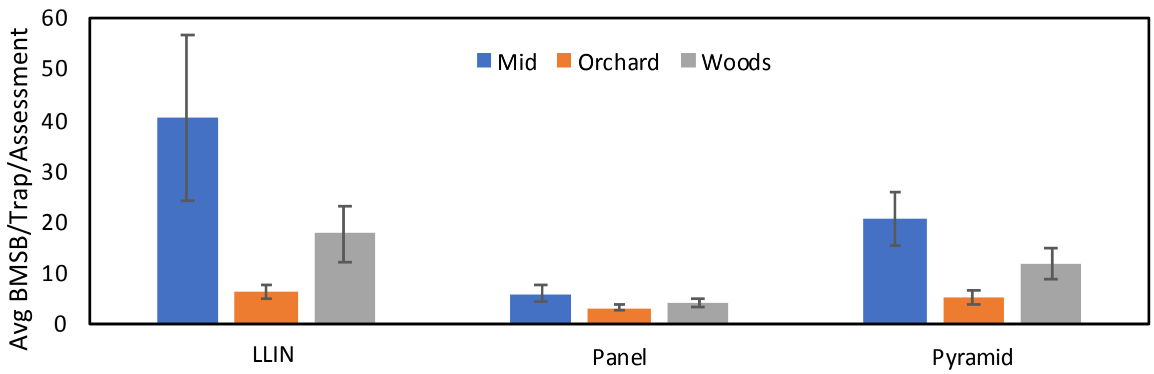


Figure 2 BMSB capture in three trap types placed at the wood edge, orchard perimeter or between the two locations.

<u>Attract-and-kill using LLIN traps</u>: Four mixed-variety apple orchards were selected to conduct a preliminary attract-and-kill trial. Each of the four plots were randomly assigned one of the following treatments: LLIN-30, LLIN-50, Wall or a grower standard stinkbug spray program (control). LLIN-30 and LLIN50 consisted of LLIN traps deployed around the perimeter of the plot spaced 30 m or 50m apart, respectively. The Wall consisted of a 600’ strip of 18” wide LLIN zip-tied to a deer fence along the external perimeter of the plot. The Wall was baited with low-dose dual-component BMSB lures spaced approximately 15’ apart. All treatments were deployed during late July and early August, before the peak of BMSB activity and damage. Supplemental insecticides sprays were applied to plots when high BMSB captures in traps signaled the need to treat. Counts of fruit injury were made along transects into the orchard in mid-August and late September were used to assess treatment effects. Fruit injury was high in all treatments at the first sampling period, with 57.9% of fruit displaying internal damage and 17.5% displaying externally visible damage. Both types of BMSB damage decreased substantially at the second evaluation in late September; 17.5% of fruit showed internal damage and 8.2% external visible damage. Since the initial damage sample revealed similar levels of damage between all four treatments, the change in damage at the second sampling provided some measure of treatment effects. Apples harvested from the LLIN-30 treatment were the most protected from BMSB damage (internal damage decreased from 59.5% to 9.6% and external damage decreased

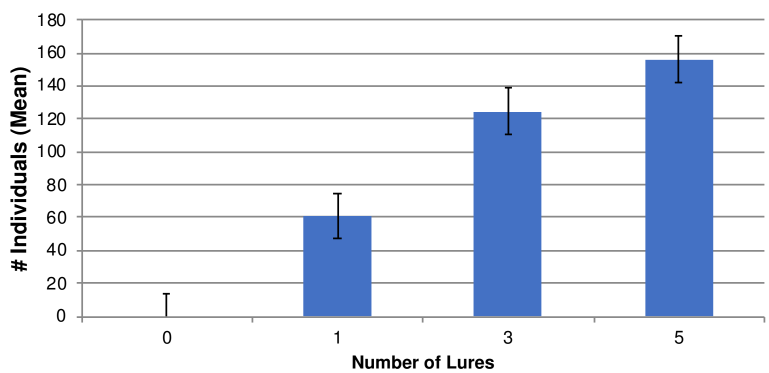
from 10.2% to 0.8%). Conversely, the grower standard treatment had the smallest reduction in damage between harvests (internal damage decreased from 57.9% to 18.8% and external damage from 11.4% to 10.5%). The results suggest that LLIN traps deployed at a spacing of 30 meters is a promising tactic for managing BMSB.

Pennsylvania trials– Greg Krawczyk lab.

Perimeter trapping: LLIN traps were deployed around the perimeters of 4 orchards. Substantial numbers of BMSB were captured at all sites. Mean catch per week ranged from about 15 to 45 individuals per trap. Peak catch occurred in September with a mean of 60 individuals killed.

Lure load: To investigate the potential effect of attractant potency, traps were baited with either one, three or five high-dose BMSB dual-component lures. Three replicates of LLIN traps baited at each loading rate were randomly deployed along an orchard perimeter. Traps were spaced 50 m apart and checked weekly from August 1 – October 15. Significantly more BMSB were captured in traps baited with 3 or 5 lures compared to a single lure (Fig. 3)

Figure 3 BMSB Adults and Nymphs by lure load



LLIN aging study: A direct comparison of BMSB captures in LLIN traps constructed using netting of different ages was conducted to investigate the longevity of the insecticide treated netting. Treatments were 1, 2 and more than 2 year-old netting and a pyramid trap as a positive control. All traps were baited with three BMSB dual-component lures. Traps were randomly deployed along an orchard perimeter spaced 50 m apart. LLIN traps employing 1 and 2 year-old netting captured substantially more BMSB than the pyramid trap. Very few bugs were captured in the trap with netting older than 2 years.

West Virginia trials - Leskey lab.

Field trials were conducted in commercial apple orchards from 2015-2018. In all years, the experiment consisted of directly comparing BMSB control in attract and kill (AK) treated plots and grower standard plots In the first two years, the AK treatment consisted of trees treated with pheromone + MDT lures and treated with insecticide to kill attracted bugs. In 2017, the AK treatment consisted of trees baited with lures with long-lasting insecticide netting as the means of killing attracted bugs (Fig. 1). In 2018, LLIN traps placed along the orchard perimeter were also included as part of the AK treatment. In all experiments the AK treatments were spaced at 50 meter intervals. Efficacy was assessed using BMSB captures in baited traps and fruit injury at harvest. Baited pyramid traps were used in the first two years of the study and panel traps were used in the last two years. The best results were obtained in 2017 when the AK treatment consisted of the LLIN placed in the tree with attractant bait (Table 1).

Fig 1. Baited tree with LLIN

Table 1.

Treatment	% Injury ± SE
Baited Trees + LLINS	2.0 ±1.0 A
Grower Standard	13.0 ± 2.0 B

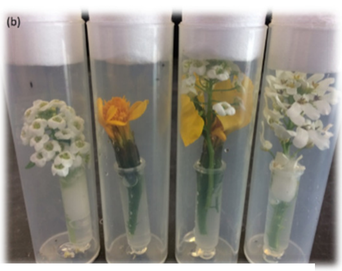
Objective 3. Develop management tools and strategies that are compatible with biological control and informed by risk from landscape factors.

Project: Habitat management and enhancing biological control of BMSB

Background: Natural enemies, such as predators and parasitoids, can suppress BMSB populations. Most work has focused on targeting the egg stage of BMSB, although there are a few reports on biological control of BMSB nymphs and adults. Predators may consume 10-30% of egg masses in the field. Egg parasitism by resident parasitoids is ~1-18%, and the recently discovered *Trissolcus japonicus* parasitizes 60-90% of eggs in its native range of Asia. Given the potential of these natural enemies and need to develop sustainable management, we are studying how to encourage natural enemies with floral insectary plants (habitat management). These flowers can attract natural enemies and provide them with nectar and pollen. It may also be advantageous to combine habitat management with augmentative releases of *T. japonicus*, so we are examining these practices in combination and rearing methods.

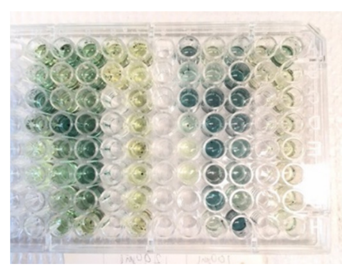
What was done:

1) We compared the longevity of *T. japonicus* on buckwheat, sweet alyssum, and Nema-gone marigolds in lab assays. Small groups of newly emerged *T. japonicus* were maintained in vials with bouquets of flowers changed 3 times a week, and compared to a water control, and a honey positive control. We also verified how well-fed wasps were when given the different flowers. Before doing this, we developed two lab protocols to assist studies with *T. japonicus* feeding, a quick-crush method to confirm feeding, and a detailed method to determine nutritional status by measuring lipid, glycogen, and sugar levels.



Longevity assays

Lab bench testing (Victoria Skillman, grad student)

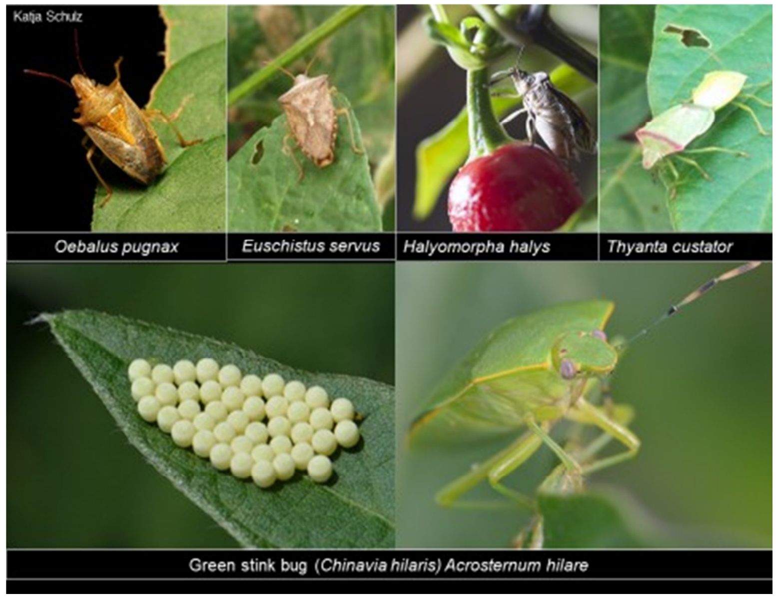


Pretty colors from nutrient assays

2) Field studies compared stink bugs of multiple species in edamame, and how this was impacted by borders of French marigold. The number of egg masses of all species were counted, and recorded for fate: parasitism, predation, and hatching.

3) To assist augmentative releases, we compared variously harvested BMSB egg masses for producing *T. japonicus:* whether eggs were fresh or frozen, eggs were collected within 0-3 days (Monday eggs) or within 1 day, and frozen eggs stored for a few weeks to several years.

Marigold borders



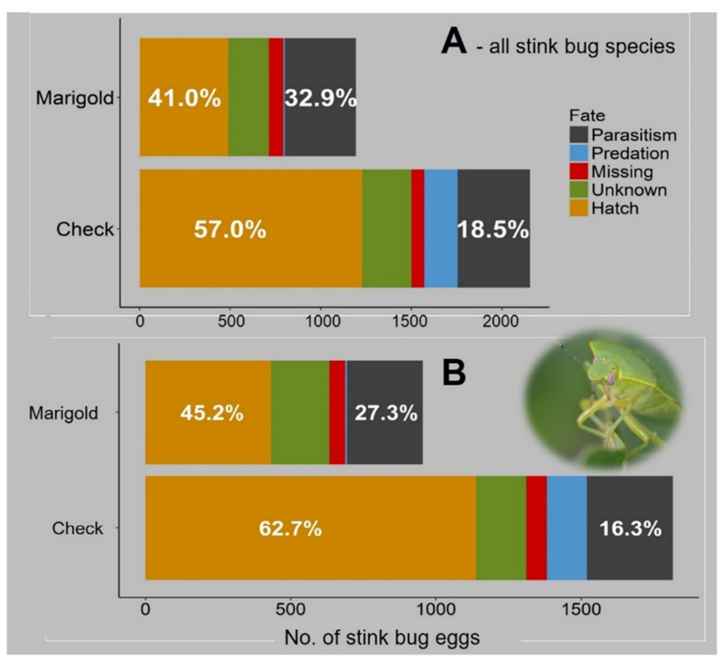
Various stink bug pests

Results:

1) Buckwheat flowers enhanced longevity of *T. japonicus* in the lab. Sweet alyssum and marigold had no or modest impacts which may explain why 2017 field trials with these floral species were disappointing. Protocols to confirm feeding and nutrient gain are published and available.

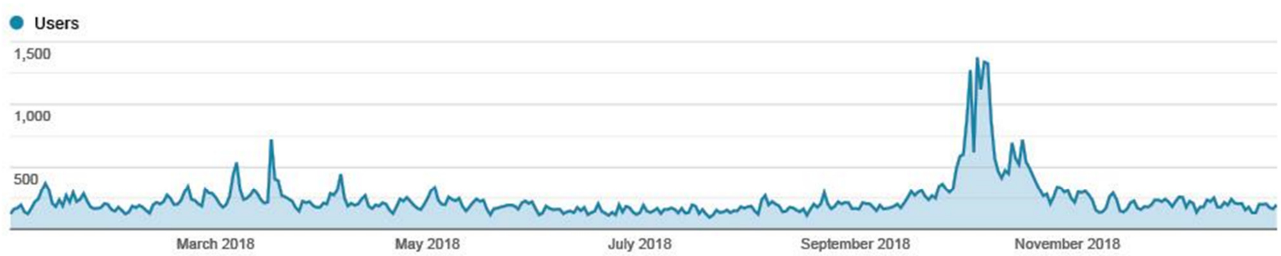
2) The presence of marigold borders resulted in fewer stink bug egg masses found, and higher parasitism rates for all species and green stink bugs (graph).

3) Parasitism rates, development time, size of emerging wasps, and sex ratios were compared with different BMSB egg masses. Monday-collected eggs (0-3 days old) were suitable for rearing *T. japonicus*. Fresh eggs were better than frozen eggs. However, if only frozen eggs are available, they can be used for the short-term with no apparent impact on sex ratio.



Objective 5. Outreach – Deliver New Information on BMSB to Stakeholders.

StopBMSB.org: The website StopBMSB.org was launched in 2012 under the first BMSB SCRI grant and is maintained by the Northeastern IPM center. It has expanded to include information on regions newly invaded by BMSB, with more collaborators added from the Midwest, West, and South. It has been updated to include new topics such as: BMSB biological control, best management practices, economics, landscape ecology, and outreach. It is a vital hub for sharing up-to-date information with commodity organizations, growers, the public, and the scientific community. In addition to information on the basic biology and identification of the pest, lists of host plants, and management tactics it includes a widely used and cited interactive map, publications, Spanish resources, updates, videos, and more. Users are being tracked by state to see if there is a frontier effect, with an increase in users in states in which the bug has newly invaded and decreases in users visiting the site from states that may already have knowledge of BMSB. New articles added to the site in 2018 include: *Scientists Deploy Attract-and-Kill Trees against Stink Bugs*, *Samurai Wasp (Trissolcus japonicus)* (detailing field recoveries with a map of locations), *Behavioral- and Landscape-Based Management: IPM Crop Perimeter Restructuring*. StopBMSB.org had 80,663 unique visitors in 2018.

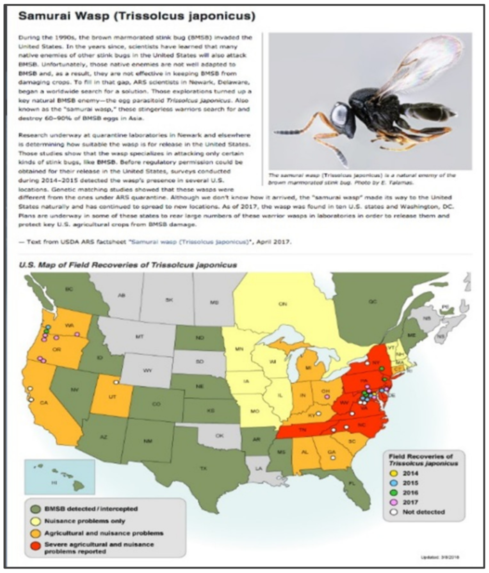


Visits to StopBMSB.org spike near Oct. 1 every year. This timing coincides with BMSB entering homes to overwinter and more media coverage of the pest.

The yearly number of unique visitors to StopBMSB.org in 2018 has doubled compared to 2013.

Lifetime Views	
Total (all videos combined)	**70,602**
Pt. 1: History and Identification	29,143
Pt. 10: Biological Control	10,398
Pt. 6: Host Plants & Damage in Vegetables	7,209
Pt. 2: Overwintering and Spread	4,470
Pt. 3: Monitoring and Mapping	4,366
Pt. 9: Management	2,813
Pt. 4: Host Plants & Damage in Orchard Crops	1,788
. . .	

StopBMSB.org offers a highly-viewed 10-part video series, “Tracking the Brown Marmorated Stink Bug,” plus 4 Research Update videos. Lifetime views are listed.



Samurai Wasp (Trissolcus japonicus)

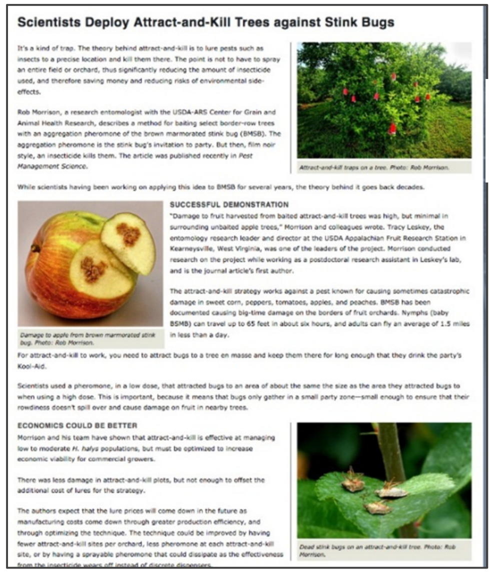
During the 1990s, the brown marmorated stink bug (BMSB) invaded the United States. In the years since, scientists have learned that many native enemies of other stink bugs in the United States will also attack BMSB. Unfortunately, those native enemies are not well adapted to BMSB and, as a result, they are not effective in keeping BMSB from damaging crops. To fill in that gap, ARS scientists in Newark, Delaware, began a worldwide search for a solution. Those explorations turned up a key natural BMSB enemy—the egg parasitoid *Trissolcus japonicus*. Also known as the "samurai wasp," these stingerless warriors search for and destroy 60–90% of BMSB eggs in Asia.

Research underway at quarantine laboratories in Newark and elsewhere is determining how suitable the wasp is for release in the United States. Those studies show that the wasp specializes in attacking only certain kinds of stink bugs, like BMSB. Before regulatory permission could be obtained for their release in the United States, surveys conducted during 2014–2015 detected the wasp's presence in several U.S. locations. Genetic matching studies showed that these wasps were different from the ones under ARS quarantine. Although we don't know how it arrived, the "samurai wasp" made its way to the United States naturally and has continued to spread to new locations. As of 2017, the wasp was found in ten U.S. states and Washington, DC. Plans are underway in some of these states to rear large numbers of these warrior wasps in laboratories in order to release them and protect key U.S. agricultural crops from BMSB damage.

The samurai wasp (Trissolcus japonicus) is a natural enemy of the brown marmorated stink bug. Photo by E. Talamas.

— Text from USDA ARS factsheet "Samurai wasp (Trissolcus japonicus)", April 2017.

U.S. Map of Field Recoveries of Trissolcus japonicus



Scientists Deploy Attract-and-Kill Trees against Stink Bugs

It's a kind of trap. The theory behind attract-and-kill is to lure pests such as insects to a precise location and kill them there. The point is not to have to spray an entire field or orchard, thus significantly reducing the amount of insecticide used, and therefore saving money and reducing risks of environmental side-effects.

Rob Morrison, a research entomologist with the USDA-ARS Center for Grain and Animal Health Research, describes a method for baiting select border-row trees with an aggregation pheromone of the brown marmorated stink bug (BMSB). The aggregation pheromone is the stink bug's invitation to party. But then, film noir style, an insecticide kills them. The article was published recently in *Pest Management Science.*

Attract-and-kill traps on a tree. Photo: Rob Morrison.

While scientists having been working on applying this idea to BMSB for several years, the theory behind it goes back decades.

Damage to apple from brown marmorated stink bug. Photo: Rob Morrison.

SUCCESSFUL DEMONSTRATION

"Damage to fruit harvested from baited attract-and-kill trees was high, but minimal in surrounding unbaited apple trees," Morrison and colleagues wrote. Tracy Leskey, the entomology research leader and director at the USDA Appalachian Fruit Research Station in Kearneysville, West Virginia, was one of the leaders of the project. Morrison conducted research on the project while working as a postdoctoral research assistant in Leskey's lab, and is the journal article's first author.

The attract-and-kill strategy works against a pest known for causing sometimes catastrophic damage in sweet corn, peppers, tomatoes, apples, and peaches. BMSB has been documented causing big-time damage on the borders of fruit orchards. Nymphs (baby BSMB) can travel up to 65 feet in about six hours, and adults can fly an average of 1.5 miles in less than a day.

For attract-and-kill to work, you need to attract bugs to a tree en masse and keep them there for long enough that they drink the party's Kool-Aid.

Scientists used a pheromone, in a low dose, that attracted bugs to an area of about the same the size as the area they attracted bugs to when using a high dose. This is important, because it means that bugs only gather in a small party zone—small enough to ensure that their rowdiness doesn't spill over and cause damage on fruit in nearby trees.

ECONOMICS COULD BE BETTER

Morrison and his team have shown that attract-and-kill is effective at managing low to moderate *H. halys* populations, but must be optimized to increase economic viability for commercial growers.

There was less damage in attract-and-kill plots, but not enough to offset the additional cost of lures for the strategy.

The authors expect that the lure prices will come down in the future as manufacturing costs come down through greater production efficiency, and through optimizing the technique. The technique could be improved by having fewer attract-and-kill sites per orchard, less pheromone at each attract-and-kill site, or by having a sprayable pheromone that could dissipate as the effectiveness from the insecticide wears off instead of discrete dispensers.

Dead stink bugs on an attract-and-kill tree. Photo: Rob Morrison.

New articles on StopBMSB.org in 2018

<u>Inspire next generation of invasive pest experts:</u> This project is playing a major role in training the next generation of scientists. Students are learning research techniques in agricultural entomology, ecology, insect behavior, microbiology, integrated pest management, and more. Training opportunities for 25 graduate students and 20 Postdoctoral researchers have been made available through this project directly and indirectly. This graduate students include international students, as the project moves to expand its reach, train students in other invaded areas, and collaborate with researchers in other countries. Two post-doctoral researchers completed their work and became faculty members at universities in 2018, continuing their entomological research. Additionally, 80 undergraduate students were either directly supported or worked on research supported by the project.

Publications		Presentations	
Research journal	18	Research conferences	55
Proceedings/abstracts	4	Extension meetings	113
Extension	16	Workshops	14
Trade journal articles	6		
News/broadcasts	37		

Number of BMSB publications and presentations between December 2017 and December 2018.

Graduate student research: sentinel egg mass deployment (left) and BMSB caged on hemp (above).

PROJECT OUTPUTS

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Farmington Daily Times. The battle of the bugs: Wasps to combat upstate stink bugs. Sarah Taddeo (reporter). P Jentsch featured. Mar 16, 2017. https://www.daily-times.com/story/news/2017/03/ 16/battle-bugs-wasps-combat-upstate-stink-bugs/99252376/

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Patch. Get Rid Of Stink Bugs: National Citizen Scientist Project: They've discovered how to eradicate the Brown Marmorated Stink Bug, so scientists are trying to map the invasive insect across the USA. Lanning Taliaferro (reporter, Patch staff). P Jentsch featured. Mar 10, 2017. https://patch.com/new-york/newcity/help-find-stinky-national-citizen-scientist-project

Penn State News. Wasp warriors: entomologists on samurai mission to slay stink bugs. Jeff Mulhollem (reporter). H Peterson and G Krawczyk featured. May 2018. https://news.psu.edu/story/521917/2018/05/16/academics/wasp-warriors-entomologists-samurai-mission-slay-stink-bugs?

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Seattle Times. Local researcher is breeding an army of wasps to devour invasive stink bugs. Katherine Long (reporter). J Milnes, K Hoelmer, EH Beers featured. Aug 23, 2018. https://www.seattletimes.com/seattle-news/a-local-researcher-is-breeding-an-army-of-wasps-to-devour-invasive-stink-bugs/

Seattle Times. WSU: Destructive stink bugs infest King, Pierce and Thurston Counties. AP. M Bush and EH Beers featured. Apr 17, 2018. https://www.seattletimes.com/seattle-news/wsu-stink-bugs-infesting-king-pierce-and-thurston-counties/

Star Tribune. Keep an eye out for the BMSB, and yes there's an app for that. Adam Belz (reporter). R Koch and W Hutchison interview. Aug 2018. http://www.startribune.com/keep-an-eye-out-for-the-brown-marmorated-stink-bug-and-yes-there-s-an-app-for-that/491132461/

Statesman Journal. Oregon hopes 'samurai wasp' will battle invasive brown marmorated stink bug. Tracy Loew (reporter). K Hoelmer, N Wiman, P Jenstch featured. Mar 23, 2017. https://www.nrtoday.com/oregon-hopes-samurai-wasp-will-battle-invasive-brown-marmorated-stink/article_3a756bc5-0388-563e-90f6-696bdb197dc6.html

The Beacon-News and the Chicago Tribune. If it's autumn, it is stink bug season in Aurora. Interview with David Sharos (reporter, The Beacon-News) and Kate Thayer (reporter, The Chicago Tribune). T Kuhar featured. Oct 11, 2017. https://www.chicagotribune.com/suburbs/aurora-beacon-news/news/ct-abn-stink-bugs-st-1006-20171005-story.html

The Olympian. Berry-sized bugs have caused millions in damages in Mid-Atlantic states. Camille Lemke (reporter). EH Beers and M Bush featured. Mar 16, 2018 https://www.theolympian.com/news/local/article205574034.html

The Poughkeepsie Journal. It's war! Against stinkbugs. Amy Wu (reporter). P Jentsch and K Hoelmer featured. Dec 20, 2017. https://www.poughkeepsiejournal.com/story/news/2017/12/20/its-war-against-stinkbugs/942109001/

The Poughkeepsie Journal. Stink bugs: What to know. Geoffrey Wilson and Sarah Taddeo (reporters). P Jentsch featured. Oct 3, 2017. https://www.poughkeepsiejournal.com/story/news/health/2017/10/03/stink-bugs-2017/725639001/

Today. Why stink bug populations are booming (and what you can do about it). Embry Roberts (reporter). P Jentsch featured. Oct 19, 2017.

Tribune Review. Answer for controlling stink bugs may rest with other pests. Jeff Himler (reporter). H Peterson featured. May 20, 2018. https://triblive.com/local/regional/13660987-74/answer-for-controlling-stink-bug-population-may-rest-with-other-pests

Utah Public Radio. Invasive insect pests in Utah. DG Alston interview. Green Thumb Tips (aired between NPR "All Things Considered" show segments). Logan, UT. Sep 19, 2017.

WBKO Bowling Green. Stink bugs and other fall invaders. Sep 4, 2018. Audience of 24,000.

Westchester Magazine. Scientists wage war on stink bugs. Jonathan Ortiz (reporter). P Jentsch featured. Mar 13, 2017. http://www.westchestermagazine.com/Scientists-Wage-War-on-Stink-Bugs/

Western IPM Center. Can caging orchards protect apples? EH Beers featured. Sep 2018. http://westernipm.org/index.cfm/ipm-in-the-west/agriculture/can-caging-orchards-protect-apples/

WHYY radio. Asian wasps arrival in S. Jersey brings hope to scientists, farmers fighting stink bugs. Catalina Jaramillo (reporter). Aug 30, 2018.

WHYY. Asian wasp's arrival in S. Jersey brings hope to scientists, farmers fighting stink bugs. Catalina Jamarillo (reporter). A Nielsen, K Hoelmer, K Rice featured. Aug 30, 2018. https://whyy.org/segments/asian-wasps-arrival-in-s-jersey-brings-hope-to-scientists-farmers-fighting-stink-bugs/

WSU Insider. Tiny Samurai wasps deployed to fight stink bug invasion. J Milnes featured. Aug 15, 2018. https://news.wsu.edu/2018/08/15/tiny-samurai-wasps-deployed-fight-stink-bug-invasion/

Research Conference Presentations

Akotsen-Mensah, C, T Leskey, C Bergh and AL Nielsen. Nov 2017. IPM-CPR in apples and peaches. BMSB Areawide and Working Group, Winchester, VA.

Alston, DG, LR Spears, MC Holthouse and ZR Schumm. Jun 10-13, 2018. Impact of BMSB on fruit and vegetable production in Utah, a Mountain West state. Pacific Branch of the Entomological Society of America 102nd Annual Meeting, Reno, NV.

Beers, EH, AT Marshall, JM Milnes and J Hepler. Jan 18-19, 2018. Management strategies for the oncoming brown marmorated stink bug invasion. Utah State Horticultural Association, Spanish Fork Fairground, Spanish Fork, UT.

Beers, EH. Jun 12, 2018. Preventative restoration of IPM for brown marmorated stink bug in Washington tree fruits. Entomological Society of America, Pacific Branch Meeting, Reno, NV.

Bergh, JC, TC Leskey and BD Short. Mar 9, 2018. Pheromone-based trap thresholds for BMSB: Current status and potential applications. USAID/CNFA/REAP Scientific Mission Conference, Tblisi, Georgia.

Bergh, JC, TC Leskey, BD Short, WR Morrison, G Krawczyk and AL Nielsen. Mar 9, 2018. Attract-and-kill for BMSB: Promising results from the Mid-Atlantic, USA. USAID/CNFA/REAP Scientific Mission Conference, Tblisi, Georgia.

Bergh, JC. Mar 9, 2018. Opportunities to reduce adult BMSB populations during its dispersal to overwintering sites. USAID/CNFA/REAP Scientific Mission Conference, Tblisi, Georgia.

Bergh, JC, NF Quinn, WT Hadden, and JP Engelman. 2018. Response of adult Halyomorpha halys to insecticide-treated netting during its autumn dispersal phase: Results from 2018. Cumberland-Shenandoah Fruit Workers Conference, Nov 29-30, Winchester, VA.

Bergh, JC, A Edwards, K Lawrence, K Reed, and EJ Talamas. 2018. Monitoring and redistribution releases of Trissolcus japonicus in Virginia. Entomological Society of America, Nov 11-14, Vancouver, BC, Canada.

Chiginsky, J, and R Hilton. Jun 2018. Incidental stink bug captures in BMSB traps in southern Oregon. Entomological Society of America, Pacific Branch meeting. Reno, NV.

Fann, L (presenter and author), RT Bessin, RT Villanueva. Nov 2018. Predation and parasitism assessment of sentinel and naturally occurring egg masses of the brown marmorated stink bug. ESA annual meeting, Vancouver, Canada.

Fisher, JJ, C Ingels, R Jhalendra and F Zalom. Jun 13, 2018. The impact of temperature on the brown marmorated stink bug, Halyomorpha halys, in California. PB-ESA meeting, Reno, NV.

Fisher, J, J Rijal, C Ingels, and F Zalom. 2018. The role of temperature and humidity on BMSB population outbreaks in California. Entomological Society of America, Nov 11-14, Vancouver, BC, Canada.

Formella, AJ and TP Kuhar. May 23-25, 2018. Survivorship of brown marmorated stink bug on select vegetables under laboratory conditions. Virginia Academy of Science 96th Annual Meeting, Farmville, VA.

Hadden, WT, TC Leskey, and JC Bergh. 2018. Big picture, small picture: Why does BMSB population density exhibit site-specific differences? Cumberland-Shenandoah Fruit Workers Conference, Nov 29-30, Winchester, VA

Hadden, WT, TC Leskey and JC Bergh. 2018. Host plant effects on seasonal captures of Halyomorpha halys in Virginia. Entomological Society of America, Nov 11-14, Vancouver, BC, Canada.

Hepler, J, A Marshall, J Milnes, and EH Beers. BMSB in the shrub-steppe: Parasitoids, purshia, and proteins. Entomological Society of America National Meeting, Vancouver, BC. Nov 14, 2018.

Hoelmer, K. Nov 2019. “Accidental versus intentional introductions of parasitoids against brown marmorated stink bug” in ESA Program Symposium: Crossing Borders Without Permission: Accidental Introduction of Biological Control Agents, a Significant Phenomenon with Risks, Benefits, and Policy Implications. Ent. Soc. America annual meeting, Vancouver, BC, Canada.

Hoelmer, K, et al. Mar 17-19, 2018. Current distribution of the samurai wasp, *Trissolcus japonicus*, in North America. Poster, Eastern Branch Entomological Society of America, Annapolis MD.

Hoelmer, K, et al. Mar 19-22, 2018. Current distribution of the samurai wasp, *Trissolcus japonicus*, in North America. Poster, International Symposium of IPM, Baltimore, MD.

Hoelmer, K. Jun 13, 2018. 2018 Update: Pest status and biological control of *Halyomorpha halys* in invaded ranges. Invited seminar, Chinese Academy of Forestry, Beijing, China.

Holle, S, EC Burkness, R Koch and WD Hutchison. November 11-13, 2018. Lethal effects of conventional and certified organic insecticides on the parasitic wasp, *Trissolcus japonicus*, a parasitoid of the brown marmorated stink bug, Halyomorpha halys. Poster presentation, Entomol. Soc. Am., national meeting, Vancouver, BC.

Holthouse, MC, DG Alston and LR Spears. Jun 10-13, 2018. Brown marmorated stink bug in the urban landscape of northern Utah: host plants, trap efficacy and biological control. Pacific Branch of the Entomological Society of America 102nd Annual Meeting, Reno, NV.

Jentsch, P. Nov 29, 2017. Redistribution of *Trissolcus japonicus* in NYS Orchards. BMSB IPM Working Group, Winchester, VA. (Audience: 45, 20 min)

Jentsch, P. Feb 21, 2018. Expanding the range for establishing the samurai wasp, *Trissolcus japonicus*, in orchards and vegetable crops of NYS. The Desmond Conference Center, Albany, NY. (Audience: 320, 20 min)

Jentsch, P. Feb 28, 2018. Monitoring and management of the stink bug complex in the Northeast. Red Tomato – Annual Growers Meeting, Henry A. Wallace Center, FDR Presidential Library, Hyde Park, NY. (Audience: 40, 60 min)

Jentsch, P. Feb 8, 2018. Old, new and novel tools for management of the Asian invasive brown marmorated stink bug. SW Horticultural Days, Benton Harbor, MI. (Audience: 45, 20 min)

Jentsch, P. Feb 8, 2018. Redistribution of Trissolcus japonicus in NYS orchards. SW Horticultural Days, Benton Harbor, MI. (Audience: 45, 30 min)

Jentsch, P. Mar 19, 2018. Redistribution of Trissolcus japonicus in NYS orchards, Entomological Society of America Eastern Branch Meeting, 89th Annual Meeting of the Eastern Branch of the Entomological Society of America, Annapolis, MD. (Audience: 55, 20 min)

Jentsch, P. Results of 2018 Insecticide efficacy screening studies. Oct 10th, 2018. HVRL IPM Workshop, Highland, NY. (Audience: 21, 60 min)

Jentsch, P. Biologicals: What are they and do they really work? Nov 27, 2018. Connecticut Pomological Society, Annual Meeting, Middletown Elks Lodge, 44 Maynard St, Middletown, CT.

Lara, JR, C Pickett and MS Hoddle. Jun 12, 2018. Biological control of brown marmorated stink bug in California. 102nd Pacific Branch ESA Annual Meeting. Reno, NV.

Lara, JR, C Pickett and MS Hoddle. Jun 13, 2018. Prospects and challenges: safety testing with samurai wasp for classical biological control of brown marmorated stink bug in Califorina. 102nd Pacific Branch ESA Annual Meeting. Reno, NV.

Lauren, F (presenter), RT Bessin, RT Villanueva. Mar 2018. ESA NCB meeting, "Biological control of the brown marmorated stink bug, Halymorpha halys, in Kentucky.," North Central Branch of ESA, Madison, WI.

Leskey, T, WR Morrison, BR Blaauw, BD Short, KB Rice, A Acebes-Doria, AL Nielsen, JC Bergh, G Krawczyk, Y-L Park, B Butler and DW Weber. 2018. Management of the invasive brown marmorated stink bug in apple orchards using pheromone-based technologies. 9th International IPM Symposium, Baltimore, MD.

Lowenstein, DM, and V Walton. Jun 2018. Episodic cold shock and its effects on Halyomorpha halys diapause survival and emergence behavior. Entomological Society of America - Pacific Branch meeting. Reno, NV.

Marshall, AT, and EH Beers. Feb 14, 2018. Orchard netting in our valley. Science in our Valley, Wenatchee, WA.

Marshall, AT, and EH Beers. Jun 11, 2018. Utilizing migration behavior for exclusion of stink bugs from apple orchards. Entomological Society of America, Pacific Branch Meeting, Reno, NV.

Marshall, A, and EH Beers. Exploiting migration behavior as a novel control tactic for stink bugs. Entomological Society of America National Meeting, Vancouver, BC. Nov 14, 2018.

McIntosh, H, G Galindo, D Lowenstein, N Wiman, and J Lee. 2018. Host egg and floral resources for Trissolcus japonicus. Entomological Society of America, Vancouver, Canada, Nov 2018.

Milnes, JM, and EH Beers. Jun 11, 2018. Brown marmorated stink bug biological control options in Washington State. Entomological Society of America, Pacific Branch Meeting, Reno, NV.

Milnes, JM, and EH Beers. Biological control of the brown marmorated stink bug in eastern Washington. Entomological Society of America National Meeting, Vancouver, BC. Nov 14, 2018.

Mulder, P, B Lingren, C Bergh, K Hoelmer, and G Krawczyk. 2018. Developing an areawide approach to management of the brown marmorated stink bug, Halyomorpha halys, in Georgian hazelnuts, a cooperative effort of industry, university, and USDA personnel. Entomological Society of America, Nov 11-14, Vancouver, BC, Canada.

Nielsen, AL. 2018. Developing a trap crop method for BMSB based on insect behavior. 9th International IPM Symposium, Baltimore, MD.

Nielsen, AL. 2018. What growers and crop advisors need to know about managing brown marmorated stink bug based on the latest research. 9th International IPM Symposium, Baltimore, MD.

Ogburn, EC, and JF Walgenbach. 2018. Comparison of biological control of the brown marmorated stink bug among habitat types: Sentinel egg mass assessment of parasitoid and predator impact under different pest management systems. Entomological Society of America Annual Meeting. Nov 11, 2018, Vancouver, BC, Canada.

Ogburn EC and JF Walgenbach. 2018. Parasitoid impact on brown marmorated stink bug under differing management programs: a comparison of egg fates in corn and apple agroecosystems in North Carolina. Cumberland-Shenandoah Fruit Workers Conference. Nov 29, Winchester, VA.

Pagani, MK, HG Bush and TP Kuhar. May 23-25, 2018. Efficacy of apritone repellent on Halyomorpha halys. Virginia Academy of Science 96th Annual Meeting, Farmville, VA.

Preston, C. Presence of Nosema maddoxi in Halyomorpha halys populations in eastern and western U.S. ESA, ESC and ESBC Joint Annual Meeting, Vancouver, BC, Canada. Nov 2018. (Audience: 90, 10 min).

Quinn, NF, EJ Talamas, TC Leskey, and JC Bergh. 2018. Trapping Trissolcus japonicus in Virginia: Habitat and host plant effects. Cumberland-Shenandoah Fruit Workers Conference, Nov 29-30, Winchester, VA.

Quinn, NF, EJ Talamas, TC Leskey, and JC Bergh. 2018. Trapping Trissolcus japonicus in Virginia: Seasonal phenology and patch size effects. Entomological Society of America, 11-14 Nov, Vancouver, BC, Canada.

Rijal, J, R Duncan, J Fisher, F Zalom. Jun 10-13, 2018. Seasonal phenology and damage characterization by BMSB feeding in almond and peach in California. PB-ESA meeting, Reno, NV.

Rijal, J, A Medina, J Fisher, and F Zalom. 2018. Biology, monitoring, and management of brown marmorated stink bug (BMSB) in almond orchards. Entomological Society of America, 11-14 Nov, Vancouver, BC, Canada.

Rijal, J, J Fisher, and F Zalom. 2018. Story of the BMSB invasion into California agriculture, including almonds—a five-billion dollar industry. Entomological Society of America, 11-14 Nov, Vancouver, BC, Canada.

Schoof SC and JF Walgenbach. 2018. Agroecosystem effects on BMSB pheromone trap capture and damage in NC apple orchards. Cumberland-Shenandoah Fruit Workers Conference. Nov 30, Winchester, VA.

Schumm, ZR, DG Alston and LR Spears. Jun 10-13, 2018. Brown marmorated stink bug overwintering success and survey for natural enemies in Utah. Pacific Branch of the Entomological Society of America 102nd Annual Meeting, Reno, NV.

Spears LR, DG Alston, MC Holthouse, Z Schumm and C Cannon. Jan 19, 2018. Invasive fruit pest update. Utah State Horticultural Association, Spanish Fork, UT.

Spears LR. Apr 9, 2018. Brown marmorated stink bug: a new threat to Utah agriculture. Weber State University, Ogden, UT.

Walgenbach JF, SC Schoof and EC Ogburn. 2018. Phenology and relation of BMSB pheromone trap captures to damage in NC apples. Orchard Pest & Disease Management Conference. Jan 11, Portland, OR.

Walgenbach JF. 2018. Management of BMSB in US specialty crops. Poster at 2018 USDA-NIFA Specialty Crops Research Initiative Project Directors Meeting. July 31, Washington DC.

Walgenbach JF. 2018. Managing SCRI large projects, presented in symposium "Tactics for success in Specialty Crops Research Initiative." Am Soc Hort Sci Annual Meeting. Aug 1, Washington DC.

Weber, D, A Wallingford, R Morrison, T Leskey and A Khrimian. Aug 2018. Invasive stink bugs: Semiochemical patterns and application of cross-attraction, synergy, and component ratios. International Society of Chemical Ecology annual meeting, Budapest, Hungary. (invited symposium talk)

Extension presentations

Alston, DG. Nov 16, 2017. IPM for tree fruit pests. Utah Fruit School, Spanish Fork, UT.

Alston, DG. Feb 13-15, 2018. IPM concepts and common fruit and vegetable insect and mite pests. USU Extension Master Gardener Course. West Jordan, Lehi and Provo, UT.

Alston, DG. Feb 6-8, 2018. IPM for the garden and landscape. USU Extension Master Gardener Course. Kanab, Hurricane and Cedar City, UT.

Beers, EH, A Marshall, J Milnes, and J Hepler. Invasive species: the new normal. Washington State Tree Fruit Association Annual Meeting, Yakima, WA. Dec 5, 2018.

Bergh, JC. Apr 3 - Aug 28, 2018. Tree fruit pest management update. Nine "In-orchard" and "Twilight" meetings, various locations throughout northern and southwest VA.

Bergh, JC. Apr 5 - May 31, 2018. Tree fruit pest management update. Five "In-Depth" and Breakfast meetings at Virginia Tech research and extension center, Winchester, VA.

Bessin, R. Dec 4, 2017. Emerging insect pests of grain crops. 2017 Western Kentucky Pesticide Workshop. Russelville, KY. (Audience: 80, 60 min)

Bessin, R. Dec 7, 2017. Invasive insect pests of grain crops. 2017 Central Kentucky Pesticide Workshop. Lancaster, KY. (Audience: 14, 60 min)

Bessin, R. Feb 28, 2018. Managing vegetable pests and pollinators. Allen Co., Perryville Market. Perryville, KY. (Audience: 22, 180 min)

Bessin, R. Feb 28, 2018. Managing vegetable pests and pollinators. Hart Co. Produce Auction. Munfordville, KY. (Audience: 25, 180 min)

Bessin, R. Jan 24, 2018. Problem vegetable pests of 2017. Lincoln Co. Produce Auction, Crab Orchard, KY. (Audience: 65, 30 min)

Bessin, R. Jan 25, 2018. Managing stink bugs and Japanese beetle. KLNI, Louisville, KY. (Audience: 68, 60 min)

Bessin, R. Jan 30, 2018. Problem vegetable pests. Daviess Co., Owensboro, KY. (Audience: 23, 60 min)

Bessin, R. Mar 19, 2018. Pest management for vegetable gardens. Greenville, KY. (Audience: 8, 60 min)

Bessin, R. Mar 19, 2018. Sustainable pest management for arthropod pests of vegetables. Fleming Co. Farmers Market. Flemingsburg, KY. (Audience: 42, 60 min)

Bessin, R. Mar 7, 2018. 2017 studies in row crops. IPM field school. Hopkinsville, KY. (Audience: 30, 60 min)

Bessin, R. Nov 2, 2017. Entomology research studies at the UK Hort. Farm. 2017 Kentucky Hort. Council Meeting. Lexington, KY. (Audience: 15, 20 min)

Bessin, R. Aug 23, 2018 - Present. 4 presentations given with total attendance of 35. Description: Boyd County, Vegetable insect management update.

Bessin, R. Feb 28, 2018 - Present. 2 presentations given with total attendance of 47. Description: Managing vegetable pests and pollinators (Allen and Hart Co).

Bessin, R. Apr 20, 2017 - Present. 2 presentations given with total attendance of 59. Description: Fruit bagging for pest management (Perry, Knott Co).

Bessin, R. May 3, 2018 - Present. 1 presentations given with total attendance of 35. Description: Apple IPM field day for commercial producers (Bourbon Co).

Bessin, R. Jul 18, 2017 - Present. 2 presentations given with total attendance of 22. Description: IPM for horticultural crops with CSA Interns (South Farm).

Bessin, R. Sep 15, 2018 - Present. 2 presentations given with total attendance of 35. Description: Mason, Fleming, Bath, Lewis, Pendleton Cos. Orchard and home fruit pest management.

Bessin, R. Mar 19, 2018 - Present. 2 presentations given with total attendance of 50. Description: Sustainable pest management for vegetables (Fleming, Muhlenburg Co)

Bessin, R. Mar 3, 2018 - Present. 1 presentations given with total attendance of 34. Description: Fruit bagging for pest management (Fleming and surrounding Co's).

Bessin, R. Jan 25, 2018 - Present. 1 presentations given with total attendance of 68. Description: Managing stink bugs and Japanese beetles at KLNI meeting (Jefferson Co.).

Bessin, R. Jan 24, 2018 - Present. 2 presentations given with total attendance of 88. Description: Problem insect pests of 2017 (Lincoln, Daviess Co)

Daane, K. Aug 2018. Update on arthropod pests of grapes. CSU Fresno’s Grape Day. Fresno, CA.

Doughty, H, and T Kuhar. Feb 21, 2018. Insect control update. Hampton Roads Fruit and Vegetable Conference, Chesapeake, VA.

Gut, L. Apr 2018. Insect management outlook for 2018. Ridge/Belding Spring Spray Meeting. Grand Rapids, MI.

Gut, L. Dec 2017. Apple insect pest management update. Michigan State Horticultural Society. Grand Rapids, MI.

Gut, L. Feb 2018. Latest findings on insect management in tree fruit. Southwest Michigan Horticultural Days, Benton Harbor, MI.

Gut, L. Jan 2018. Monitoring and management of key invasive tree fruit pests. Crop Production Services Specialty Crop Meeting. Mt. Pleasant, MI.

Gut, L. Mar 2018. Tree fruit insect and insecticide update and management options for 2018. Southeast MI Spring Tree Fruit Meeting. Flint, MI.

Hamilton, G. BMSB trapping and mid-season pests. South Jersey twilight, Mullica Hill. (25)

Hamilton,G. Midseason management of tree fruit pests. North Jersey twilight, Lebanon, NJ. (20)

Hepler, J, and EH Beers. Apr 3, 2018. Brown marmorated stink bug. Palouse and Panhandle Invasive Species and Exotic Pest Workshop, Pullman, WA.

Hilton, R. Jul 12, 2018. BMSB status and management. Southern Oregon Annual Pear Field Day, Central Point, OR.

Hutchison, WD. 2018. BMSB IPM. Total of 5 presentations to: MN Extension Service, county meetings (3), MN Fruit & Veg. Growers Assn., annual meeting. (1), MN Grape Growers Assoc., annual meeting (1).

Jentsch, P. Nov 13, 2017. Brown marmorated stink bug - what can we expect in 2018? Ag In-Service Fruit Track Presentations; Geneva, NY. (30 min)

Jentsch, P. Nov 2017. Northeast IPM Brown Marmorated Stink Bug Working Group Meeting, Virginia Agriculture Experiment Station, Winchester, VA.

Jentsch, P. Dec 20, 2017. Current research projects in entomology. HVRL Apple Forum, Hudson Valley Research Laboratory, Highland, NY. (Audience: 40, 25 min)

Jentsch, P. Feb 20, 2018. Expanding the range for establishing the samurai wasp, *Trissolcus japonicus* (Hymenoptera: Scelionidae) in orchards in NYS. Eastern NY Fruit & Vegetable School, Albany, NY.

Jentsch, P. Feb 7-8, 2018. Expanding the range for establishing the samurai wasp, *Trissolcus japonicus* (Hymenoptera: Scelionidae) in orchards in NYS. 2018 Horticultural Days - Southwest Michigan, Lake Michigan College, Benton Harbor, MI.

Jentsch, P. Brown marmorated stink bug management in northeastern orchards. Mississippi Valley Fruit Company, TruEarth Growers Meeting, Monday, Mar 27, 2018, 10:00 AM – 3:00 PM, The Green Mill Restaurant, 1025 Hwy 61 E, Winona, MN 55987. (Remote via GoToMeeting.com).

Krawczyk, G. Dec 5-6, 2018. BMSB management options. International Conference " Fighting against BMSB, *Halyomorpha halys*: experience, results and prospects." Georgian National Food Agency and AgriGeorgia, Tbilisi, Georgia.

Krawczyk, G. Feb 13, 2018. Brown marmorated stink bug update. Snyder County Tree Fruit Educational Meeting, Mifflinburg, PA.

Krawczyk, G. Feb 14, 2018. Brown marmorated stink bug update. Southeast Pennsylvania Tree Fruit Meeting, Leesport, PA.

Krawczyk, G. Feb 15, 2018. Brown marmorated stink bug update. Northeast Pennsylvania Tree Fruit Educational Meeting, Avoca, PA.

Krawczyk, G. Feb 16, 2018. New and evolving pests in commercial orchards. Western Maryland Regional Fruit Meeting. Keedysville, MD.

Krawczyk, G. Feb 16, 2018. Update on alternative methods to manage BMSB. Western Maryland Regional Fruit Meeting. Keedysville, MD.

Krawczyk, G. Feb 19, 2018. New and evolving pests in commercial orchards. President's Day Commercial Tree Fruit School. Biglerville, PA.

Krawczyk, G. Feb 23, 2018. Brown marmorated stink bug update. Appalachian Fruit Growers Meeting, Hollidaysburg, PA.

Krawczyk, G. Feb 27, 2018. Brown marmorated stink bug update. Erie County Tree Fruit Meeting, North East, PA.

Krawczyk, G. Feb 28, 2018. Brown marmorated stink bug update. Commercial Tree fruit School. Wexford, PA.

Kuhar, T. Aug 27, 2018. Stink bugs. On-Farm Twilight Vegetable Growers Meetings - 2018, Washington, VA.

Kuhar, T. Feb 20, 2018. Entomology update in vegetables. Southeast Virginia Vegetable Production Meeting, Holland, VA.

Kuhar, T. Feb 21, 2018. Insect management update. Richmond Area Vegetable Growers Meeting, Richmond, VA.

Kuhar, T. Feb 22, 2018. Vegetable insect pests and strategies to control them. Northern Piedmont 2018 Winter Vegetable School, Warrenton, VA.

Kuhar, T. Jan 10, 2018. Brown marmorated stink bug management. Virginia Tech Private and Commercial Applicator Recertification Course, Blacksburg, VA.

Kuhar, T. Jan9, 2018. Use of insecticide-impregnated netting. BMSB SCRI Stakeholder Advisory Panel Meeting, Portland, OR.

Kuhar, T. Mar 22, 2018. Vegetable insect pest update for Virginia. Roanoke and Botetourt Vegetable Grower's Meeting, Roanoke, VA.

Lara, JR, C Pickett and MS Hoddle. Aug 10, 2018. StoryTime touch-a-bug session host. Michelle Obama Neighborhood Public Library. Long Beach, CA.

Lara, JR, C Pickett and MS Hoddle. Jul 17, 2018. StoryTime guest book reader and touch-a-bug session host. Riverside Orange Terrace Public Library. Riverside, CA.

Lara, JR, C Pickett and MS Hoddle. Aug 16, 2018. A new pest threat for California? Biology and management of brown marmorated stink bug. California Association of Pest Control Advisers Meeting. Simi Valley, CA.

Lara, JR, C Pickett and MS Hoddle. Sep 13, 2018. Who's got the funk? Brown marmorated stink bug (BMSB) in California. California Association of Pest Control Advisers Meeting. Fresno, CA.

Lara, JR, C Pickett, and MS Hoddle. Sep 12, 2018. What's the big stink? Brown marmorated stink bug (BMSB) in California. California Association of Pest Control Advisers Meeting. San Diego, CA.

Lee, J. Dec 5, 2017. Earth-Natural enemies in nurseries. OR Association of Nurseries. Salem, OR.

Leskey, TC. 2018. Impact of BMSB on stone fruit and pears. Ontario Fruit and Vegetable Conference, Niagara Falls, Canada. (40+ stakeholders)

Leskey, TC. 2018. Pheromone-based monitoring and management tools for BMSB in apple. Ontario Fruit and Vegetable Conference, Niagara Falls, Canada. (100+ stakeholders)

Leskey, T. Sep 2018. Insect and disease management. Presentation and panel discussion, Urban Agriculture Symposium, ARS Beltsville Agricultural Research Center, Beltsville, MD.

Leskey, T. Sep 2018. Research to support detection, monitoring, and management of invasive species: brown marmorated stink bug as an example. Presentation to delegation from Kazakhstan (Agrohub KazNAU), ARS Beltsville Agricultural Research Center, Beltsville, MD.

Leskey, T. Nov 2017. Attractant for the brown marmorated stink bug. ARS Beltsville Agricultural Research Center presentation to Honorable Chris Van Hollen, U.S. Senator, Beltsville, MD.

Leskey, T. Oct 2017. Insect plusses and minuses: challenges for urban agriculture. Virginia Urban Agriculture Summit, George Mason University, Arlington, VA.

Lowenstein, DM. Aug 2018. Biological control of brown marmorated stink bug in hazelnut. Hazelnut summer tour, Aurora, OR. (868 attendees)

Lowenstein, DM. Feb 2018. More than a bad smell: Detection and control of the brown marmorated stink bug. Utah Urban and Small Farms Conference. West Jordan, UT.

Lowenstein, DM. Mar 2018. More than a bad smell: Detection and control of the brown marmorated stink bug. Landscape/Ornamental/Turf pest management course. La Grande, OR.

Lowenstein, DM. Oct 2018. Brown marmorated stink bug update. Oktoberpest meeting for nursery and greenhouse growers, North Willamette Research and Extension Center, Aurora, OR.

Marshall, A, and Beers, EH. Dec 14, 2017. Integrated stink bug management: Part II. GS Long recertification, GS Long, Chelan, WA.

Marshall, A, and E Beers. Jan 10-12, 2018. Netting applications for direct apple pest control. 92nd Orchard Pest and Disease Management Conference, Portland, OR.

Marshall, AT, and EH Beers. Feb 14, 2018. Orchard netting in our valley. Science in our Valley, Wenatchee, WA.

Marshall, AT, and EH Beers. Feb 2018. Pest update – stink bug. Wilbur-Ellis Co., Chelan, WA.

Marshall, AT, and EH Beers. Feb 2018. Washington stink bugs: background and current research. Manson Grower Meeting, Manson, WA.

Marshall, AT, and EH Beers. Jan 15, 2018. Native stink bug management. Chelan Fruit Day. Chelan, WA.

Marshall, AT, and EH Beers. Jan 2018. Current research on stink bug exclusion. Gebbers Farm, Organic Stink Bug Options. Brewster, WA.

Marshall, AT, and EH Beers. Jan 2018. Stink bug biology and management. Northwest Wholesale Pesticide Recertification Credit Meeting. Okanogan, WA.

Milnes, JM, and EH Beers. Jan 30, 2018. Integrative pest management and biological control of pests [Part I]. Master Gardener Program, Kennewick, WA.

Milnes, JM, and EH Beers. Nov 11, 2017. 2017 Update on the brown marmorated stink bug. Washington State Grape Society, Grandview, WA.

Milnes, JM, and EH Beers. Nov 16, 2017. An update on the distribution of the brown marmorated stink bug in WA and potential biocontrol options. 31st Pacific Northwest Vegetable Association, Kennewick, WA.

Milnes, JM, and EH Beers. Nov 8, 2017. The evolution of pest management practices in both agriculture & gardens. WSU Master Gardener Program Clark County, Vancouver, WA.

Milnes, JM, and EH Beers. Sep 23, 2017. Insect ID: Good guy vs bad guy. Central Washington Fair, Yakima, WA.

Milnes, JM, I Ozuna and EH Beers. Apr 11, 2018. Controlling horticultural pests with beneficial insects. Master Gardener Program, Yakima, WA.

Milnes, JM, I Ozuna and EH Beers. Jan 30, 2018. Integrative pest management and biological control of the brown marmorated stink bug in Washington State [Part I]. Master Gardener Program, Kennewick, WA.

Milnes, JM, I Ozuna and EH Beers. Jan 30, 2018. Integrative pest management and biological control of the brown marmorated stink bug in Washington State [Part II]. Master Gardener Program, Kennewick, WA.

Milnes, JM, M Bush, P Landolt, B Gerdeman and C Looney. Aug 10, 2018. Invasive bugs & BMSB workshop. Highline Community College, live in Des Moines, WA, live-streamed in Vancouver, WA and Mt. Vernon, WA.

Ogburn EC, A Hentz-Botz and JF Walgenbach. 2018. Assessment of native natural enemies on biological control of the brown marmorated stink bug. Tomato Field Day, Aug 16. MHCREC, Mills River, NC.

Peterson, HM, C Hirt, and G Krawczyk. Jul 2018. Brown marmorated stink bug biological control in Pennsylvania orchards. Penn State Fruit Research and Extension Center Centennial Celebration & Field Day. Biglerville, PA.

Pote, J, C Adams and L Gut. Dec 2017. Monitoring and trapping brown marmorated stink bug (poster). Michigan State Horticultural Society. Grand Rapids, MI.

Rijal, J. Aug 23, 2018. Major arthropods and their control in almond orchards. Meeting organized by Nutrient Ag Solution (Crop Production Services), San Luis Obispo, CA.

Rijal, JP. Apr 20, 2018. Seasonal pest management in almonds and updates on BMSB. Almond Board Pest Management CASP Field meeting, Modesto, CA.

Rijal, JP. Apr 4, 2018. Updates on BMSB spread and infestation. Tree and Vine IPM Breakfast meeting, Modesto, CA.

Rijal, JP. Jan 31, 2018. Navel orangeworm mating disruption and BMSB. Bayer Winter Meeting, Hilmar, CA.

Rijal, JP. Aug 29, 2018. Brown marmorated stink bug: identification, biology, and monitoring. PAPA Seminar, Modesto, CA.

Rijal, JP. Dec 6-8, 2017. New pest update: brown marmorated stink bug (BMSB). Annual Almond Board Conference, Sacramento, CA. (talk and poster)

Rijal, JP. Feb 15, 2018. Brown marmorated stink bug invasion in California: what's new? PAPA Seminar, Stockton, CA.

Rijal, JP. Jan 25, 2018. Brown marmorated stink bug: identification, biology, and status of the pest status in California. CAPCA Seminar, Tracy, CA.

Rijal, JP. Mar 14, 2018. Updates on brown marmorated stink bug invasion in California. PAPA Seminar, Sacramento, CA.

Rijal, JP. Oct 31, 2017. Be on the alert for brown marmorated stink bug (BMSB): ID, monitoring tools, and crops at risk. Extension talk at Mid-Valley PCA meeting, Oakdale, CA.

Schumm, ZR, and MC Holthouse. Sep 1, 2017 to April 16, 2018. Utah State University Insect Tours, Logan, UT. A total of nine separate 30-min presentations.

Spears, LR, C Cannon, DG Alston and MC Holthouse. Feb 26, 2018. Brown marmorated stink bug in fruit and vegetable crops in Utah. Utah State University Annual Extension Conference, Lehi, UT.

Spears, LR, DG Alston, MC Holthouse, Z Schumm and C Cannon. Feb 23, 2018. Brown marmorated stink bug and spotted wing drosophila. Urban and Small Farms Conference, West Jordan, UT.

Spears, LR, DG Alston, MC Holthouse, Z Schumm and C Cannon. Feb 22, 2018. Update on brown marmorated stink bug in Utah. Urban and Small Farms Conference, West Jordan, UT.

Spears, LR, DG Alston, MC Holthouse, Z Schumm and C Cannon. Feb 1, 2018. Brown marmorated stink bug and spotted wing drosophila. Northern Utah Fruit Growers Meeting, Brigham City, UT.

Spears, LR, C Cannon and DG Alston. Feb 26, 2018. Brown marmorated stink bug in fruit and vegetable crops in Utah. Utah State University Annual Extension Conference, Thanksgiving Point, UT.

Spears, LR, DG Alston, MC Holthouse, Z Schumm and C Cannon. Feb 23, 2018. Brown marmorated stink bug and spotted wing drosophila. Urban and Small Farms Conference, West Jordan, UT.

Spears, LR, DG Alston, MC Holthouse, Z Schumm and C Cannon. Feb 22, 2018. Update on brown marmorated stink bug in Utah. Urban and Small Farms Conference, West Jordan, UT.

Spears, LR, DG Alston, MC Holthouse, Z Schumm and C Cannon. Feb 1, 2018. Brown marmorated stink bug and spotted wing drosophila. Northern Utah Fruit Growers Meeting, Brigham City, UT.

Spears, LR, DG Alston, MC Holthouse, Z Schumm, and C Cannon. Jan 19, 2018. Invasive fruit pest update. Utah State Horticultural Association, Spanish Fork, UT.

Spears, LR. Apr 9, 2018. Brown marmorated stink bug: a new threat to Utah agriculture. Weber State University, Ogden, UT.

Walgenbach, JF. 2018. Brown marmorated stink bug management. Southeastern Apple Growers Association. Jan 10. Asheville, NC.

Walgenbach, JF. 2018. Apple insect and BMSB update. Blue Ridge Apple Growers Association. Feb 7. Hendersonville, NC.

Walgenbach, JF. 2018. Apple and peach insect update. Brush Mountain Tree Fruit Meeting. Mar 6. Wilkesboro, NC.

Walgenbach, JF. 2018. Selection of insecticides for key insect pests of tomatoes and peppers. Southeastern Vegetable Exp, Dec 15. Myrtle Beach, SC.

Walgenbach JF. 2018. Tree Fruit Insects: biology, ecology and management. Henderson County Master Pomology Class. Feb 13, Hendersonville, NC

Walgenbach JF and EC Ogburn. 2018. Good bugs and bad bugs: with particular reference to parasites of the brown marmorated stink bug. Transylvania County Master Gardner's, Mar 28. MHCREC, Mills River, NC.

Welty, C, J Jasinski and E Long. Jan 15, 2018. Improved monitoring network for new invasive insect pests in Ohio. Ohio Produce Network (Annual Conference of the Ohio Produce Growers & Marketers Association). Sandusky OH.

Welty, C. Jan 15, 2018. Monitoring and control of stink bugs and worms in fruit crops. Ohio Produce Network (Annual Conference of the Ohio Produce Growers & Marketers Association). Sandusky OH.

Wiman, NG, DL Lowenstein and H Andrews. Feb 9, 2018. Brown marmorated stink bug research and management update. Hood River Winter Horticulture Meeting. Hood River, OR. (150 attendees)

Zalom, F. Nov 28, 2018. Brown marmorated stink bug (BMSB) activity in CA crops, including almonds. Madera Ag Commissioner Office Meeting, Madera, CA.

Zalom, F. Dec 5, 2018. Brown marmorated stink bug update. Almond Board of California, Sacramento, CA.

Zalom, F. Dec 8, 2018. BMSB infestation in CA crops. Contra Costa Ag Commissioner CE Education, Knightsen, CA.

Conferences/Workshops

Alston, DG, and LR Spears. Feb 22-23, 2018. Hands-on pest identification and scouting methods. Utah Urban and Small Farms Conference, West Jordan, UT.

Alston, DG, and MS Murray. Jun 20, 2018. IPM for small acreage orchards. Utah State University Horticultural Research Field Day, Kaysville, UT.

Beers, EH. Aug 18, 2018. Invasive bugs & BMSB workshop. Highline Community College, Des Moines, WA. Presentations targeted for Master Gardeners, concerned citizens, backyard hobbyists, and growers. Included 6 presentations by WSU/USDA scientists and hands-on ID workshops.

Beers, EH. Aug 6, 2018. Farm Walk. Quincy, WA. Provided entomology expertise for an organic orchard pest management farm walk. The farm walk series is a farmer-to-farmer educational event hosted by organic, sustainable, and innovative farm and food businesses throughout Washington State. The Quincy farm walk was hosted by WSU Food Systems, WSU Center for Sustaining Agriculture and Natural Resources, and the Tilth Alliance in cooperation with Viva Farms and White Bear Orchards.

Entomological Society of America – Invasive Species Security Field Tour, Aug 20-22, 2018. Philadelphia, Lancaster, and Berks Counties, PA.

Jentsch, P. Oct 25, 2017. Field and laboratory based efficacy studies on BMSB using reduced-risk and short-PHI insecticides. New England, New York, Canadian Fruit Pest Management Workshop, Burlington, VT. (Audience: 55)

Leskey, T. Jun 2018. Insect pests and beneficials. Hour-long workshop at the Central Public Library, Arlington, VA.

Peterson, HM, C Hirt and G Krawczyk. Nov 2017. An update on the area wide BMSB and natural enemies project in Pennsylvania. IPM Working Group Meeting. Winchester, VA. (oral presentation)

Rijal, J. May 22-24, 2018. Updates on brown marmorated stink bug infestation in almonds. UC-ANR Farm Advisor Field Tour. Hughson, CA.

Rijal, JP. Apr 13, 2018. Brown marmorated stink bug: biology and monitoring. California State University-Stanislaus, Turlock, CA. (guest lecture)

Rijal, JP. Apr 24, 2018. Implementing IPM practice with monitoring tools. Merced College, Merced, CA. (guest lecture)

Spears, LR, ZR Schumm and MC Holthouse. Sep 22, 2017. Brown marmorated stink bug. First Detector Training Workshop for Master Gardeners, Midvale, UT.

Spears, LR. Sep 21, 2017. Utah Pests In-Service Training – Utah State University, Logan, UT.

Spears, LR. Sep 22, 2017. First Detector Training – State Master Gardener Conference, Utah State University, Logan, UT.

Funding Leveraged

Alston, DG, and LR Spears. 2017-2020. Utah Specialty Crop Block Grant Program. Brown marmorated stink bug: new invasive pest in Utah's fruit industry. $34,137

Alston, DG. 2018-2023. Utah Agricultural Experiment Station: Brown marmorated stink bug; an invasive pest of economic importance to Utah's specialty crops. $29,250

Beers, E. H. 2015. April 1 2016-March 31 2019. Washington Tree Fruit Research Commission (WTFRC). Brown marmorated stink bug control in Washington. CP-16-101. $254,793

Beers, E. H. 2017. 1 July 2017 - 30 June 2018. Grant #17AN029. Washington State Commission on Pesticide Registration (WSCPR). Biological control of brown marmorated stink bug. $18,733

Beers, E. H. 2018. 1 July 2018 - 30 June 2019. Washington State Commission on Pesticide Registration (WSCPR). Biological control of brown marmorated stink bug. Project #18AN011. $21,851

Daane, K. 2018. California Pistachio Research Board. Comparing the feeding damage of the invasive brown marmorated stink bug to native large bugs. $18,600

Gut, L. Michigan Apple Research Committee: Managing invasive pests to maintain fruit quality and profitability. $16,150

Gut, L. Michigan Apple Research Committee: Manipulating symbiotic bacteria to manage brown marmorated stink bug. $10,200

Gut, L. MSU Project GREEEN: Monitoring and management of BMSB. $40,000

Hutchison, W. 2017-2021. Significant funding has been leveraged with two projects to Hutchison and Koch, funded by the Minn. Invasive Terrestrial Plant and Pest Center (MITPPC), University of Minnesota (2017-2021), including ~$750,000 in BMSB projects (biology, ecology, dispersal, and forecasting models for IPM).

Jentsch, P, and D Acimovic. 2018-2019 (25%). ARDP: Biological control of the brown marmorated stink bug in New York State. $77,897

Jentsch, P, and J Nyrop. 2018-2019 (5%). HATCH: Biological control of arthropod pests (*T.japonicus*_BMSB). $15,000

Jentsch, P, D Acimovic, and T Lampasona. 2017-2018 (25%). ARDP: biological control of the brown marmorated stink bug in New York State. $43,746

Krawczyk, G. 2018. State Horticultural Association of Pennsylvania. Research Committee. Utilization of insecticide treated nets as an alternative method to monitor and manage brown marmorated stink bug. $23,500

Kuhar, T. 2018. FMC Corp. Received contract research funding for the evaluation of experimental insecticides for control BMSB on fruiting vegetables. $5000

Kuhar, T. advised Mika J. Pagani who received a Virginia Tech Fralin Undergraduate Research Fellowship for project entitled "*Halyomorpha halys* feeding impact on industrial hemp yield and quality." $1,000

Leskey, T. Ministry of Primary Industries New Zealand. BMSB surveillance project: trap improvement and lure attractiveness. (PD). $180,664

Leskey, T. USDA-ARS Areawide: An areawide biointensive management plan for brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), to reduce impacts throughout the agro-urban interface. $371,278 annually for up to 5 years.

Peterson, H. 2018. Pennsylvania Peach and Nectarine Marketing Board. Biological control options for the brown marmorated stink bug. $9,560

Peterson, H. 2018. State Horticultural Association of Pennsylvania. Research Committee. Utilizing the samurai wasp as a potential control tool against brown marmorated stink bug. $6,776

Spears LR, and C Nischwitz. 2018-2019. USDA-APHIS-PPQ (Farm Bill). Orchard commodity survey. $17,000

Spears LR, and DG Alston. 2017-2018. Utah Extension IPM and Sustainable Agriculture Mini-Grant Program. Finding the best traps and lures for brown marmorated stink bug (*Halyomorpha halys*). $10,000

Spears LR, and DG Alston. 2018-2019. USDA-APHIS-PPQ. Survey for native and introduced natural enemies of brown marmorated stink bug. $9,870

Spears LR, J Gunnell, K Wagner, R Davis, M Murray, DG Alston, and RA Ramirez. 2018-2019. USDA-APHIS-PPQ (Farm Bill). Invasive pest outreach. $49,995

Spears LR, R Davis, J Gunnell, K Wagner, D Alston, and RA Ramirez. 2017-2018. USU Extension Grant Program. Expanding the invasive insect detection and prevention outreach program in Utah. $30,000

Spears, LR, DG Alston, and C Nischwitz. 2017-2019. USDA AFRI Cooperative Agricultural Project (through NCSU). iPIPE: Vegetable Survey. $77,324

Spears, LR, and C Nischwitz. 2018-2019. USDA-APHIS-PPQ (Farm Bill). Orchard commodity survey. $17,000 (funded, but award amount pending)

Spears, LR, and DG Alston. 2018-2019. USDA-APHIS-PPQ (CAPS). Survey for native and introduced natural enemies of brown marmorated stink bug, Halyomorpha halys. $9,870 (funded, but award amount pending)

Spears, LR, R Davis, M Murray, J Gunnell, K Wagner, DG Alston, and RA Ramirez. USDA-APHIS-PPQ (Farm Bill). 2018-2019. Invasive pest outreach. $49,995 (funded, but award amount pending)

Welty, C. The Ohio IPM program supported our pheromone trap network for BMSB monitoring in Ohio.

Agricultural and Forest Entomology

Agricultural and Forest Entomology (2019), **21**, 99–108 DOI: 10.1111/afe.12312

Presence of the invasive brown marmorated stink bug *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) on home exteriors during the autumn dispersal period: Results generated by citizen scientists

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Abstract

1 The invasive brown marmorated stink bug *Halyomorpha halys* (Stål) is a serious nuisance pest in buildings.
2 To address how *H. halys* select potential overwintering sites and to predict the risk of home invasion, citizen scientists, primarily from the Mid-Atlantic region of the U.S.A., were recruited to count the number of *H. halys* present on the exterior of their homes during the autumn dispersal periods in 2013 and 2014.
3 Volunteers provided daily count data on numbers present on each exterior aspect of the home during the peak dispersal, as well as their home's location, colour and structural material.
4 Among volunteers, fewer adults were counted on white homes compared with brown and tan homes in 2013 and with grey homes in both years. Across all homes, greatest numbers were counted on the north and east walls in both years and on homes with wood, cement or stone exteriors.
5 In addition, significantly more adults were counted on homes in rural landscapes compared with urban areas in both years. *Halyomorpha halys* were found in greater numbers on darker coloured homes made of natural materials, even though these were less common than other types in the landscape.
6 Thus, homes located in rural landscapes with these features could be prone to larger nuisance infestations of overwintering *H. halys*.

Keywords Brown marmorated stink bug, citizen science, nuisance pest, overwintering.

Introduction

Brown marmorated stink bug *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) is an invasive pest that has caused severe agricultural crop losses and has become a significant nuisance pest in parts of the U.S.A. (Hamilton, 2009; Leskey *et al.*, 2012; Rice *et al.*, 2014; Leskey & Nielsen, 2018). Research has been conducted to develop monitoring and management tools for growers (Leskey *et al.*, 2015a; Short *et al.*, 2017) and to understand its life history (Nielsen & Hamilton, 2009; Nielsen *et al.*, 2016), although few studies have addressed the cues associated with dispersal to overwintering sites or overwintering site selection.

Adult *H. halys* overwinter in natural settings (Lee *et al.*, 2014) and in human-made structures (Inkley, 2012; Aigner & Kuhar, 2014). In laboratory studies, *H. halys* was found to prefer settling in a dark refuge rather than a lighted refuge during a choice test, suggesting that photosensitivity has a fundamental influence on overwintering site selection (Toyama *et al.*, 2011). In nature, overwintering *H. halys* were found beneath the dry bark of dead, standing oak and locust trees (Lee *et al.*, 2014); downed trees and leaf litter did not yield *H. halys* in that study, although other native pentatomids do overwinter in leaf litter (Jones Jr. & Sullivan, 1981). Overwintering *H. halys* were also found aggregating in large numbers in darkened knee walls and attic spaces in a highly infested home (Inkley, 2012). However, how *H. halys* initially located these overwintering sites is unknown.

Orientation to and selection of overwintering sites by other autumn nuisance pests, such as the multicoloured Asian lady beetle *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), is related to prominent visual features on the horizon, such as buildings or other large silhouettes (Hagen, 1962; Nalepa *et al.*, 2005).

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Received: 15 January 2018 Revised: 7 July 2018 Accepted article published: 31 July 2018 Published online in Wiley Online Library: 21 September 2018

(wileyonlinelibrary.com) DOI 10.1002/ps.5156

Successful management of *Halyomorpha halys* (Hemiptera: Pentatomidae) in commercial apple orchards with an attract-and-kill strategy

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Abstract

BACKGROUND: Introduction of *Halyomorpha halys* (Stål) in the USA has disrupted many established integrated pest management programs for specialty crops, especially apple. While current management heavily relies on insecticides, one potential alternative tactic is attract-and-kill (AK), whereby large numbers of *H. halys* are attracted to and retained in a circumscribed area using attractive semiochemicals and removed from the foraging population with an insecticide. The goal of this study was to evaluate if AK implementation in commercial apple orchards can result in levels of *H. halys* damage that are equal to or less than those from grower standard management programs.

RESULTS: Over 2 years at farms in five Mid-Atlantic USA states, we found that the use of AK resulted in 2–7 times less damage compared with grower standard plots, depending on year and period. At selected trees on which AK was implemented, over 10,000 *H. halys* individuals were killed in two growing seasons, and the use of AK reduced the crop area treated with insecticide against *H. halys* by 97%. Using AK had no impact on the natural enemy or secondary pest community over the same period.

CONCLUSIONS: Overall, the use of AK was effective at managing low to moderate *H. halys* populations in apple orchards, but must be optimized to increase economic feasibility for grower adoption.

Supporting information may be found in the online version of this article.

Keywords: behaviorally-based management; brown marmorated stink bug; integrated pest management; pheromones; semiochemicals

1 INTRODUCTION

The unexpected introduction and establishment of a destructive invasive pest species often forces researchers and growers to rapidly develop alternative management tactics, as has been true for the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). *Halyomorpha halys* were accidentally imported from China[1] to the USA[2] in the late 1990s through four separate events,[3] and it has spread to 44 USA states. It feeds on >170 host plants, including many important food crops (www.stopbmsb.org), and in 2010 its infestation of fruit and vegetables reached outbreak status, causing about $37 million in damage to USA Eastern apples.[4] Injury in apple usually consists of hardened, inedible necrotic flesh (termed internal corking, hereafter), with characteristic stylet penetration in the fruit, and discolored dimpling at the site of feeding.[5,6] Both adult and nymphal *H. halys* inflict damage on tree fruits during the cropping period.[6] In response, growers applied as much as four times more insecticide to ameliorate this damage.[7] Since then, *H. halys* has become a problem in Canada[8] and Europe,[9] with a projected global distribution to result in range expansion into many more locations.[3,10–12]

Since 2010, pheromone-based technology for *H. halys* has developed rapidly.[13] Prior to 2012, large wooden pyramid traps[14] baited

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Journal of Economic Entomology, 112(1), 2019, 108–114
doi: 10.1093/jee/toy340
Advance Access Publication Date: 20 November 2018
Research

Biological and Microbial Control

Effects of Insecticides Used in Organic Agriculture on *Anastatus reduvii* (Hymenoptera: Eupelmidae) and *Telenomus podisi* (Hymenoptera: Scelionidae), Egg Parasitoids of Pestivorous Stink Bugs

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Subject Editor: Julio Bernal

Received 30 June 2018; Editorial decision 4 October 2018

Abstract

Lethal and sublethal effects of insecticides used in organic agriculture were tested against *Anastatus reduvii* and *Telenomus podisi*, native North American hymenopteran egg parasitoids of the native *Euschistus servus* Say (Hemiptera: Pentatomidae) and the invasive *Halyomorpha halys* Stål. Entrust (spinosad), PyGanic (pyrethrin), Neemix (azadirachtin), and Azera (pyrethrin + azadirachtin) were tested at equivalent field rates of 1×, 0.5×, and 0.1×. Bioassays included insecticide exposure to parasitoids through residue on substrate, parasitized host eggs, and their food source. When exposed to dried residues, Entrust caused 100% mortality at the 0.5× rate to both species; PyGanic, Neemix, and Azera exhibited low toxicity. Exposure of parasitized host eggs to Entrust 1× during the egg stage of parasitoid development reduced parasitoid emergence compared to all other treatments in both species. *Anastatus reduvii* emergence was also reduced by PyGanic at 0.5× and 1×. Parasitoid emergence from host eggs exposed during the pupal stage was more variable than egg stage exposure; emergence of both species was reduced in 0.5× and 1× rates of PyGanic, and *A. reduvii* was reduced in the 0.5× rate of Entrust compared to controls. Longevity of emerged parasitoids surviving exposure within host eggs showed that Entrust was more deleterious than Neemix or PyGanic. When *A. reduvii* was fed insecticide-laced honey, all treatments except Neemix at 0.1× reduced adult longevity compared to the control. These studies demonstrated that insecticides commonly used in organic agriculture can negatively affect two common parasitoids of stink bugs; specifically, negative effects were most pronounced with Entrust, and variable with Neemix and Pyganic.

Key words: biological control, brown marmorated stink bug, organic production, pyrethrin, spinosad

Several species of stink bugs (Hemiptera: Pentatomidae) are economically important agricultural pests in the southern United States, including the native brown stink bug, *Euschistus servus* (Say) and more recently the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål). These polyphagous pests damage numerous vegetable, tree fruit, and row crops through feeding injury that can result in unmarketable or entirely lost produce (Koppel et al. 2009, Nielsen and Hamilton 2009, Leskey et al. 2012). Effective control of *E. servus* and *H. halys* often necessitates use of broad-spectrum insecticides, such as pyrethroids and neonicotinoids. Management of stink bug pests is difficult in organically approved production where reliance on synthetic broad-spectrum pesticide regimes is not possible, and the efficacy of approved insecticides is often less than acceptable (Kamminga et al. 2009, Morehead and Kuhar 2017). Hence, preservation of native natural enemies is a high priority in these systems, where they can perform valuable ecosystem services through biological control of agricultural insect pests (Eilenberg et al. 2001, Crowder et al. 2010).

Egg parasitoids play an important role in controlling pentatomids. *Telenomus podisi* is an important egg parasitoid of phytophagous stink bugs, especially *E. servus* in the United States and *Euschistus heros* (Fabricius) in Brazil (Corrêa-Ferreira and Moscardi 1995, Moraes et al. 2008, Koppel et al. 2009, Tillman 2016). It is often the most common parasitoid attacking *Euschistus* species in North America (Yeargan 1979, Orr et al. 1986, Koppel et al. 2009). In a 2-y regional study in the eastern United States, *T. podisi* was the most common parasitoid in organically produced crops, comprising 54.0, 100, and 77.3% of parasitoid species in *H. halys*, *E. servus*, and *Chinavia hilaris* (Say) eggs, respectively (Ogburn et al. 2016). *Telenomus podisi* (Ashmead) is most often recovered in vegetable

Environmental Entomology, 48(1), 2019, 173–180
doi: 10.1093/ee/nvy180
Advance Access Publication Date: 19 December 2018
Research

Behavior

Vertical Sampling in Tree Canopies for *Halyomorpha halys* (Hemiptera: Pentatomidae) Life Stages and its Egg Parasitoid, *Trissolcus japonicus* (Hymenoptera: Scelionidae)

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Subject Editor: Matthew Ginzel

Received 20 September 2018; Editorial decision 12 November 2018

Abstract

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is an invasive agricultural and nuisance pest that has established across much of the United States and caused significant crop losses in the Mid-Atlantic region. While it has been monitored extensively using ground-deployed pheromone traps, the vertical distribution of its life stages in the canopy of wild tree hosts has not been examined. In Virginia, small pyramid traps baited with 'low-dose' *H. halys* pheromone lures were deployed via a pulley system at the lower, mid-, and upper canopy of female tree of heaven (*Ailanthus altissima* (Mill.) Swingle) in 2016 and 2017 and male *A. altissima* and hackberry (*Celtis occidentalis* L.) in 2017. Weekly captures of adults and nymphs were recorded throughout each season. Each year, additional female *A. altissima* trees were felled during the two main periods of *H. halys* oviposition. The number and relative locations of all pentatomid egg masses found on foliage were recorded and any parasitoids that emerged from them were identified. *Halyomorpha halys* adults and nymphs were captured in greatest numbers in upper canopy traps and in lowest numbers in traps near the tree base. More *H. halys* egg masses were collected from mid-canopy than from the lower or upper canopy. The adventive egg parasitoid, *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), emerged most frequently from egg masses found at mid-canopy and was not recovered from those in the lower canopy. Results are discussed in relation to the foraging ecology of *H. halys* and its natural enemies, including *TT. japonicus*.

Key words: brown marmorated stink bug, biological control, parasitoid, invasive species

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) is an invasive pest from Asia (Hoebeke and Carter 2003) that feeds or reproduces on many cultivated and wild plants (www.stopbmsb.org). A widespread outbreak of *H. halys* in the Mid-Atlantic region of the United States in 2010 resulted in losses of over $37 million to the apple crop and severe impacts to many peach orchards (Leskey et al. 2012). Given its broad host range, high mobility (Lee et al. 2014, Wiman et al. 2015, Lee and Leskey 2015), and propensity to 'hitchhike' in human conveyances, *H. halys* has now been detected or established in 44 states, four Canadian provinces (www.stopbmsb.org; accessed 12 March 2018), and several countries abroad (Leskey and Nielsen 2018).

Halyomorpha halys is not known to reside permanently in any crop, but moves into crops from its many wild hosts (Bakken et al. 2015). It is considered a perimeter-driven pest, and injury from its feeding is often greatest at crop borders next to wooded areas (Leskey et al. 2012, Joseph et al. 2014, Venugopal et al. 2015, Bergmann et al. 2016). Given its wide distribution and mobility in the landscape, insecticide applications can reduce *H. halys* injury to crops but likely do not have a substantial effect on its pest pressure overall. Most of the effective insecticides for managing *H. halys* injury to crops are toxic to natural enemies, resulting in disruption of integrated pest management programs and frequent outbreaks of secondary pests (Rice et al. 2014, Leskey and Nielsen 2018). Thus, effective biological control of *H. halys* in non-crop habitats is considered a key element of its sustainable management.

In the United States, numerous native parasitoids and predators that attack *H. halys* have been identified, but have not regulated its populations adequately (Abram et al. 2017). During the summer of

insects

MDPI

Article

Monitoring and Biosurveillance Tools for the Brown Marmorated Stink Bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae)

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Received: 31 May 2018; Accepted: 2 July 2018; Published: 8 July 2018

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Abstract: *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) is an invasive pest of numerous agricultural crops with an increasing global distribution. Finding simple and reliable monitoring tools for *H. halys* agricultural and surveillance programs is imperative. In 2016, we compared standard pyramid traps to clear sticky cards attached atop wooden stakes and evaluated two commercially formulated lures (Trécé and AgBio) with low and high rates of the *H. halys* aggregation pheromone (PHER) and pheromone synergist (MDT) at 12 sites (low: 5 mg PHER + 50 mg MDT; high: 20 mg PHER + 200 mg MDT). In 2017, we reevaluated lure efficacy using only the clear sticky traps at six locations. Sites were classified as having low, moderate, or high relative population densities of *H. halys* in 2016, and as very low or low densities of *H. halys* in 2017. Although clear sticky traps captured fewer adults and nymphs than pyramid traps, their captures were generally correlated at all population levels indicating that clear sticky traps can reliably monitor *H. halys* presence and relative abundance regardless of relative population density. During both years, adult and nymphal captures were significantly greater in traps baited with Trécé lures than with AgBio lures. Captures were greater in traps baited with high loading rate lures for each lure type, and with the exception of traps baited with AgBio lures at high relative density sites in 2016, *H. halys* captures in traps with low and high loading rates of each lure type were correlated for both years. Comparison of yellow and clear sticky cards indicated they performed equally, but yellow cards captured more nontargets. In summary, clear sticky traps attached atop wooden posts and baited with *H. halys* pheromone and pheromone synergist lures are an effective option for this pest monitoring and detection.

Keywords: trapping; lure comparison; invasive species; pest management

1. Introduction

Monitoring pest populations is critical in agricultural systems and for biosurveillance of invasive pests at high-risk areas and newly invaded locations. In agriculture, treatment thresholds based on monitoring tools can be used to effectively manage pest populations, while reducing production costs and nontarget effects [1]. In biosurveillance programs, effective monitoring and detection tools

Journal of Economic Entomology, 111(5), 2018, 2153–2162
doi: 10.1093/jee/toy200
Advance Access Publication Date: 14 July 2018
Research Article

OXFORD

Ecology and Behavior

Halyomorpha halys (Hemiptera: Pentatomidae) Responses to Traps Baited With Pheromones in Peach and Apple Orchards

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Subject Editor: Allan Showler

Received 14 February 2018; Editorial decision 20 June 2018

Abstract

Monitoring insect populations is a fundamental component of integrated pest management programs. In many cropping systems, monitoring is accomplished through captures in baited traps. The aggregation pheromone and pheromone synergist for the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) are known. We compared the response of *H. halys* to commercial lures in peach and apple orchards. Two commercial pheromone formulations, PHEROCON Trécé BMSB ('Trécé') and AgBio Inc. Stink Bug Xtra Combo ('Xtra Combo'), were compared with unbaited traps in peach orchards in 2015 and 2016 and in an apple orchard in 2016. In both crops and years, more *H. halys* responded to the Trécé lure, and fruit from trees near baited traps had correspondingly higher injury. In both years, peach fruit near Trécé baited traps had significantly higher feeding injury (52.2 ± 5.0%) than fruit near Xtra Combo baited and unbaited traps (35.2 ± 4.5% and 22.2 ± 3.4%, respectively). Injury to apple fruit near baited traps in 2016 was significantly different from fruit near unbaited traps (Trécé: 93.0 ± 3.8%, Xtra Combo: 74.1 ± 5.1%, and unbaited: 19.0 ± 2.7%). A field response index, which quantifies attraction of *H. halys* to each lure, demonstrated an equal response to both lures in 2015 peach and a higher response to Trécé lure in 2016 in both crops, which suggests the lure is pulling bugs from a larger area. We conclude that formulation differences, population pressure, and host plant species influence *H. halys* populations' response and resulting injury, and should be considered for trap-based decision management.

Key words: brown marmorated stink bug, monitoring, injury, aggregation pheromone, pyramid trap

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is an invasive agricultural pest in North America (Leskey et al. 2012a). Since its detection in Allentown, PA in the mid-1990s (Hoebeke and Carter 2003), *H. halys* has become a global invader (Leskey and Nielsen 2018) with the potential to threaten agricultural production beyond the United States and Europe (Zhu et al. 2012, Haye et al. 2015, Kriticos et al. 2017). The rapid spread of *H. halys* in North America has occurred in part because of its high mobility (Wiman et al. 2014, Lee and Leskey 2015), polyphagous feeding behavior (Bergmann 2016), and an ability to withstand climatic conditions present in much of continental North America (Cira et al. 2016, Nielsen et al. 2016, Kriticos et al. 2017). In the mid-Atlantic region of the United States, where invasive *H. halys* populations are the most abundant and damaging in North America (Rice et al. 2014), adults disperse from overwintering sites in spring, typically when temperatures begin to rise in April (Bergh et al. 2017), in search of suitable host plants. Indeed, adults can disperse into peaches (*Prunus persica* (L.) Batsch) (Rosales: Rosaceae) and apples (*Malus domestica* Borkh) (Rosales: Rosaceae) after emergence from overwintering, and dispersal into crops is continued throughout the growing season (Leskey and Nielsen 2018).

Direct monitoring of *H. halys* is primarily done using traps baited with attractive olfactory stimuli, which capture both adult and nymphal life stages, and has been utilized to determine the seasonality of *H. halys* in a wide variety of crops and wild host habitats (Leskey et al. 2012b, 2012c; Morrison et al. 2015; Leskey et al. 2015a, 2015b). Currently, the black coroplast pyramid trap with the attractive aggregation pheromone mixture of 3.5:1 ratio of (3S,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol and (3R,6S,7R,10S)-10,11-epoxy- 1-bisabolen-3-ol (Khrimian et al. 2008, Khrimian et al. 2014) and pheromone synergist methyl (2E,4E,6Z)-decatrienoate (MDT; Weber et al. 2014, 2017) is used in most monitoring efforts. Pheromone traps allow for population assessment of some hemipteran insects that have nocturnal (Krupke et al. 2001, Cambridge 2016)

Environmental Entomology, 47(6), 2018, 1501–1508
doi: 10.1093/ee/nvy120
Advance Access Publication Date: 27 August 2018
Research

OXFORD

Behavior

Can the Dispersal Behavior of *Halyomorpha halys* (Hemiptera: Pentatomidae) Inform the Use of Insecticide-Treated Netting to Mitigate Homeowner Issues From its Fall Invasion?

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Subject Editor: Matthew Ginzel

Received 2 May 2018; Editorial decision 25 July 2018

Abstract

Brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is a serious agricultural pest and can be a significant nuisance when it invades human dwellings during its fall dispersal to overwintering sites. Methods informed by behavioral data to exclude or reduce its entry into buildings are needed. The temporal and spatial distribution of adults on an invaded building was assessed over multiple years, revealing its seasonal dispersal pattern and that its numbers varied by wall aspect. Moreover, its density was higher in recessed doorways than on associated walls, raising questions about its behavioral response to dark, contrasting surfaces. This response was evaluated using black, framed panels of deltamethrin-incorporated netting, non-treated netting, and an open frame with no netting, deployed in pairs on the wall of a private residence. More dispersing adults landed on panels of non-treated netting than on open panels, but there was no difference between panels with treated and non-treated netting. Adults remained on treated panels for less time than on non-treated panels, and most walked rather than flew from both. Adult male and female *H. halys* collected during the dispersal period were exposed to panels of treated and non-treated netting in a laboratory, using durations derived from field recordings. Exposures to treated panels intoxicated but did not kill them over a 7-d assessment period. The deployment of insecticide-treated netting, guided by the behavior of adult *H. halys* alighting on buildings, is discussed in relation to potential options to mitigate homeowner issues from this serious annual problem.

Key words: brown marmorated stink bug, home invasion, dispersal behavior

Since its widespread and severe outbreak in the Mid-Atlantic United States in 2010, the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), has established or been detected in 44 U.S. States, four Canadian provinces (StopBMSB.org), and several European countries (Haye et al. 2014, Leskey and Nielsen 2018), and is continuing to spread in the United States and abroad. Being highly polyphagous and feeding on both wild and cultivated plants, *H. halys* is widely distributed in the landscape and has caused significant economic losses to a range of crops in some areas (Leskey et al. 2012a, Leskey and Nielsen 2018). Moreover, it has proved to be a major nuisance pest for some home and business owners when the adults fly to and enter these dwellings during their search for an overwintering site in September and October. *H. halys* also utilizes overwintering sites in nature (Lee et al. 2014). Although the distribution of the overwintering population between natural and human-made sites is unknown, many thousands of adults may inundate the exterior walls of some residences over several weeks in the fall, causing significant life quality issues for the owners. An extreme illustration of this is depicted in a television news broadcast from northern Italy on 4 October 2017 (UdineToday 2017).

These adults are adept at entering dwellings via various crevices and openings. Some immediately infest the living areas, while others find tight, dark, and dry spaces (e.g., in the attic) where they tend to aggregate, become quiescent, and enter a facultative diapause. Subsequently, an equally problematic and more prolonged issue arises when they become active prematurely during the winter months and find their way into the living spaces, presumably in response to heat and light. Inkley (2012) reported collecting >26,000 adult *H. halys* from the interior of his home in rural MD between January and June of 2011.

Progress toward monitoring and managing *H. halys* in affected crops has been substantial (Leskey et al. 2012b, Khrimian et al. 2014,

Team *Trissolcus*: Integrating Taxonomy and Biological Control to Combat the Brown Marmorated Stink Bug

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KEYWORDS: Scelionidae, Pentatomidae, biological control, taxonomy, *Trissolcus japonicus*, *Halyomorpha halys*

Invasive species, and their impacts on natural and agricultural resources, are a growing, multi-billion dollar problem worldwide. For insect species, this is particularly true, as many are small and hard to detect; they can hitchhike on rapid modes of transportation, facilitating survival; and some have the potential to reproduce quickly when accidentally introduced into new areas, assisting their establishment. Responding to these invaders is a three-fold endeavor, involving detection or interception (e.g., port identifiers, surveys), accurate and fast identification (taxonomy), and thorough ecological investigations in native ranges and associated natural enemy complexes (i.e., biological control agents). We use a current project of investigating natural enemies of the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae), as an example of how taxonomy and biological control projects are mutually informative, stimulating joint research and shortening the time lag between field observation, publishing data, and using that data for management decisions. We make the case that taxonomic preparedness is critical to this success.

Fig. 1. ***Halyomorpha halys*** **infestation on apple (USDA-ARS).**

Fig. 2. ***Halyomorpha halys*** **nymphs on soybean (Wil Hershberger).**

Journal of Economic Entomology, 111(2), 2018, 780–786
doi: 10.1093/jee/tox361
Advance Access Publication Date: 30 January 2018
Research Article

OXFORD

Horticultural Entomology

Phenology of Brown Marmorated Stink Bug in a California Urban Landscape

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Subject Editor: Cesar Rodriguez-Saona

Received 8 September 2017; Editorial decision 3 December 2017

Abstract

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is an invasive pest that has been resident in California since 2006. To better understand its seasonal phenology, we used baited traps to estimate nymph and adult population densities in midtown Sacramento, the focal area of the Northern California invasion. Adult *H. halys* populations were found soon after trapping began in February (2015–2016) or March (2014); the first egg masses for 2014, 2015, and 2016 were found on 5 May, 17 April, and 12 April, respectively, and the first nymphs were found 3 June, 19 May, and 9 May, respectively. There were two generations per year, with one peak in June and another in September. Summer temperatures above 36°C in July and August were associated with reduced catches in traps of both nymphs and adults. This extreme heat may have helped to form two clear nymph peaks and suppressed egg deposition. In 2016, two trap types and four lures were also compared. Trap type influenced season-long nymph captures, with fewer nymphs in double cone traps than pyramid traps. Lure type influenced season-long trap catch, with more nymphs and adults trapped with the Rescue lure than the AgBio Combo lure, Alpha Scents, or Trécé Pherocon Combo lures, although this difference was only associated with the capture of nymphs and we did not compare for longevity or seasonal variation. These data are discussed with respect to *H. halys*' phenology from the mid-Atlantic region.

Key words: *Halyomorpha halys*, seasonal population dynamics, monitoring, traps

The brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is an invasive pest, considered to be native to Asia (Hoebeke and Carter 2003) and currently found throughout much of the United States and parts of Canada and Europe (Haye et al. 2015, Valentin et al. 2017). Since its first detection in North America in the 1990s, *H. halys* has been found in 43 states and the District of Columbia, although its population density and pest status vary among regions (Anonymous 2017, Hahn et al. 2017). To date, large populations are often found in the mid-Atlantic region, Tennessee and North Carolina, where *H. halys* has caused severe damage to tree and small fruit, vegetable and forage crops (Nielsen and Hamilton 2009, Leskey et al. 2012b, Joseph et al. 2014, Bakken et al. 2015, Acebes-Doria et al. 2016a, Philips et al. 2017). In other U.S. regions, such as Oregon, *H. halys* populations are either more moderate or may still be increasing (Wiman et al. 2015), but have not yet caused the levels of damage as those found in the mid-Atlantic region. For most of the United States and Canada, *H. halys* has been not detected, detected but with no evidence of a breeding population, or has established but populations are still early in the infestation process (Anonymous 2017). *H. halys* populations in California fit into this latter category where the pest has established in many regions of the state, but its future population densities or damage have yet to be determined.

In California, *H. halys* was first detected in 2006 in Pasadena and San Marino (Los Angeles County), but in Northern California it was not until 2013 that a substantial population was found in Sacramento (Ingels and Varela 2014). Key among this stink bug's highly invasive characteristics are its wide host range (Bergmann et al. 2016a), which includes woody ornamentals (Bergmann et al. 2016b) and wild hosts (Bakken et al. 2015); it is on ornamental hosts, especially the tree of heaven (*Ailanthus altissima* (Mill.) Swingle [Sapindales: Simaroubaceae]) that this pest is most commonly found in Sacramento. Both large and small urban areas with *H. halys* populations are interspersed with California's billion-dollar agriculture industry, and Sacramento is close to commercial stone and pome fruits and vegetable plantings that are susceptible to *H. halys*. Nevertheless, until 2016, there had been no reports of *H. halys* on agricultural crops, although the populations appeared to be increasing in some urban regions. These established populations on urban ornamental plantings are, therefore, a concern for the State's diverse specialty crops, including grapes, stone and pome fruits, small berry crops, nut crops, and vegetables.

Ecological Applications, 28(4), 2018, pp. 1081–1092

Biological control effects of non-reproductive host mortality caused by insect parasitoids

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Abstract. As the rate of spread of invasive species increases, consumer–resource communities are often populated by a combination of exotic and native species at all trophic levels. In parasitoid–host communities, these novel associations may lead to disconnects between parasitoid preference and performance, and parasitoid oviposition may result in death of the parasitoid offspring, death of the host, or death of both. Despite their relevance for biological control risk and efficacy assessments, the direct and indirect population-level consequences of parasitoids attacking and killing their hosts without successfully reproducing (non-reproductive mortality) are poorly understood. Non-reproductive mortality induced by egg parasitoids (parasitoid-induced host egg abortion) may be particularly important for understanding the population dynamics of the invasive agricultural pest *Halyomorpha halys* (Hemiptera: Pentatomidae) and endemic stink bugs in North America, which are attacked by a suite of both native and introduced egg parasitoids. It is unclear, however, how various factors controlling parasitoid foraging and developmental success manifest at the population level. We constructed two related versions of a two-host–one-parasitoid model to evaluate the population-level consequences of non-reproductive host mortality. Egg abortion can result in strong negative or positive enemy-mediated indirect effects, taking the form of apparent competition, apparent parasitism, apparent amensalism, or apparent commensalism. For parasitoids limited in their reproductive output by the number of eggs they can produce, higher non-reproductive host mortality can reduce the strength of the positive indirect effect in cases of apparent parasitism, and it can reduce the negative indirect effect on the more suitable host in cases of apparent competition. For time-limited parasitoids, unsuitable hosts with high levels of non-reproductive parasitoid-induced mortality can be strongly suppressed in the presence of a suitable host, while the suitable host is only negligibly impacted (i.e., apparent amensalism). We evaluate these model-derived hypotheses within the context of *H. halys* and its native and nonnative parasitoids in North America, and discuss their application to risk assessment in biological control programs.

Key words: brown marmorated stink bug; difference equations; ecological risk assessment; evolutionary trap; invasive species; population models; Trissolcus japonicus.

Introduction

The global spread of invasive species continues to increase (Hulme 2009), and in the process, exotic resource populations are often reconnected with accidentally introduced consumer species from their native ranges (Colazza et al. 1996, Ramani et al. 2002, Heimpel et al. 2010, Medal et al. 2015, Talamas et al. 2015). These inadvertent partial reconstructions of exotic food webs may be beneficial when the resource population is invasive and the exotic consumer functions as a biological control agent (Colazza et al. 1996, Ramani et al. 2002). However, introduced populations have the potential to cause harm, either directly or indirectly, when the exotic consumer or resource interacts with native species. Polyphagous exotic consumers may directly attack native species, and exotic resource populations may shift food web dynamics via resource enrichment and natural enemy-mediated indirect effects (Carvalheiro et al. 2008; Heimpel et al. 2010, Kaser and Ode 2016). Moreover, novel interspecific associations may result in maladaptive behaviors, like high foraging preference by native consumers on exotic species that constitute poor food resources, with potential population-level consequences (Schlaepfer et al. 2005, Berthon 2015). Parasitoids, insects that complete their immature development on or in a single host organism and in the process obligately kill their host (Godfray 1994), provide a particularly useful system to look at the effects of preference and performance on population dynamics (Asplen et al. 2012). In addition to accounting for more than 20% of insect biodiversity (Lasalle and Gauld 1991; Smith et al. 2008), parasitoids are critically important for regulating many biological communities and for their utility in biological control of invasive species (Murdoch 1994, Hochberg and Ives 2000).

The range of hosts that a parasitoid will attack in the field, its ecological host range, is a key determinant of its safety and efficacy in biological control programs (Onstad and McManus 1996, Haye et al. 2005). Ecological host range is limited by many factors, including the host's physiological suitability for parasitoid development, parasitoid preference for hosts and for the host's habitat, phenological synchrony, and geographic co-occurrence (Vinson 1998, Rutledge and Wiedenmann 1999, Kuhlmann et al. 2006, Desneux et al. 2009). The ecological host range of a

Manuscript received 5 July 2017; revised 28 December 2017; accepted 2 January 2018. Corresponding Editor: Matthew P. Ayres.
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First report of *Trissolcus japonicus* parasitizing *Halyomorpha halys* in North American agriculture

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The invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) is a polyphagous agricultural pest that feeds on over 170 plant species, including many cultivated fruits, vegetables, row crops, ornamentals, and wild host plants (Leskey & Nielsen 2018). Native to Asia, the earliest record of *H. halys* in North America is from 1996 in Allentown, Pennsylvania, in the eastern USA (Hoebeke & Carter 2003). It has since spread throughout much of North America, causing widespread economic harm (Rice et al. 2014; Leskey & Nielsen 2018). In 2014, an Asian egg parasitoid, *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), was found successfully parasitizing laboratory reared, field deployed (sentinel) *H. halys* egg masses in Beltsville, Maryland, USA (Talamas et al. 2015; Herlihy et al. 2016). Several other field populations have since been reported in the mid-Atlantic and Pacific Northwestern regions of the US (10 states and Washington, DC, Hoelmer personal communication), which likely represent multiple independent introductions of the parasitoid (Milnes et al. 2016; Lara et al. 2016; Hedstrom et al. 2017). It is unclear through what pathways *T. japonicus* entered North America, but genetic data indicate that the parasitoid did not escape from quarantine facilities where it is being studied as a potential classical biological control agent of *H. halys* (Bon et al. 2017).

The recent introductions of *T. japonicus* in North America may increase biological control of *H. halys*. However, to our knowledge, *T. japonicus* has yet to be documented parasitizing *H. halys* within North American cultivated crops. All published recoveries of adventive *T. japonicus* in North America have occurred in non-agricultural, largely woody habitat despite surveys in crops (Talamas et al. 2015; Cornelius et al. 2016a, b; Herlihy et al. 2016; Ogburn et al. 2016; Hedstrom et al. 2017; Morrison et al. 2018) that has led to concern that introduced strains of *T. japonicus* may have limited biological control potential in North America. During the invasion process, genetic bottlenecks can affect life history characteristics, such as ecological host range (i.e., the number of host species that a parasitoid is able to complete development on in the field), and may limit the ability of introduced biological control agents to attack pests across the same breadth of habitat as in their native range (Hufbauer 2002).

We conducted surveys in 2 commercial apple and 3 peach orchards in southern New Jersey, USA (apple: Monroeville, Gloucester County [39.6877°N, 75.1875°W] and Richwood, Gloucester County [39.7355°N, 75.1748°W]; peach: Richwood, Gloucester County [39.7355°N, 75.1748°W], Glassboro, Gloucester County [39.7085°N, 75.1331°W], and Salem, Salem County [39.5665°N, 75.4248°W]) that had previous pest issues with *H. halys*. On each farm, contiguous blocks were selected ranging from 2.0 to 9.7 ha of peach or apple, and assigned to 1 of 2 management regimes: Integrated Pest Management - Crop Perimeter Restructuring (IPM-CPR) or grower standard. There were 3 IPM-CPR blocks and 1 grower standard block replicated on 4 orchards for peach and 2 orchards for apple. Blocks within the IPM-CPR (Crop Perimeter Restructuring; described in detail in Blaauw et al. [2015]) management protocol applied insecticides only to the orchard border plus the first full row for *H. halys* management. In peach, this began at 100 DD_{14} and continued weekly until harvest. In apple, border-based management was initiated when a cumulative threshold of 10 adult *H. halys* were found in any aggregation pheromone-baited *H. halys* trap (Short et al. 2016) and then continued until harvest. All IPM-CPR blocks per farm had a companion grower standard block of a minimum of 2.0 ha, managed according to recommendations from Rutgers University Fruit Management Guidelines (NJAES 2017). In each block, sentinel *H. halys* egg masses < 24 h old were sourced from the New Jersey Department of Agriculture, Trenton, New Jersey, USA, and deployed on orchard trees at 3 time points in apples (11 Jul, 27 Jul, and 8 Aug 2017) and 4 time points in peach (20 Jun, 11 Jul, 27 Jul, and 8 Aug 2017). Sentinel egg masses were glued using Elmer's Multi-purpose Glue-ALL (Elmer's Products, Inc., High Point, North Carolina, USA) onto paper cardstock and deployed by attaching an egg mass card to the underside of a leaf using a paper clip. Egg masses were deployed on 2 border trees and 2 interior trees (about 6 trees = 18.3 m) in a transect, and placed between 2 and 3 m from the ground. Trees on the border were adjacent to a pheromone baited *H. halys* trap. There were 192 sentinel *H. halys* egg masses (5,458 individual eggs) deployed in peach, and 48 in apple (1,321 individual eggs) (Table 1). Egg masses were left in orchards for about 48 h, then returned to the laboratory where each egg mass was placed separately in closed plastic containers, placed in an incubator (25 °C, 60–70% RH, 16:8h (L:D) photoperiod), monitored until emergence of *H. halys* or parasitoids, and the species identified based on adult morphological characteristics. If parasitoids emerged from an egg mass, or a guarding female was found in association with the retrieved egg mass, after waiting > 1 mo, the remaining unhatched eggs were dissected and inspected for dead parasitoids (larvae or pharate adults) or *H. halys* nymphs.

The effect of management strategy on the number of parasitized egg masses was analyzed using a 2-sided Fisher's exact test (FET) (Sokal and Rohlf 1995), pooling border and interior trees. The analysis was conducted on a 2 × 2 contingency table of management regime (IPM-CPR vs. grower standard) and parasitism status (parasitized vs. unparasitized egg mass). The GPS locations of sentinel egg masses were

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NEW ZEALAND ENTOMOLOGIST, 2018
https://doi.org/10.1080/00779962.2018.1438758

ARTICLE

Laboratory assessment of feeding injury and preference of brown marmorated stink bug, *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), for *Actinidia chinensis* var. *deliciosa* 'Hayward' (Zespri® Green) and *Actinidia chinensis* var. *chinensis* 'Zesy002' (Zespri® SunGold)

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ABSTRACT

The brown marmorated stinkbug (BMSB), *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), is native to Asia and is characterised by its polyphagous feeding habits and high hitchhiking potential. In invaded areas, such as the eastern USA, economic damage to agricultural crops by BMSB has been significant. In northern Italy, where BMSB is invasive, feeding damage has been recorded in commercial kiwifruit orchards. In New Zealand, a major kiwifruit producer, BMSB originating from the USA, Italy and China (the native range of kiwifruit) have been intercepted. These BMSB interceptions pose a high biosecurity risk to key agricultural industries in New Zealand, including kiwifruit. However, information on the ability of BMSB to feed on key commercial kiwifruit varieties, and the types of damage it may cause to this crop, is lacking. To address this issue, *Actinidia chinensis* var. 'SunGold' (G3) and *Actinidia deliciosa* var. 'Green' (Hayward), were exposed to adult BMSB under no-choice and choice feeding trials. Across kiwifruit cultivars (i.e. Green and SunGold) and experimental setups (i.e. choice and no-choice), mixed adult groups (i.e. males and females feeding together) caused significantly more damage than individual females and males. After accounting for adult density, there was no experimental evidence that BMSB exhibited a feeding preference for either SunGold or Green varieties. However, there were variety differences for the development of BMSB feeding injury, with lower incidence of damage recorded for SunGold.

KEYWORDS
BMSB; feeding injury; invasive species; kiwifruit; pentatomid

Introduction

Brown marmorated stink bug (BMSB), *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), is a polyphagous stink bug species native to East Asia (i.e. China, Japan, Taiwan and Korea) (Rice et al. 2014). Adult BMSB have strong flight dispersal and hitchhiking capabilities (Lee & Leskey 2015; Wiman et al. 2015a). These dispersion traits in combination with a polyphagous feeding habit have assisted BMSB in spreading and colonising new areas with favourable climate, food and lack of natural enemies (Rice et al. 2014). Invasive BMSB populations are well established in parts of North America (i.e. USA in the 1990s and Canada in 2012) and Europe (e.g. Switzerland [detected 2004], Liechtenstein [2004], France [2012], Greece [2011], Italy [2012], Hungary [2013], Russia [2013], Romania [2014], Georgia [2015] and Abkhazia [detected after 2013]) where it causes

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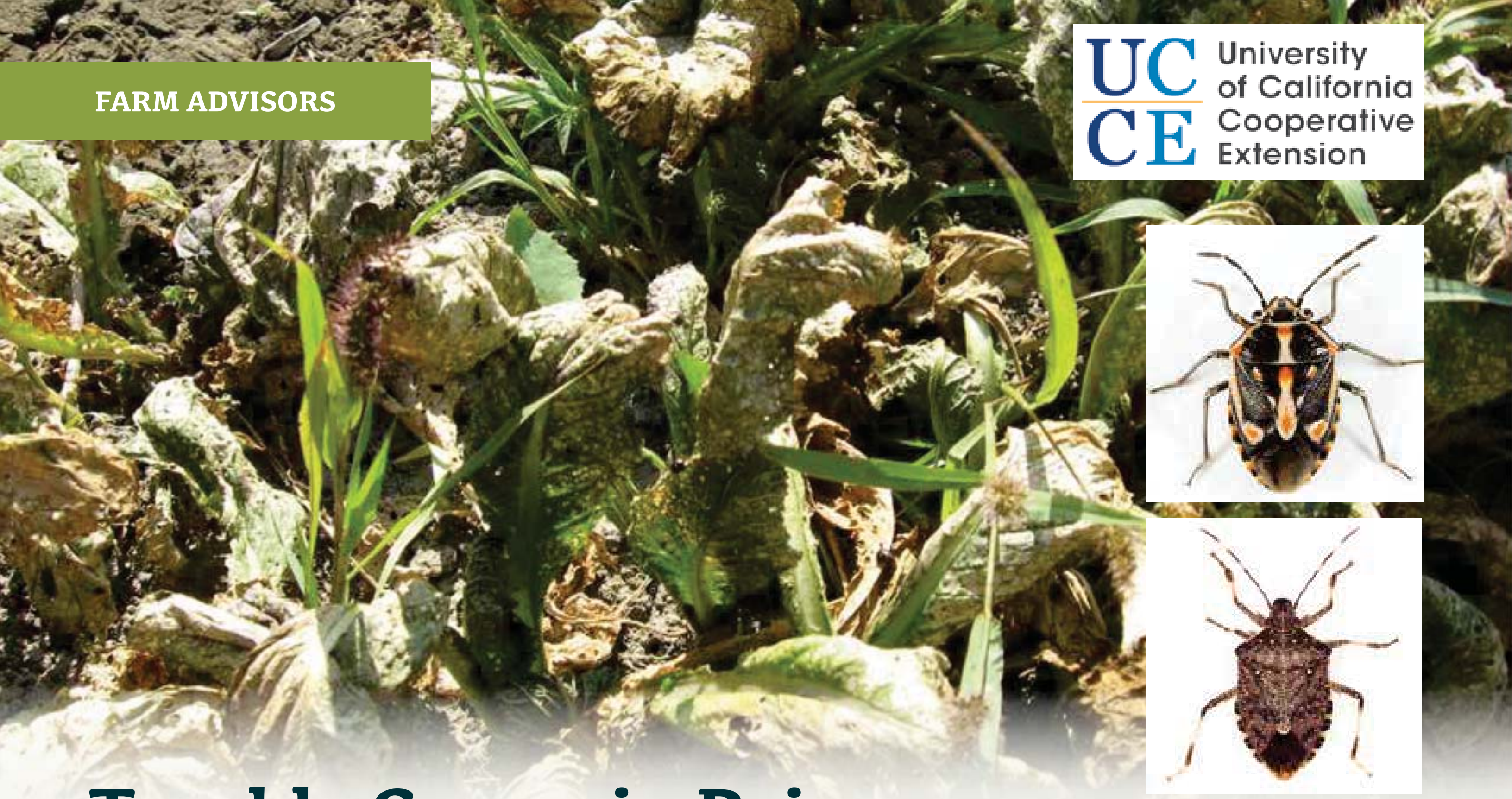

Trouble Comes in Pairs: Invasive stink bugs in California

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Worldwide, stink bugs are an economically important insect group that can be injurious to food crops. California (CA) has more than 70 stink bug species, a mixture of non-native and native species (Froeschner 1988; Lara et al. 2016). Among the non-natives are bagrada bug (BB; *Bagrada hilaris*) and brown marmorated stink bug (BMSB; *Halyomorpha halys*). Their invasion into CA poses a considerable threat to the state's specialty crop production and has triggered the development of pest management programs. Both stink bugs use their needle-like mouthparts to pierce and feed on plants and fruit, which may cause economic damage. With respect to BMSB and BB, there are notable differences and similarities in their invasion ecology which have influenced management programs in CA.

BB was first detected in the U.S. in CA (Los Angeles County) during 2008 and follow-up DNA analyses indicate CA populations originated from Pakistan (Reed et al. 2013; Sforza et al. 2017). In the U.S., BB has been recorded on 32 host plants from 8 families (Bundy et al. 2018). However, BB is mainly a pest threat to cultivated cole crops (Brassicaceae), including broccoli, cauliflower, cabbage, and kale. Feeding damage from BB causes stunted/malformed vegetative growth, wilting, and stippling (Fig 1). Severe damage symptoms from BB feeding, leading to plant death, are commonly observed with direct-seeded cole crops. BB's distribution in the U.S. is limited to southwestern states (CA, AZ, NV, NM, TX, and UT) and it thrives in warm climates, more so than BMSB. BB's current CA distribution ranges from Imperial Valley to parts of the Sacramento Valley, for a total of 22 invaded CA counties (Bundy et al. 2018). In CA, BB has peak activity occurring in spring and fall months, coinciding with the cole crop field season in agricultural areas in the state (Reed et al. 2013). It is estimated that during 2010-2014 BB generated >10% stand losses and plant injury to commercial broccoli crops in AZ and CA (Bundy et al. 2018).

When BMSB was first detected CA in 2002 (Riverside County) and breeding populations were confirmed in 2006 (Los Angeles County), it was already established on the East Coast where it arrived during the 1990s from Asia (Lara et al. 2016). Presently, BMSB has been recorded in 44 U.S. states on more than 100 host plant species from 56 families, including economically important vegetable, fruit, and nut specialty crops (NIC 2016). BMSB's feeding on fruit and nuts, for example, results in external peel discoloration and internal necrotic tissue (Fig 2). BMSB has

Annals of the Entomological Society of America, 111(3), 2018, 122–126
doi: 10.1093/aesa/say010
Advance Access Publication Date: 4 April 2018
Research article

OXFORD

Behavior

Astata unicolor (Hymenoptera: Crabronidae) Population in Oregon With Observation of Predatory Behavior on Pentatomidae

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Subject Editor: Hector Carcamo

Received 18 December 2017; Editorial decision 2 March 2018

Abstract

Predatory wasps are one of the few natural enemies to attack late instar pentatomid nymphs and adults. However, there is a substantial lack of information about their flight and nesting behavior, making them poorly understood. We report 3 yr of observational data of *Astata unicolor* Say 1824 foraging behavior and phenology from a residential site in Portland, OR. *A. unicolor* attacked and paralyzed at least four hemipteran species, and 64% of paralyzed prey were from the invasive *Halyomorpha halys* (Stål; Hemiptera: Pentatomidae). Peak flight occurred between late July and mid-September. Though unmanaged and solitary, *A. unicolor*'s preference for *H. halys* demonstrates that native predators contribute to mortality and potentially management of economically important insects. This is one of the few studies to document predatory wasps' potential for biological control of *H. halys*. Additional work on *Astata* is necessary to determine whether trap nesting, dispersal, or habitat enhancement, broadens the potential for expanded biological control.

Key words: biological control, sand wasp, nesting, *Halyomorpha halys*

Astata, a genus of predatory wasps within the Astatinae (Hymenoptera: Crabronidae) subfamily, are distributed globally and specialize on several Hemipteran families including Pentatomidae (Parker 1962, Bohart and Menke 1976). Immature and adult stink bugs are the preferred prey items of these wasps (Evans 1957, Evans 1962). Eight *Astata* species including *A. bakeri* Parker 1962, *A. bechteli* Parker 1962, *A. leuthstromi* Ashmead 1897 (Hymenoptera: Crabronidae), *A. nevadica* Cresson 1881 (Hymenoptera: Crabronidae), *A. nubecula* Cresson 1865 (Hymenoptera: Crabronidae), *A. occidentallis* Cresson 1881 (Hymenoptera: Crabronidae), *A. unicolor* (Hymenoptera: Crabronidae), and *A. williamsi* Parker 1962, are documented in Oregon (Lowenstein et al. 2018). All voucher specimens for these species in Oregon date were collected 1898–1973, and recent information on their distribution is scant. It is difficult to distinguish species externally due to morphological similarities such as abdominal color. For example, *Astata unicolor* has variants with orange or black abdomens, while *A. bicolor* Say 1823 (Hymenoptera: Crabronidae) has an orange abdomen and is distinguished by the presence of a spine on the femur (Parker 1962). While no observations of the closely related *A. bicolor* exist in Oregon (Lowenstein et al. 2018), this species' distribution has recently expanded into British Columbia (Ratzlaff 2016), an area several hundred kilometers to the North with a similar climate.

Most information on *Astata* nesting and behavior is limited to several studies during the mid 20th century. *Astata* are reported to nest in hard-packed, bare, and open soils with burrow depths of 7–10 cm (Evans 1962, Bohart and Menke 1976). Nests are typically multicellular with cells prepared individually for each offspring (Evans 1957, Bohart and Menke 1976). Female wasps paralyze adults or nymphs singly, holding the prey item with the mandible, and delivering a venomous sting. Paralyzed prey are carried on the ventral side and brought to the nest cell, where an egg is laid on the prey's prosternum (Evans 1957). Male *Astata* often perch on plants or stones while waiting to intercept females (Bohart and Menke 1976), and this behavior is reflected in their large holoptic eyes. Wasps use visual cues to orient themselves towards nests (Baerends 1941), and there is evidence that they use the stink bug pheromone, methyl (2E, 4Z, 6Z)-decatrienoate (MDT) to locate at least one pentatomid species, *Thyanta Pallidovirens* (Stål 1859) (Hemiptera: Pentatomidae) (Millar et al. 2001). *Astata unicolor* has never been recovered from pyramid or other traps baited with the two-component aggregation pheromone (Khrimian et al. 2014) and the synergist MDT (Weber et al.

Journal of Economic Entomology, 111(3), 2018, 1210–1218
doi: 10.1093/jee/toy093
Advance Access Publication Date: 17 April 2018
Research Article

OXFORD

Ecology and Behavior

Halyomorpha halys (Hemiptera: Pentatomidae) Winter Survival, Feeding Activity, and Reproduction Rates Based on Episodic Cold Shock and Winter Temperature Regimes

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Subject Editor: Michael Furlong

Received 1 November 2017; Editorial decision 11 March 2018

Abstract

Globally distributed nonnative insects thrive by having a generalist diet and persisting across large latitudinal gradients. *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) is a cold-tolerant invasive species that enters reproductive diapause in temperate North American and European climates. While it can survive the acute effects of subzero (°C) temperatures, it is poorly understood how exposure to infrequent cold temperatures affects postdiapause survival and behavior. We studied the impacts of episodic cold shock at temperatures of −6 to −2 (°C) at the onset of *H. halys* diapause, followed by an extended overwintering period. These conditions simulated three distinct climates, with above-freezing, near-freezing, and below-freezing daily low temperatures, to explore a range of possible effects on *H. halys*. We measured mortality regularly and evaluated postdiapause feeding damage and fecundity in each treatment. Postdiapause survival rates ranged from 40 to 50% in all treatments, except for −6°C. At this temperature, fewer than 25% *H. halys* survived. Feeding damage was greatest in the warmest simulated climate. The highest number of egg masses was laid under subfreezing episodic cold shock conditions. The controlled diapause simulations suggest that brief exposure to cold temperatures as low as −4°C does not have immediate or long-term effects on *H. halys* mortality. Exposure to cold temperatures may, however, increase postdiapause fecundity. These data provide insight into the impacts of cold exposure on postdiapause survival, reproduction, and feeding and can help predict *H. halys*-related crop risk based on preceding winter conditions.

Key words: diapause, stink bug, nonnative insect, fecundity, intrinsic rate of growth

Stink bugs (Hemiptera: Pentatomidae) can undergo long-term suspended development, known as facultative diapause (Saulich and Musolin 2012) due to reduced temperature, photoperiod, and photoperiod regimes. These primary cues initiate physiological changes and acclimation prior to and during seasonal cold weather conditions at Northern latitudes exceeding 30° (Slachta et al. 2002, Bradshaw 2010). In pentatomids, less than 13 h of daylight often results in changes in physiology (including melanin formation; Niva and Takeda 2003), feeding behavior and body size (Hahn and Denlinger 2007), cessation of reproduction (reference), and movement from host plants in search of natural or man-made overwintering sites (McPherson 1974, Niva and Takeda 2003). In addition to photoperiod, acclimation to colder temperatures may contribute to cold tolerance and enhanced postdiapause survival (Chen and Walker 1994). Suboptimal cold exposure at any time during the dormant period may increase stress and reduce long-term fitness (Sinclair and Chown 2005, Hoffmann 2010, Marshall and Sinclair 2015). Alternatively, some insects acquire cold tolerance because of rapid cold hardening (Lee et al. 1987). Stink bugs do not lay eggs during diapause (Watanabe et al. 1978), and their exposure to varied temperatures during the acclimation process may have implications for reproduction and economic damage in the following growing season.

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae), known by its common name the brown marmorated stink bug, is an agricultural pest with a broad host range (Nielsen and Hamilton 2009). First detected in the United States in the late 1990s, *H. halys* has rapidly spread across North America to 45 states and multiple Canadian provinces (Leskey et al. 2012, Gariepy et al. 2014, Rice et al. 2014, Abram et al. 2017) and has recently caused economic damage in Western Europe (Callot and Brua 2013, Haye et al. 2014, Bosco et al. 2018, Musolin et al. 2017, Vetek and Koranyi 2017). The pest's polyphagous feeding and capacity for long-distance flight (Wiman et al. 2015) threaten fruit, vegetable, and agronomic crops in regions with diverse cropping systems. As *H. halys* can have multiple generations per year, there is an extended period for economic damage

Biological Control 121 (2018) 140–150

Contents lists available at ScienceDirect

Biological Control

journal homepage: www.elsevier.com/locate/ybcon

Predation and parasitism by native and exotic natural enemies of *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) eggs augmented with semiochemicals and differing host stimuli

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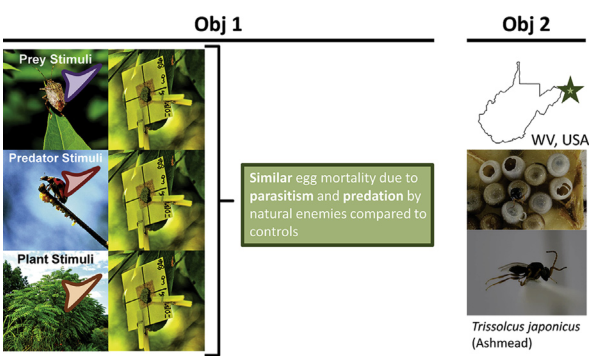
GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Biological control
Brown marmorated stink bug
Trissolcus japonicus

ABSTRACT

Escape from the natural enemy community by invasive species in their introduced range is a key determinant to their success. Historically in North America, there have been only low levels of predation and parasitism for *Halyomorpha halys* (Stål), the brown marmorated stink bug. In our study, we sought to determine whether prey-, predator-, or plant-associated stimuli increase mortality of *H. halys* egg masses, and whether the exotic parasitoid *Trissolcus japonicus* (Ashmead) is present in West Virginia or New Jersey. We deployed sentinel egg masses over two years in a variety of studies. We found that the *H. halys* aggregation pheromone was not used as a kairomone by natural enemies, the presence of methyl salicylate and varying host species stimuli did not impact egg mortality, and other predator attractants did not increase predation damage to egg masses. However, we documented *Trissolcus japonicus* for the first time in Jefferson Co., West Virginia, USA. Ultimately, our study suggests that other related stimuli and potential landscape factors should be investigated for increasing the impact of the natural community on *H. halys*.

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https://doi.org/10.1016/j.biocontrol.2018.02.016
Received 26 December 2017; Received in revised form 15 February 2018; Accepted 17 February 2018
Available online 19 February 2018
1049-9644/ Published by Elsevier Inc.

PLOS | ONE

RESEARCH ARTICLE

Identification of volatiles released by diapausing brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae)

Laura J. Nixon[1,2]*, William R. Morrison[3,4], Kevin B. Rice[4], Eckehard G. Brockerhoff[2,5], Tracy C. Leskey[4], Filadelfo Guzman[6], Ashot Khrimian[6], Stephen Goldson[1,7], Michael Rostás[1]

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OPEN ACCESS

Citation: Nixon LJ, Morrison WR, Rice KB, Brockerhoff EG, Leskey TC, Guzman F, et al. (2018) Identification of volatiles released by diapausing brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae). PLoS ONE 13(1): e0191223. https://doi.org/10.1371/journal.pone.0191223

Editor: Choong-Min Ryu, Korea Research Institute of Bioscience and Biotechnology, REPUBLIC OF KOREA

Received: June 1, 2017

Accepted: December 5, 2017

Published: January 17, 2018

Data Availability Statement: Data extracted from chromatograms has been made available from the open access online database figshare.com at the DOI: 10.6084/m9.figshare.5056906.

Funding: Contributions by L.J.N. and E.G.B. were supported by the New Zealand government via Ministry of Business, Innovation, and Employment core funding to Plant and Food Research and Scion (contract C04X1104), respectively, and the Better

Abstract

The brown marmorated stink bug, *Halyomorpha halys*, is an agricultural and urban pest that has become widely established as an invasive species of major concern in the USA and across Europe. This species forms large aggregations when entering diapause, and it is often these aggregations that are found by officials conducting inspections of internationally shipped freight. Identifying the presence of diapausing aggregations of *H*. *halys* using their emissions of volatile organic compounds (VOCs) may be a potential means for detecting and intercepting them during international freight inspections. Headspace samples were collected from aggregations of diapausing *H*. *halys* using volatile collection traps (VCTs) and solid phase microextraction. The only compound detected in all samples was tridecane, with small amounts of *(E)*-2-decenal found in most samples. We also monitored the release of defensive odors, following mechanical agitation of diapausing and diapause-disrupted adult *H*. *halys*. Diapausing groups were significantly more likely to release defensive odors than diapause-disrupted groups. The predominant compounds consistently found from both groups were tridecane, *(E)*-2-decenal, and 4-oxo-*(E)*-2-hexenal, with a small abundance of dodecane. Our findings show that diapausing *H*. *halys* do release defensive compounds, and suggest that volatile sampling may be feasible to detect *H*. *halys* in freight.

Introduction

Halyomorpha halys, commonly known as the brown marmorated stink bug, has emerged as a severe agricultural and urban pest in the USA [1]. Originally from China, Korea, Japan, and Taiwan, this invasive species has spread across 43 states of the US and two provinces in Canada since it was first officially detected in Pennsylvania in 2001 [1]. As of September 2017,

Journal of Economic Entomology, 111(1), 2018, 495–499
doi: 10.1093/jee/tox316
Advance Access Publication Date: 20 December 2017
Short Communication

Short Communication

OXFORD

Enhanced Response of *Halyomorpha halys* (Hemiptera: Pentatomidae) to Its Aggregation Pheromone with Ethyl Decatrienoate

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Subject Editor: Cesar Rodriguez-Saona

Received 12 September 2017; Editorial decision 17 October 2017

Abstract

The invasive stink bug species, *Halyomorpha halys* (Stål) (Hemiptera; Pentatomidae), severely damages multiple agricultural commodities, resulting in the disruption of established IPM programs. Several semiochemicals have been identified to attract *H. halys* to traps and monitor their presence, abundance, and seasonal activity. In particular, the two-component aggregation pheromone of *H. halys*, (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 (PHER), in combination with the pheromone synergist, methyl (2*E*,4*E*,6*Z*)-decatrienoate (MDT), were found to be attractive. Here, we report that an analogous trienoate, ethyl (2*E*,4*E*,6*Z*)-decatrienoate (EDT), enhances *H. halys* captures when combined with PHER. In trials conducted in Eastern and Western regions of the United States, we observed that when traps were baited with the *H. halys* PHER + EDT, captures were significantly greater than when traps were baited with PHER alone. Traps baited with EDT alone were not attractive. Thus, the addition of EDT to lures for attracting *H. halys* to traps may further improve monitoring efficiency and management strategies for this invasive species.

Key words: brown marmorated stink bug, BMSB, pheromone, attractants, trapping

Introduction

Halyomorpha halys (Stål) (Hemiptera; Pentatomidae) is an invasive stink bug that causes severe economic damage to fruits, vegetables, field crops, nuts, and ornamental nursery plants (Rice et al. 2014). Originating in Asia, established populations of *H. halys* were first detected in Pennsylvania in 2001 (Hoebeke and Carter 2003), and have since been reported throughout the United States, four Canadian provinces, many European countries (www.stopbmsb.org, Rice et al. 2014, Kriticos et al. 2017), and most recently in South America (Faúndez and Rider 2017). This invasive insect severely disrupts established IPM programs as growers now rely on calendar-based insecticide applications to reduce economic damage (Leskey et al. 2012a,b), often leading to secondary pest outbreaks (Leskey et al. 2012c), thus emphasizing the need for effective monitoring techniques.

Prior to its introduction to North America, researchers in Asia reported *H. halys* captures in traps baited with the aggregation pheromone of the oriental stink bug *Plautia stali* Scott (Hemiptera; Pentatomidae), methyl (2*E*,4*E*,6*Z*)-decatrienoate (MDT) (Sugie et al. 1996), suggesting this compound could be used to monitor and detect *H. halys* populations in invaded regions. In the United States, MDT combined with visually attractive black pyramid traps successfully captured *H. halys* adults and nymphs in the latter part of the growing season, but early season monitoring remained difficult because *H. halys* adults did not respond to MDT at that time (Leskey et al. 2012d). In 2014, the *H. halys* aggregation pheromone (PHER) (3*S*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol (SSRS) and (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol (RSRS) (in approximate 3.5:1 ratio of SSRS:RSRS) was identified and synthesized

Journal of Economic Entomology, 111(5), 2018, 2136–2142
doi: 10.1093/jee/toy185
Advance Access Publication Date: 3 July 2018
Research Article

OXFORD

Ecology and Behavior

Improved Trap Designs and Retention Mechanisms for *Halyomorpha halys* (Hemiptera: Pentatomidae)

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Subject Editor: Charles Burks

Received 27 March 2018; Editorial decision 9 June 2018

Abstract

Current monitoring systems for the invasive *Halyomorpha halys* (Stål) (Hemiptera; Pentatomidae) in orchard agroecosystems rely on ground-deployed tall black pyramid traps baited with the two-component *H. halys* aggregation pheromone and pheromone synergist. Pyramid traps are comparatively costly, require considerable time to deploy and service, and may not be best suited to grower needs. Therefore, we evaluated other traps for *H. halys*, including modified pyramid traps (lures deployed on the outside), a canopy-deployed small pyramid, a pipe trap, delta traps, and yellow sticky cards in 2015 and 2016 in commercial apple and peach orchards. We also compared various *H. halys* killing agents for use in standard pyramid trap collection jars, including VaporTape kill strips, cattle ear tags, and plastic netting treated with various pyrethroids. Finally, we evaluated the effect of positioning the lures inside versus outside the collection jar on standard pyramid traps on overall captures. Among trap types, modified pyramid and pipe traps were most effective, capturing more adults than all other trap designs. Adult captures in small canopy-deployed pyramid, delta, and yellow sticky traps were lower, but significantly correlated with the standard black pyramid. Placing lures on the outside of collection jars on pyramid traps resulted in significantly greater captures and insecticide-impregnated netting was as effective for retaining bugs as VaporTape strips. These studies demonstrate that trapping systems for *H. halys* can be simplified and improved by modifying the trap design, lure deployment location, and/or killing agent.

Keywords: BMSB, brown marmorated stink bug, monitoring, integrated pest management

Effective monitoring tools for insect pests are an essential component of integrated pest management (IPM). Efficient traps can support management decisions such as timing of insecticide applications based on captures, thereby reducing production costs, nontarget effects, and secondary pest outbreaks (Toscano et al. 1974, Ragsdale et al. 2007). Invasive insect species can severely disrupt established IPM programs (Szczepaniec et al. 2011, Leskey et al. 2012b), and can be particularly difficult to monitor because of general lack of knowledge about their behavior and ecology in the invaded range (Elton 1958, Lockwood et al. 2013).

Halyomorpha halys (Stål) (Hemiptera; Pentatomidae) is an invasive herbivore originating from Asia that currently has established populations in the United States, Canada, Western and Eastern Europe, and South America (Hoebeke and Carter 2003, Wermelinger et al. 2008, Gariepy et al. 2014, Faúndez and Rider 2017, Leskey and Nielsen 2018). *H. halys* is a major agricultural pest of a wide range of commodities including fruits, vegetables, field crops, and ornamentals, and has caused severe economic injury (American Western Fruit Grower 2011, Rice et al. 2014, Leskey and Nielsen 2018). In response, growers have relied on weekly insecticide applications, leading to increased production costs and secondary pest outbreaks (Leskey et al. 2012b).

In Asia, stink bug monitoring programs suggested that *H. halys* were cross-attracted to the aggregation pheromone of the oriental stink bug *Plautia stali* Scott (Hemiptera; Pentatomidae), methyl (*2E,4E,6Z*)-2,4,6-decatrienoate (MDT) (Tada et al. 2001a,b; Lee et al. 2002). This was confirmed later with invasive *H. halys* populations in the United States (Aldrich et al. 2007, Khrimian et al. 2008). In 2014, the two-component aggregation pheromone of *H. halys* was identified as (*3S,6S,7R,10S*)-10,11-epoxy-1-bisabolen-3-ol and (*3R,6S,7R,10S*)-10,11-epoxy-1-bisabolen 3-ol (PHER) (Khrimian et al. 2014). When deployed with visually attractive black pyramid

insects

MDPI

Article

Monitoring Nutrient Status of Brown Marmorated Stink Bug Adults and Nymphs on Summer Holly

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Received: 13 August 2018; Accepted: 14 September 2018; Published: 17 September 2018

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Abstract: *Halyomorpha halys* (Stål), or brown marmorated stink bug (BMSB), has become a major pest and nuisance for both agricultural growers and homeowners since its arrival in North America and Europe. The nutritional ecology of BMSB is important for understanding its life history and rearing requirements. However, little is known about the nutritional status of wild populations, especially in the U.S. This research monitored the nutrient status of nymphal and adult BMSB collected from English holly in western Oregon. We measured their weight, nutrient index (weight/(prothorax × width)^3), lipid, glycogen and sugar levels and egg load from May–September/October. First, glycogen and sugar levels of adults were often lowest sometime in June-August with a general increase by September. Meanwhile, their lipid levels varied without a discernible trend. Second, adult females had few eggs in May, with the highest egg load in June and July, and no eggs by September. Lastly, first and second nymphal instars were found in June, and fourth and fifth instars in September. Because nothing is known about the nutrient levels of nymphs, the reported values from this survey can assist future research on physiological responses of BMSB to treatments or environmental impacts in the field.

Keywords: *Halyomorpha halys*; nutritional ecology; nymphal development; lipid; glycogen; sugar

1. Introduction

The brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), was first detected in the United States in 1996 and Europe in 2004 [1–3]. It has established in 44 U.S. states including Oregon in 2004 [4]. Native to eastern Asia, BMSB nymphs and adults feed on ~150 different plant species in the U.S. and damage the leaves, buds, stems and fruits [5]. In Oregon, BMSB are often found on English holly, maple, tree of heaven, empress tree, catalpa, ash, dogwood and Himalayan blackberries [6]. In temperate regions, BMSB have one generation per year, while in warmer tropical regions, up to five generations [2]. Adult BMSB overwinter in aggregations in man-made structures, making them a major nuisance to homeowners, as well [7].

Understanding the nutritional ecology of BMSB improves our knowledge of this pest's life history. Prior work on the development of BMSB on different diets has enabled researchers to optimize rearing BMSB for research use [8–11]. Monitoring the energetic reserves of field-collected adults has revealed that extensive nutrient depletion occurs during overwintering. In spring, emerged BMSB adults have lower glycogen and sugar reserves than concurrently overwintering BMSB [12]. Furthermore, overwintering adults exhibit a 12–25% decline in lipid, a 48–70% decline in glycogen and a 54–79% decline in sugar levels from October–June [12]. Given that BMSB have low reserves upon emergence from diapause, adults must feed on host plants to replenish their

Entomologia Experimentalis et Applicata

DOI: 10.1111/eea.12708

Nutrient declines in overwintering *Halyomorpha halys* populations

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Accepted: 27 April 2018

Key words: diapause, energy, glycogen, lipid, nutritional ecology, physiology, Pentatomidae, Hemiptera, reproduction, sugar, brown marmorated stink bug, Nutrient Index

Abstract

Brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), has become a major pest for agricultural growers since it arrived in the USA and Europe. To better understand the energetic requirements of overwintering, dispersal, and reproduction of this invasive pest, we monitored the weight, egg load, lipid, glycogen, and sugar levels of adult *H. halys* populations in western Oregon, USA, over 2 years. In the first study, overwintering *H. halys* collected monthly from inside shelters exhibited a consistent decline in weight, glycogen, and sugar levels from October to June. In the second study, post-overwintering adults that exited shelters in late spring had lower lipid, glycogen, and sugar levels than those that exited in early spring. Also, adults that just exited shelters had lower weight, glycogen, sugar, and sometimes lipids than adults that remained in diapause. Sugar levels declined the most during winter, followed by lipid and glycogen. These findings suggest that nutritional depletion may cause *H. halys* to emerge from diapause. In the third study, overwintered and first-generation adults (G_1) were simultaneously collected from holly in July and August. Overwintered adults often had lower nutrient levels than G_1 adults, which may reflect overwintered adults having expended energy for dispersal and reproduction. In the fourth study, we evaluated whether the Nutrient Index [weight (mg)/prothorax width $(mm)^3$], a convenient index of physiological status, correlated with nutrient reserves. The Nutrient Index correlated with the adults' lipid, glycogen, or sugar levels in 57% of cases, ranging from weakly negative to moderately positive correlations.

Introduction

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is a serious economic pest prompting extensive research on monitoring, chemical, biological, and cultural control (Rice et al., 2014; Abram et al., 2017; Kuhar & Kamminga, 2017; Weber et al., 2017). Native to Asia, *H. halys* has become established in 43 states of the USA, including Oregon in 2004 (StopBMSB.org, 2017), six countries in Europe, and Canada (Haye et al., 2015). Contributing to its ability to cause widespread damage, *H. halys* is clearly successful in overwintering, dispersing, and reproducing in its introduced range. Yet, diapause, flight, and reproduction are energetically costly, and few studies have examined this. Therefore, our research was comprised of four studies that examined energetic reserves of wild *H. halys* in Oregon during overwintering (study 1), post-emergence (study 2), and mid-summer (study 3) to understand its dynamics during diapause and summer activity. Study 4 evaluated a simple, nondestructive biometric index for *H. halys* adults as a representation of lipid, glycogen, and sugar status.

Halyomorpha halys enters overwintering sites generally from late September to mid-November in Asia (Lee et al., 2013) and the eastern USA (Bergh et al., 2017), and exits from March to June. These adults spend 6–9 months overwintering out of the 12 months lived as an adult (Figure 1). For insects, diapause is an energetically expensive period that relies on stored triacylglycerides (lipids), glycogen, and trehalose (sugar) (Hahn & Denlinger, 2007). Based on this review, insects can alternate between using lipid and carbohydrate reserves during diapause; sugars, amino acids, and proteins are thought to be primarily used for cold and desiccation resistance, whereas glycogen may

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 RESEARCH COMMUNICATIONS

Early detection of invasive exotic insect infestations using eDNA from crop surfaces

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The number of exotic species invasions has increased over recent decades, as have the ecological harm and economic burdens they impose. Rapid-response eradication of nascent exotic populations is a viable approach to minimizing damage, but implementation is limited by the difficulty of detecting such species during the early stages of infestation due to their small numbers. The use of environmental DNA (eDNA) has helped address this issue in aquatic ecosystems, but to the best of our knowledge has not been trialed for surveillance of exotic species in terrestrial systems. Using a high-resolution, real-time (quantitative) polymerase chain reaction assay, we developed a highly efficient protocol to survey agricultural fields for the invasive non-native brown marmorated stink bug (BMSB; *Halyomorpha halys*). We compared results using eDNA to those for conventional monitoring traps and documented substantially higher sensitivity and detection effectiveness. Our methodology is transferable to situations in which the DNA of terrestrial target species can be accumulated into a single substrate, suggesting that eDNA-based approaches could transform our ability to detect exotic insects in non-aquatic settings.

Front Ecol Environ 2018; doi: 10.1002/fee.1811

Early detection of exotic populations, followed by rapid management responses, has resulted in successful eradication of several species known to cause ecological or economic harm (Mehta *et al.* 2007). Eradication requires lethal control measures, many of which have unwanted secondary effects (eg harm to non-target species leading to loss of ecosystem services). Delays in detection and eradication of exotic populations lead to increases in the magnitude and geographical extent of the invasion, and subsequently to escalation of the economic costs, while the probability of successful eradication declines substantially (Simberloff *et al.* 2013). Furthermore, when exotic populations are left unmanaged for long periods, efforts shift from eradication to protection of valued assets, which is often accomplished through the continual application of control methods (Simberloff *et al.* 2013). This general approach emphasizes the need for detection of unwanted and harmful exotic species when their presence is still very limited. However, this has proven extraordinarily difficult due to the low likelihood of detecting these small populations of individual invaders (Simberloff *et al.* 2013). In response, researchers have invested in improving survey design and statistical analysis, and in devising more sensitive surveillance tools (Mehta *et al.* 2007; Jerde *et al.* 2011). Here, we describe the use of environmental DNA (eDNA) to substantially improve the detection of agricultural insect pests, and in doing so provide a precedent for the use of eDNA for surveillance in other terrestrial invasion scenarios.

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Environmental DNA consists of freely available DNA or biological material containing DNA that has been shed or dropped by organisms as they move through the environment (eg skin flakes, hair, feathers, scales, setae [bristles], exuviae [molted exoskeletons], fecal matter) (Bohmann *et al.* 2014). This DNA can persist and accumulate within (or in terrestrial systems on the surface of) environmental materials or substrates, which can then be collected and tested using high-resolution processing techniques to detect trace amounts of DNA (Rees *et al.* 2014; Barnes and Turner 2016). Environmental DNA has been used successfully to surveil for invasive aquatic organisms (Jerde *et al.* 2011, 2013), and is considered a burgeoning field of investigation within invasion science (Ricciardi *et al.* 2017). However, as of this writing, the use of eDNA for exotic species surveillance in terrestrial ecosystems is comparatively rare. Extraction and analysis of DNA within soil is used extensively to characterize microbial and other communities, clearly indicating that the technical issues associated with using eDNA in terrestrial settings are minor. However, in the context of surveillance, eDNA approaches must be capable of detecting individuals of focal species when they are very rare. Due to the nature of water, aquatic systems can mix more readily and sampling approaches that filter large amounts of water facilitate the accumulation of DNA, making detection of exotic species more likely even when abundance is very low. However, the same conditions may not always be true for terrestrial systems, perhaps limiting the usefulness of eDNA approaches on land.

Nonetheless, terrestrial systems could benefit greatly from the use of eDNA techniques in terrestrial invasive species surveillance. Successful development of this methodology for exotic insects could translate into rapid-response eradications of species known to be harmful to

