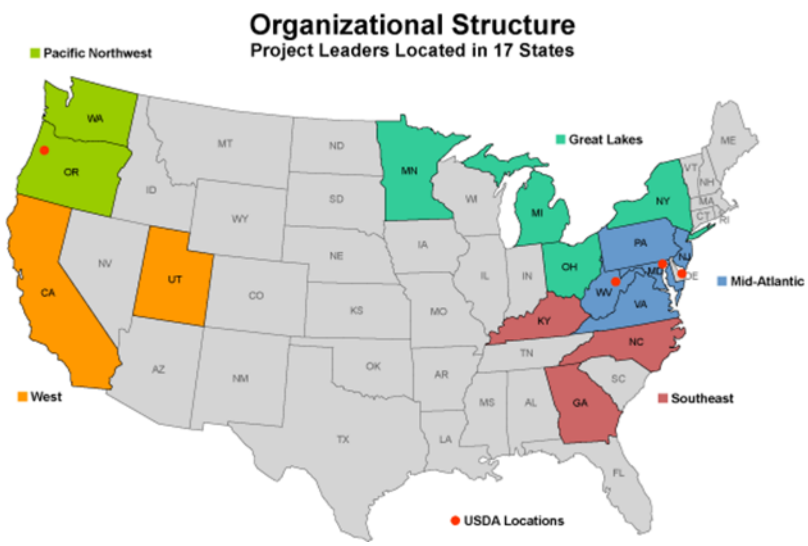
Management of Brown Marmorated Stink Bug in US Specialty Crops

2019

ANNUAL REPORT



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BMSB SCRI SAP Meeting

February 20, 2020, Hyatt Place UC Davis, Davis, CA

8:30-8:45	Welcome and introductions
8:45-9:15	**Regional reports** (5 minutes per region) Southeast – Mike Toews, University of Georgia Mid-Atlantic – Tom Kuhar, Virginia Tech Great Lakes – Larry Gut, Michigan State University West – Kent Daane, University of California-Berkeley Pacific Northwest – Betsy Beers, Washington State University
	Landscape ecology
9:15	• National and regional BMSB models and factors affecting presence/absence and population abundance. Dave Crowder and Javier Illan, Washington State University.
10:00	• Temperature and photoperiod influences on phenology in NC. Jim Walgenbach, NC State Univ.
10:15	• Temperature and humidity interaction to influence BMSB survival. Joanna Fisher and Frank Zalom, UC-Davis.
10:30	BREAK
10:45	• Wild host plants of BMSB in the western US. Lori Spears, Utah State University.
11:00	• BMSB on pistachio, and survival on crops common in the SJV. Judith Stahl and Kent Daane, UC-Berkeley.
	Native natural enemies
11:15	• Who are the native natural enemies in the southeast? Glynn Tillman and Mike Toews, USDA-ARS and University of Georgia.
11:35	• Natural enemy impacts in apple and corn agroecosystems. Emily Ogburn, Jim Walgenbach, and Amelia Heintz-Botz, NC State University.
	StopBMSB.org:
11:50	• Search Engine Optimization Basics. Mike Webb, Kevin Judd and Deb Grantham. NEIPM Center, Cornell University. (Zoom presentation)
12:00	Lunch
	Trissolcus japonicus
1:00	• Redistribution, dispersal, foraging, and reproduction of *Trissolcus japonicus*. Joe Kaser and Kim Hoelmer, USDA-ARS, Newark, DE.
1:20	• California *T. japonicus* update. Ricky Lara and Mark Hoddle, UC-Riverside.
1:35	• Oregon Samurai: Statewide redistribution efforts and prospects for biocontrol in orchards. Heather Andrews, Claire Donahoo, and Nik Wiman, Oregon State Univ.
1:50	• *Quo Vadis Japonicus*? Unfortunate non-target effects of parasitoids on native stink bugs. Jim Hepler and Betsy Beers, Washington State University.
2:05	• Classical stink bug biocontrol: what does success look like? Betsy Beers, Wash. State Univ.
	Management Strategies
2:20	• Attract and Kill, Perimeter Spraying, Thresholds – Tracy Leskey, USDA-ARS, WV. (Zoom)
2:35	• 16 years post detection in Oregon: BMSB distribution, damage and management. Rick Hilton, Oregon State University.
2:50	• Netting as a BMSB exclusion barrier. Jim Hepler and Betsy Beers, WSU.
3:05	BREAK
3:15	• The gap between research and extension: a survey of current BMSB management strategies across the US. Art Agnello, David Lane, and Deb Grantham, Cornell University.
3:30	• Seasonal and orchard-related factors affecting BMSB activity and damage to almonds. Jhalendra Rijal, UCANR, Merced County.
3:45	• Areawide management of BMSB: the Republic of Georgia experience. Greg Krawczyk, Penn State University.
4:00	Stakeholders meet without PIs to discuss progress of the project.
4:30	All participants reconvene to hear stakeholder comments and discuss plans for the coming year, and select set meeting site for 2021.
5:00	Adjourn

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. Evaluate impact of insecticides on natural enemies.

3c. Improve agroecosystem sustainability through spatially focused management or habitat manipulation.
- i. Evaluate 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 costs 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.

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Journal publications (including those in press)

Acebes-Doria, A, A Agnello, D Alston, H Andrews, E Beers, JC Bergh, R Bessin, BR Blaauw, GD Buntin, E Burkness, S Chen, T Cottrell, K Daane, L Fann, S Fleischer, C Guedot, L Gut, G Hamilton, R Hilton, K Hoelmer, W Hutchinson, P Jentsch, G Krawczyk, T Kuhar, J Lee, D Patel, B Short, A Sial, L Spears, K Tatman, M Toews, J Walgenbach, C Welty, N Wiman, J van Zoeren, and T. Leskey. 2019. Season-long monitoring of the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), throughout the United States using commercially available traps and lures. J. Econ. Entomol. http://doi.org/10.1093/jee/toz240 (in press).

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Quinn, NF, E Talamas, AL Acebes-Doria, TC Leskey, and JC Bergh. 2019. Vertical sampling in tree canopies for *Halyomorpha halys* (Hemiptera: Pentatomidae) life stages and its egg parasitoid, *Trissolcus japonicus* (Hymenoptera: Scelionidae). Environ. Entomol. 48: 173-180. https://doi-org.prox.lib.ncsu.edu/10.1093/ee/nvy180

Talamas EJ, M-C Bon, KA Hoelmer, and M Buffington. 2019. Molecular phylogeny of *Trissolcus wasps* (Hymenoptera: Scelionidae), natural enemies of stink bugs. J. Hymenoptera Res. 73:201-217. https://doi.org/10.3897/jhr.73.39563

Tillman, PG, TE Cottrell, and GD Buntin. 2019. Potential of *Melia azedarach* L. (Meliaceae) as a host plant for *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). Fla. Entomol. 102: 222-226. https://doi-org.prox.lib.ncsu.edu/10.1653/024.102.0136

Weber, DC, WR Morrison, A Khrimian, KB Rice, BD Short, MV Herlihy, and TC Leskey. 2020. Attractiveness of pheromone components with and without the synergist, methyl (2E,4E,6Z)-2,4,6-decatrienoate, to brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). J. Econ. Entomol. 113. https://doi.org/10.1093/jee/toz312. (in press).

Presentations/posters at scientific meetings

Akotsen-Mensah, C, B Blaauw, C Rodriguez-Saona, and AL Nielsen. March 2019. Behavioral response of *Halyomorpha halys* (Stål) and its egg parasitoid *Trissolcus japonicus* to host based plant volatiles. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Akotsen-Mensah, C, AL Nielsen Dec. 5-6, 2019. Behavioral responses of *Halyomorpha halys* and its egg parasitoid, *Trissolcus japonicus*, to host based plant volatiles. Annual Cumberland-Shenandoah Fruit Workers Conference, Winchester, VA.

Alford, A, and T Kuhar. March 9-12, 2019. Where we stand today with insecticides for stink bug control. Symposium: Applied Agriculture and Ag-Industry. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Alford, A, T Kuhar, and J Walgenbach. March 9-12, 2019. Use of long lasting insecticidal netting for control of stinkbugs in Southeastern tomatoes and peppers. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Alston, D, and K Daane. February 19, 2019. Western region update on BMSB distribution and pest status. USDA NIFA SCRI Brown Marmorated Stink Bug Stakeholder Advisory Panel Meeting, Columbus, OH.

Alston, D, L Spears, MC Holthouse, and Z Schumm. February 19, 2019. BMSB phenology and voltinism in Utah. USDA NIFA SCRI Brown Marmorated Stink Bug Stakeholder Advisory Panel Meeting, Columbus, OH.

Avila, N, and AL Nielsen. November 17-20, 2019. Evaluating insectary plants in the field for *Trissolcus japonicus*. Entomological Society of America Annual Meeting. St. Louis, MO.

Avila, N, K Rice, and AL Nielsen. 2019. Effects of marking on *Trissolcus japonicus* behavior. Entomological Society of America Eastern Branch Meeting, Blacksburg, VA.

Bergh, JC, A Edwards, K Reed, A Elliott, K Lawrence, and EJ Talamas. Dec. 5-6, 2019. Redistributing *Trissolcus japonicus* in Virginia: 2019 Update. Cumberland-Shenandoah Fruit Workers Conference, Winchester, VA.

Bergh, JC, NF Quinn, and EJ Talamas. Aug. 29, 2019. The development and use of sampling protocols for *Trissolcus japonicus* and native parasitoids of BMSB in Virginia. BMSB Scientific Mission Conference, Tbilisi, Georgia.

Bergh, JC, NF Quinn, EJ Talamas, and TC Leskey. Jan. 21-25, 2019. Habitat and tree species effects on *Trissolcus japonicus* (Hymenoptera: Scelionidae) detections in Virginia, USA. IOBC PheroFIP conference, Lisbon, Portugal.

Bergh, JC, P Jentsch, and C Welty. Feb. 19, 2019. Status of *Trissolcus japonicus* redistribution releases in the eastern USA. SCRI Stakeholder Advisory Panel conference, Columbus, OH.

Bessin, R, and L Fann. 2020. Attract and kill strategies for brown marmorated stink bug in sweet corn. Joint Eastern Branch and Southeastern Branch ESA meeting.

Britt, K, M Pagani, and T Kuhar. March 2019. Brown marmorated stink bug feeding impact on industrial hemp yield and quality. Entomological Society of America North Central Branch Annual Meeting. Cincinnati, OH.

Britt, K, M Pagani, and T Kuhar. November 17-20, 2019. Understanding the relationship between brown marmorated stink bug and industrial hemp. Entomological Society of America Annual Meeting. St. Louis, MO.

Dyer, J, EJ Talamas, TC Leskey, and JC Bergh. December 5-6, 2019. Are detections of *Halyomorpha halys* egg masses and *Trissolcus japonicus* increased in pheromone-baited trees? Cumberland-Shenandoah Fruit Workers Conference, Winchester, VA

Fann, L, and R Bessin. 2019. Polyculture trap cropping for the brown marmorated stink bug (*Halyomorpha halys*). Ohio Valley Entomological Society Meeting.

Fann, L, and R Bessin. Polyculture trap cropping for the brown marmorated stink bug (*Halyomorpha halys*). Entomological Society of America North Central Branch Annual Meeting. Cincinnati, OH.

Fisher, JJ, C Ingles, J Rijal, and F Zalom. November 17-20, 2019. Analyzing the potential threat of the brown marmorated stink bug to walnuts and determining if shell hardness protects almonds. Entomological Society of America Annual Meeting. St. Louis, MO.

Girod, P, and G Hamilton. November 2019. *Halyomorpha halys* and *Trissolcus japonicus* in New Jersey - What's next? Entomological Society of America Annual Meeting. St. Louis, MO.

Girod, P, and G Hamilton. May 27-29, 2019. Risques et bénéfices de la redistribution mondiale de *Trissolcus japonicus* agent de biocontrôle contre *Halyomorpha halys*. 41ème journée des Entomophagistes. Antibes, France.

Gut, L, and J Pote. Jan. 2019. Improved trapping for brown marmorated stink bug using long-lasting insecticidal netting. Orchard Pest and Disease Management Conference.

Hadden, W, TC Leskey, and C Bergh. November 17-20, 2019. Deciphering the seasonal host-use patterns of *Halyomorpha halys* on select deciduous plants. Entomological Society of America Annual Meeting. St. Louis, MO.

Hadden, W, TC Leskey, and C Bergh. Mar. 9-12, 2019. Does the presence of a cultivated crop affect captures of *Halyomorpha halys*? Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Hadden, W, TC Leskey, and JC Bergh. Dec. 5-6, 2019. Life on the edge: Woods-to-orchard pheromone trap transects for *Halyomorpha halys*. Cumberland-Shenandoah Fruit Workers Conference, Winchester, VA.

Hadden, W, TC Leskey, and JC Bergh. November 17-20, 2019. Deciphering the seasonal host-use patterns of *Halyomorpha halys* on selected deciduous host plants. Entomological Society of America Annual Meeting. St. Louis, MO.

Hajek, A. March 2019. Biological control of invasive organisms impacting the Eastern Branch (focused largely on *Trissolcus japonicus*). Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Hepler, J, and EH Beers. November 17-20, 2019. Suitability of the arid shrub-steppe flora for brown marmorated stink bug feeding and development. Entomological Society of America Annual Meeting. St. Louis, MO.

Hepler, J, and EH Beers. March 31-April 3, 2019. The Poncho Trap: A novel attract-and-kill BMSB trap design. Entomological Society of America Pacific Branch Annual Meeting, San Diego, CA.

Hepler, J, and EH Beers. January 9-11, 2019. Fickle flaps of fate: Building a better stink bug trap. 93rd Annual Orchard Pest & Disease Management Conference, Portland, OR.

Herlihy,MV, D Weber, and M Cornelius. March 2019. Attack of samurai wasp and native parasitoids on eggs of brown marmorated stink bug and native stink bug sentinel eggs in different habitats. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Hilton, R. January 2019. BMSB and IPM in Southern Oregon: an irresistible fruit meets a movable insect. 93rd Orchard Pest and Disease Management Conference. Portland, OR.

Hoelmer, K, E Talamas, and M-C Bon. March 2019. Domestic and international plans for using *Trissolcus japonicus* as a biological control agent of *Halyomorpha halys*. Sympoisum talk. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Hoelmer, K, H Broadley, J Gould, J Kaser, X Wang, T Hagerty, and C Bartlett. November 17-20, 2019. Advances in Hemipteran Biology and Control in Symposium: Successes and challenges for biological control of recent invasive Hemiptera: BMSB & spotted lanternfly as examples. Entomological Society of America Annual Meeting. St. Louis, MO.

Hoelmer, K, J Kaser, M-C Bon, and E Talamas. August 2019. Update: BMSB natural enemy research, focusing on *T. japonicus*, its current distribution, and its potential role in BMSB biocontrol. BMSB – Global Challenge: International Experience and Best Solutions, Tbilisi, Rep. Georgia.

Hoelmer, K. February 2019. Overview of efforts to establish Trissolcus japonicus in the invaded range of BMSB. BMSB SCRI Stakeholder Advisory Panel Meeting, Columbus, OH.

Holthouse, M, Z Schumm, L Spears, and D Alston. November 17-20, 2019. Voltinism and parasitoids of brown marmorated stink bug in Utah. Entomological Society of America Annual Meeting. St. Louis, MO.

Jentsch, P. January 8, 2019. 2018 Insect Pest Management Updates: efficacy screening & invasive insect studies. Long Island Agricultural Forum, Suffolk County Community College; Eastern Campus, Riverhead, NY.

Jentsch, P. March 1, 2019. Biological control of brown marmorated stink bug, *Halyomorpha halys* Stål (Hemiptera: Pentatomidae) in NYS. Red Tomato Annual Growers Meeting, Henry A. Wallace Center, Hyde Park, NY.

Jentsch, P. February 2, 2019. Invasive insect tsunami: managing brown marmorated stink bug in NYS orchards. ENYCHP Winter Fruit Schools, Desmond Hotel & Conf. Ctr., Albany, NY.

Jentsch, P. March 6, 2019. New materials vs. old pests new monitoring for new pests. Maine State Pomological Society. Preseason Tree Fruit Meeting, Lewiston Auburn College, Lewiston, ME.

Jentsch, P. March 9-12, 2019. Presence and redistribution of samurai wasp, *T. japonicus* (Ashmead, 1904), in NYS. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Jentsch, P. February 4, 2019. Progress on developing management strategies for brown marmorated stink bug and spotted wing drosophila. Lake Ontario Winter Fruit Schools, Niagara County CCE Training Center, 4487 Lake Ave., Lockport, NY.

Kaser, JM, K Tatman, and KA Hoelmer. November 17-20, 2019. Parasitoid release numbers and establishment of adventive Trissolcus japonicus in Delaware. Entomological Society of America Annual Meeting. St. Louis, MO.

Kaser, JM, K Tatman, W Cissel, D Owens, and KA Hoelmer. March 2019. Redistribution of adventive *Trissolcus japonicus* in Delaware. Symposium talk. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Keyes, T, DM Lowenstein, E Rudoph, A Mugica, H Andrews, and NG Wiman. April 1, 2019. Testing compatibility of a biocontrol agent of *Halyomorpha halys* with pest management regimes in Pacific Northwest hazelnuts. Annual meeting of the Pacific Branch of the Entomological Society of America. San Diego, CA.

Kuhar, T. February 19, 2019. BMSB response to insecticides. BMSB SCRI Stakeholder Advisory Panel Meeting, Columbus, OH.

Kuhar, T. March 9-12, 2019. Challenges of implementing IPM in vegetables. Symposium: Challenges of Integrated Pest Management (IPM) in High Value Commodities. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Kuhar, T. November 17-20, 2019. IPM challenges from a vegetable crops perspective. P-IE Section Symposium: Advocating for IPM in a Dynamic Agricultural World. Entomological Society of America Annual Meeting. St. Louis, MO.

Kuhar, T. February 19, 2019. Update from the Mid-Atlantic U.S. BMSB SCRI Stakeholder Advisory Panel Meeting, Columbus, OH.

Lancaster, J, A Khrimian, S Young, B Lehner, AK Wallingford, SK Ghosh, ME Sparks, C Tittiger, D Weber, DE Gundersen-Rindal, T Kuhar, and D Tholl. March 2019. Aggregation pheromone biosynthesis: New genetic tools for pest management? Invited symposium talk. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Lee, J, H McIntosh, G Galindo, V Skillman. January 2020. Sweetly benefiting the Samurai wasp. Pacific Northwest Insect Management Conference, Portland, OR.

Lee, J, H McIntosh, G Galindo. January 2019. Helping out the Samurai wasp. Pacific Northwest Insect Management Conference, Portland, OR.

Leskey, T, D Kirkpatrick, D Ludwick, A Nielsen, C Bergh, G Krawczyk, T Kuhar, A Acebes-Doria, W Morrison, and K Rice. March 9-12, 2019. Integrating IPM tactics for the

invasive brown marmorated stink bug into orchard management systems. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Leskey, TC, D Kirkpatrick, D Ludwick, AL Nielsen, C Bergh, G Krawczyk, T Kuhar, A Acebes-Doria, W Morrison, K Rice. March 2019. Integrating IPM tactics for the invasive brown marmorated stink bug into orchard management systems. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Leskey, TC. 2019. Integrating IPM Tactics for the invasive brown marmorated stink bug. Clemson University. Departmental Seminar.

Leskey, TC. 2019. Monitoring and management tools for the invasive brown marmorated stink bug. Invited seminar to a delegation from the Republic of Georgia. Fresno, CA.

Lowenstein, DM, and NG Wiman. November 17-20, 2019. *Trissolcus japonicus* winter survival. Entomological Society of America Annual Meeting. St. Louis, MO.

Lowenstein, DM, HE Andrews, NG Wiman. April 1, 2019. Wa wa wa wasps staying alive: The *Trissolcus japonicus* story. Entomological Society of America Pacific Branch Annual Meeting, San Diego, CA.

Lowenstein, DM, HE Andrews, R Hilton, E Rudolph, and NG Wiman. January 10, 2019. *Trissolcus japonicus* redistribution efforts in orchard crops and small fruits. 93rd Orchard Pest and Disease Management Conference. Portland, OR.

Malek, R, J Kaser, K Tatman, S Guggilapu, G Anfora, A Khrimian, D Weber, and K Hoelmer. March 2019. *Trissolcus japonicus* foraging behavior: Implications for host preference and classical biological control. Invited symposium talk. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Marshall, AT, J Hepler, and EH Beers. November 17-20, 2019. Convergent management strategies: The intersection of netting and semiochemicals for insect control. Entomological Society of America Annual Meeting. St. Louis, MO.

Marshall, AT, and EH Beers. January 9-11, 2019. One flew over the shade net: Developing stink bug exclusion tactics. 93rd Annual Orchard Pest & Disease Management Conference, Portland, OR.

McIntosh, H, D Lowenstein, NG Wiman, J Wong, and J Lee. March 2019. Parasitism of frozen *Halyomorpha halys* eggs by *Trisoolcus japonicus*: applications for rearing and experimentation. Entomological Society of America North Central Branch Annual Meeting. Cincinnati, OH.

Milnes, J, and EH Beers. March 31-April 3, 2019. Ecology of the Asian egg parasitoid, *Trissolcus japonicus* (Ashmead), in Washington State. Entomological Society of America Pacific Branch Annual Meeting, San Diego, CA.

Nielsen, AL and K Rice. March 2019. Foraging ecology *T. japonicus* across landscapes. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Nielsen, AL, RE Valentin, D Fonseca, J Lockwood, and J Ware. November 17-20, 2019. Can haplotype data guide management programs for tree fruit pests? Entomological Society of America Annual Meeting. St. Louis, MO.

Nielsen, AL, A DiPaola, C Akotsen-Mensah, N Avila, and K Rice. December 5-6, 2019. Foraging ecology and predictions of *Trissolcus japonicus* in fruit systems. Annual Cumberland-Shenandoah Fruit Workers Conference, Winchester, VA

Nielsen, AL. 2019. Integrating Behavioral Ecology into Pest Management. Institute for Biological Control, JKI, Darmstad, Germany

Nixon, L, W Morrison, K Rice, TC Leskey, S Goldson, E Brockerhoff, and M Rostas. March 2019. BMSB group behavioral responses to conspecific chemical stimuli: Is their stink communicative? Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Ohmen, T, G Kennedy, and JF Walgenbach. Nov 18, 2019. Post emergence reproductive phenology and partial life table analysis of the brown marmorated stink bug. Meeting of the Entomological Society of America. St Louis, MO.

Pagani, M, K Britt, and T Kuhar. March 9-12, 2019. *Halyomorpha halys* feeding impact on industrial hemp yield and quality. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Pagani, M, K Britt, and T Kuhar. April 2019. *Halyomorpha halys* feeding impact on industrial hemp yield and quality. Dennis Dean Undergraduate Research and Creative Scholarship Conference. Blacksburg, VA.

Pagani, MK, KE Britt, and TP Kuhar. May 24-25, 2019. Brown marmorated stink bug (*Halyomorpha halys*) association with industrial hemp. Virginia Academy of Science 97th Annual Meeting, Norfolk, VA.

Pote, J, C Guimond, and L Gut. November 17-20, 2019. Exploring the influence of variety on experienced BMSB damage in Michigan apple systems. Entomological Society of America Annual Meeting. St. Louis, MO.

Potter, M, and PM Shrewsbury. March 2019. Redistribution of *Trissolcus japonicus* in Maryland and associated native parasitoid activity. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Potter, ME, RA Waterworth, and PM Shrewsbury. November 17-20, 2019. Redistribution of *Trissolcus japonicus* and native parasitoid activity associated with the brown marmorated stink bug in Maryland. Department of Entomology, University of Maryland, College Park, MD. Entomological Society of America Annual Meeting. St. Louis, MO.

Preston, C. March 2019. *Nosema maddoxi* effects on *Halyomorpha halys*. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Preston, C. January 2019. Prevalence of *Nosema maddoxi* in brown marmorated stink bug (*Halyomorpha halys* (Stål)) populations in Eastern and Western states in the US. Entomology Dept. Symposium, Cornell Univ, Ithaca, NY.

Quinn, N, E Talamas, TC Leskey, and C Bergh. November 17-20, 2019. Host plant and trap color effects on captures of *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae). Entomological Society of America Annual Meeting. St. Louis, MO.

Quinn, NF, EJ Talamas, TC Leskey, and JC Bergh. March 9-12, 2019. Aspects of the foraging ecology of *Trissolcus japonicus* in Virginia. Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Quinn, NF, EJ Talamas, TC Leskey, and JC Bergh. December 5-6, 2019. Habitat, temporal, and host plant effects on *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae) detections in Virginia. Cumberland-Shenandoah Fruit Workers Conference, Winchester, VA.

Quinn, NF, EJ Talamas, TC Leskey, and JC Bergh. November 17-20, 2019. Host plant and trap color effects on captures of *Trissolcus japonicus* (Hymenoptera: Scelionidae). Entomological Society of America Annual Meeting. St. Louis, MO.

Rijal, J, A Medina, J Fisher, and F Zalom. February 5-6, 2019. Brown marmorated stink bug in CA crops: Pest ID, damage assessment, and management. Annual Conference of American Society of Agronomy-California Chapter, Fresno, CA.

Rijal, J, A Medina, J Fisher, and F Zalom. January 9-11, 2019. Characterization of brown marmorated stink bug (BMSB) feeding damage in California almonds. 93rd Orchard Pest and Disease Management Conference, Portland, CA.

Rijal, J, T Herrera, J Fisher, and F Zalom. December 10-12, 2019. Brown marmorated stink bug (BMSB). Almond Board Conference, Sacramento, CA.

Rijal, J, T Herrera, J Fisher, and F Zalom. March 31-April 3, 2019. What do we know about BMSB invasion in agricultural areas in San Joaquin Valley, California? Pacific Branch-Entomological Society of America, San Diego, CA

Rijal, J., T. Herrera, J. Fisher, and F. Zalom. November 17-20, 2019. Influence of the external factors on the distribution of BMSB damage in California almond orchards. Entomological Society of America Annual Meeting. St. Louis, MO.

Schoof, SC, and J Walgenbach. 2019. Trapping for Brown Marmorated Stink Bug in Appalachian Forests. 95th Cumberland-Shenandoah Fruit Workers Conference. Winchester, VA. Dec 6, 2019. (45)

Schumm, Z, D Alston, and L Spears. November 17-20, 2019. Brown marmorated stink bug feeding impact on tart cherry. Entomological Society of America Annual Meeting. St. Louis, MO.

Shrewsbury, PM, et al. February 2019. Native natural enemies: Regional and habitat variation. Brown marmorated stink bug SCRI Stakeholder Advisory Panel Meeting. Columbus, OH.

Stahl, J, D Scaccini, and K Daane. November 17-20, 2019. Survival of the brown marmorated stink bug on different crops - Is California a special case? Entomological Society of America Annual Meeting. St. Louis, MO.

Szucs, M, L Gut, J Wilson, and J Pote. July 24, 2019. Biological control of brown marmorated stink bug in Michigan. MSU AgNews.

Tholl, D, J Lancaster, B Lehner, A Khrimian, SK Ghosh, A Wallingford, DC Weber, ME Sparks, D Gundersen-Rindal, and T Kuhar. November 17-20, 2019. Understanding pentatomid

pheromone biochemistry for developing new pest management strategies. Invited symposium talk. Entomological Society of America Annual Meeting. St. Louis, MO.

Walgenbach, JF, SC Schoof, and A Heintz-Botz. Dec 5, 2019. Residual activity of bifenthrin and dinotefuran for control of BMSB on apples. 95th Cumberland-Shenandoah Fruit Workers Conference. Winchester, VA.

Walgenbach, JF, and SC Schoof. Aug 22, 2019. Impact of adjacent habitats on brown marmorated stink bug pheromone trap capture and damage in apple orchards. Conference on Management of Brown Marmorated Stink Bug, Tiblisi, Republic of Georgia.

Walgenbach, JF and SC Schoof. Jan 20-25, 2019. Impact of adjacent habitats on brown marmorated stink bug pheromone trap capture and damage in apple orchards. IOBC Conference on Merging Pheromones and Other Semiochemicals with Integrated Fruit Production. Lisbon, Portugal.

Waterworth, R, and P Shrewsbury. March 2019. Help wanted: Citizen scientists support efforts to determine the distribution and diversity of native and exotic stink bug egg parasitoids in Maryland. In the Biological control of invasive organisms impacting the Eastern Region Symposium at the Entomological Society America Eastern Branch Meeting, Blacksburg, VA.

Waterworth, RA, and PM Shrewsbury. November 17-20, 2019. Engaging citizen scientists in the search for biological controls of the invasive brown marmorated stink bug in Maryland: Everyone learns! Department of Entomology, University of Maryland, College Park, MD in the Symposium Advocacy in Action: Tackling Invasive Species through Collaboration, Policy, and Public Engagement. Entomological Society of America Annual Meeting. St. Louis, MO.

Non-refereed publications (proceedings, abstracts, popular magazines, etc.)

Krawczyk, G, H Morrin, and C Hirt. Jan 20-25, 2019. Alternative methods to manage brown marmorated stink bug, *Halyomorpha halys*. Book of abstracts: Joint Meeting of IOBC/WPRS Working Groups "Pheromones and other semiochemicals in integrated production" and "Integrated Protection of Fruit Crops" PheroFip 19. Lisbon, Portugal. Page 98. https://www.isa.ulisboa.pt/cong/iobc2019/files/PheroFip%2019_Book%20of%20abstracts%20_final.pdf

Peterson, H, J Ali, and G Krawczyk. Jan 20-25, 2019. Biocontrol of invasive *Halyomorpha halys*. Book of abstracts: Joint Meeting of IOBC/WPRS Working Groups "Pheromones and other semiochemicals in integrated production" and "Integrated Protection of Fruit Crops" PheroFip 19. Lisbon, Portugal. Page 103. https://www.isa.ulisboa.pt/cong/iobc2019/files/PheroFip%2019_Book%20of%20abstracts%20_final.pdf

Quinn, NF, EJ Talamas, TC Leskey, and JC Bergh. 2019. Habitat and tree species effects on detections of *Trissolcus japonicus* (Hymenoptera: Scelionidae) in Virginia, USA. IOBC-WPRS Bulletin 146: 121-124

Rijal, J, A Medina, J Fisher, and F Zalom. Feb 5-6, 2019. Brown Marmorated Stink Bug in CA Crops: Pest ID, Damage Assessment, and Management. Proceeding of the Annual Conference of American Society of Agronomy-California Chapter, Fresno, CA. pp 81-86.

Stahl, JM, D Scaccini, and KM Daane. 2020. Comparing the feeding damage of the invasive brown marmorated stink bug to native large bugs. California Pistachio Board, Executive Summary 2019 Research (in press)

Weber, DC, AE Hajek, KA Hoelmer, U Schaffner, PG Mason, S Stouthamer, EJ Talamas, M Buffington, and T Haye. Unintentional biological control. Chapter 4 in Biological Control: A Global Endeavour (Peter Mason, editor) CSIRO. (accepted for publication)

Extension publications

Holthouse, MC, LR Spears, ZR Schumm, and DG Alston. 2019. The samurai wasp brings new hope in the fight against brown marmorated stink bug in Utah. Fact Sheet Paper 2045. Utah State University Extension and Utah Plant Pest Diagnostic Laboratory, Logan, UT. https://digitalcommons.usu.edu/extension_curall/2045

Holthouse, MC, Z Schumm, L Spears, and D Alston. 2019. Seasonal development and occurrence of brown marmorated stink bug in Utah. Utah Pests News, Utah Plant Pest Diagnostic Laboratory and Utah State University Extension. Vol 13 (Spring): 5-6. http://utahpests.usu.edu/files/up-newsletter/2019/UtahPests-Newsletter-spring19.pdf

Holthouse, MC, ZR Schumm, DG Alston, and LR Spears. 2019. Common stink bugs of Utah. Fact Sheet ENT-209-19. Utah State University Extension and Utah Plant Pest Diagnostic Laboratory, Logan, UT (8 pp). https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3015&context=extension_curall/

Jentsch, P. 2020. http://blogs.cornell.edu/jentsch/a-national-march-madness-citizen-science-project-to-find-the-brown-marmorated-stink-bug-2017/

Jentsch, P. 2020. http://blogs.cornell.edu/jentsch/biological-control-of-the-brown-marmorated-stink-bug-in-new-york-state/

Jentsch, P. 2020. https://blogs.cornell.edu/jentsch/2019/03/13/join-in-hvrl-efforts-for-redistribution-of-samurai-wasp-in-nys-in-2019/

Jentsch, P. October 21, 2019. Factors contributing to the 2019 Hudson Valley insect pest management anomalies, (https://blogs.cornell.edu/jentsch/2019/10/21/factors-contributing-to-the-2019-hudson-valley-insect-pest-management-anomalies/)

Jentsch, P. September 19, 2019. BMSB: High adult trap catches continue this week. (https://blogs.cornell.edu/jentsch/2019/09/19/bmsb-high-adult-trap-catches-continue-this-week-september-19th-2019/)

Jentsch, P. August 30, 2019. BMSB: 2nd Gen. Thresholds in 3 NYS Counties. (https://blogs.cornell.edu/jentsch/2019/08/30/bmsb-2nd-gen-thresholds-in-3-nys-counties-august-30th-2019/)

Jentsch, P. July 29, 2019. Section 18 EPA Approval for Bifenthrin in 2019. BMSB populations on the rise in Hudson Valley Orchards. (https://blogs.cornell.edu/jentsch/2019/07/29/section-18-epa-approval-for-bifenthrin-in-2019-bmsb-populations-on-the-rise-in-hudson-valley-orchards-july-29th-2019/)

Jentsch, P. March 13, 2019. Citizen science efforts for redistribution of samurai wasp in NYS. (https://blogs.cornell.edu/jentsch/2019/03/13/join-in-hvrl-efforts-for-redistribution-of-samurai-wasp-in-nys-in-2019/)

Preston, CE, and AE Hajek. Newly described pathogen may help control brown marmorated stink bug. Northeastern IPM Center, IPM Insights. https://www.northeastipm.org/about-us/publications/ipm-insights/newly-described-pathogen-may-help-control-brown-marmorated-stink-bug/

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Schumm, Z, MC Holthouse, L Spears, and D Alston. 2019. Biological control of brown marmorated stink bug. Utah Pests News, Utah Plant Pest Diagnostic Laboratory and Utah State University Extension. Vol 13 (Spring): 6-7. http://utahpests.usu.edu/files/up-newsletter/2019/UtahPests-Newsletter-spring19.pdf

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Szucs, M, L Gut, J Wilson, and J Pote. 2019. Biological control of brown marmorated stink bug in Michigan. MSU AgNews, July 24, 2019.

Welty, C, J Jasinski, and E Long. 2019. Filling in the gaps for the invasive pest monitoring network, Part 2: brown marmorated stink bug. Ohio Fruit News, March 2019, pages 9-10. https://cpb-us-w2.wpmucdn.com/u.osu.edu/dist/b/28945/files/2017/04/March-edition_03182019_RK_VD-1z2n0ba.pdf

Welty, C. 2019. Please help us manage stink bugs by contributing to a survey. Ohio Fruit News, March 2019, page 2. https://cpb-us-w2.wpmucdn.com/u.osu.edu/dist/b/28945/files/2017/04/March-edition_03182019_RK_VD-1z2n0ba.pdf

Extension presentations

Maas, J, J Pote, and L Gut. December 2019. Poster: Toxicity of aged long-lasting insecticide nets on BMSB and non-target insects. Michigan State Horticultural Society. Grand Rapids, MI.

Daane, K. November 8, 2019. Field Tour of the Almond Short Course. Kearney Agricultural Research and Extension Center, Parlier, CA.

Athey, K, EH Beers, DW Crowder, and TD Northfield. 2019. BMSB update and codling moth sterile insect technique. Wilbur-Ellis Grower Meeting, Chelan, WA.

Beers, EH, and J Hepler. February 5, 2019. Secondary Pest Update: Apple leafcurling midge, Apple clearwing borer, and BMSB. Okanogan Horticultural Association Annual Meeting. Okanogan County Agri-Plex, Okanogan, WA.

Beers, EH, and K Athey. February 26, 2019. Integrated control of brown marmorated stink bug and codling moth update. Wilbur Ellis Tonasket Grower Meeting. Tonasket Senior Center, Tonasket, WA.

Beers, EH, DW Crowder, J Gutierrez-Illan, N Wiman, D Lowenstein, V Walton, and R Hilton. 2019. BMSB distribution and pest status in the PNW. Stakeholder Advisory Panel Meeting, Columbus, OH.

Beers, EH. January 24, 2019. Brown marmorated stink bug control in Washington. CP-16-101. Continuing report. Apple Crop Protection Research Review, Confluence Technology Center, Wenatchee, WA.

Beers, EH. January 24, 2019. Integrated control of brown marmorated stink bug. New Project Proposal. Apple Crop Protection Research Review, Confluence Technology Center, Wenatchee, WA.

Bessin, R. 2020. Vegetable production challenges. 2020 Lincoln County Produce Area meeting. (70 participants)

Daane, K. Small bugs and stink bugs on pistachios. Pistachio Day. Visalia, CA. (100s of growers)

Daane, K. January 2019. Comparing the feeding damage of the invasive brown marmorated stink bug to native large bugs. Pistachio Research Review. Visalia, CA.

Debak, E, PM Shrewsbury, and CRR Hooks. August 07, 2019. Climate change impact on parasitoids of the brown marmorated stink bug. Crops Twilight Tour, Barbeque and Ice Cream Social, Upper Marlboro, MD. Attendance 85

Dimock, M, and CRR Hooks. August 07, 2019. Intercropping impacts on stink bug and harlequin bug egg mortality. Crops Twilight Tour, Barbeque and Ice Cream Social, Upper Marlboro, MD. Attendance 85.

Fann, L, and R Bessin. Jan 7, 2020. Polyculture trap cropping for the brown marmorated stink bug (*Halyomorpha halys*). KY Fruit and Vegetable Conference. (60 participants)

Fisher, JJ, R Jhalendra, F Zalom. Feb. 19, 2019. Understanding the role of temperature and humidity on BMSB populations. BMSB SCRI Stakeholder Advisory Panel Meeting. Columbus, OH.

Fisher, JJ, Zalom F. Dec. 3, 2019. Analyzing the potential threat of brown marmorated stink bug to walnuts. Walnut PRAC meeting. Stockton, CA

Fisher, JJ, Zalom F. May 21, 2019, Brown marmorated stink bug on walnuts. Almond and Walnut Farm Advisor Tour. Davis, CA.

Gut, L. December 2019. Exploring new options for managing codling moth, brown marmorated stink bug and San Jose scale. Michigan State Horticultural Society. Grand Rapids, MI.

Hepler, J, and EH Beers. January 9-11, 2019. Fickle flaps of fate: Building a better stink bug trap. 93rd Annual Orchard Pest & Disease Management Conference. Portland Hilton. Portland, OR.

Hilton, R. December 3, 2019. BMSB Presentation to Jackson Co. OR Board of Commissioners. Medford, OR.

Hilton, R. Aug. 1, 2019. BMSB Presentation to pear growers. Pear Field Day. Oregon State University Mid-Columbia Research and Extension Center.

Hilton, R. May 8, 2019. BMSB Presentation to Southern Oregon University Entomology class.

Hilton, R. July 18, 2019. Presentation to pear growers and samurai release. Pear Field Day, Oregon State University Southern Oregon Research and Extension Center, Central Point, OR.

Hilton, R. February 2, 2019. BMSB update. OVS grower meeting. Medford, OR.

Holthouse, M. C., D. Alston, and L. Spears. January 24-25, 2019. Urban habitats as sources of brown marmorated stink bugs for agricultural lands. Utah State Horticultural Association. Spanish Fork, UT.

Holthouse, M.C. June 9, 2019. Wheeler Historic Farm Sunday market master gardener extension booth. Wheeler Farm, Murray, UT. (50 attendees)

Hooks, CRR. August 12, 2019. Using insectary plants to mitigate stink bug problems in vegetable plantings. Southern Maryland Vegetable IPM and Production Walking Tour. Leonardtown, MD. Attendance 100

Hooks, CRR. August 7, 2019. Marigold use as an insectary plant to enhance stink bug egg mortality. Crops Twilight Tour, Barbeque and Ice Cream Social. Upper Marlboro, MD. (attendance 85)

Jentsch, P. January 8, 2020. Research studies on complete insect pest exclusion systems in tree fruit. 39th Annual Long Island Agricultural Forum. Suffolk County Community College, Eastern Campus. Riverhead, New York.

Jentsch, P. October 23, 2019. Research studies on complete insect pest exclusion systems in tree fruit. NY, New England, Canada Tree Fruit Pest Management Workshop.

Jentsch, P. March 6, 2019. New materials & monitoring for the pest complex. Maine State Pomological Society. Pre-season Tree Fruit Meeting, Lewiston Auburn College. Lewiston, Maine.

Jentsch, P. February 23, 2019. Biological control of brown marmorated stink bug, *Halyomorpha halys* Stål (Hemiptera: Pentatomidae) in NYS. ENYCHP Winter Fruit Schools, Desmond Hotel & Conf Ctr, Albany, NY

Jentsch, P. February 4-5, 2019. Progress on developing management strategies for brown marmorated stink bug and spotted wing drosophila. Lockport & Newark, NY.

Kuhar, T. Aug. 15, 2019. Brown marmorated stink bug attract and kill research. Roanoke Community Gardens Twilight Meeting. Roanoke, VA.

Kuhar, T. July 31, 2019. Brown marmorated stink bug attract and kill research. Twilight Insect Talks – Blackburg Community Garden. Blacksburg, VA.

Kuhar, T. Aug. 22, 2019. Highlighting insect pest management research. Virginia Tech Homefield Farm and Kentland Farm Field Day. Whitethorne, VA.

Kuhar, T. February 21, 2019. Insect control update. Richmond/Hanover Area Vegetable Growers Meeting. Richmond, VA.

Kuhar, T. October 23, 2019. Insect IPM. Urban-Ag Vegetable In-Service Training – VCE. Petersburg, VA.

Kuhar, T. December 5, 2019. Insect management. South central Virginia Vegetable Growers Meeting. Phenix, VA.

Kuhar, T. January 28-31, 2019. Insect pest update for peppers. Mid-Atlantic fruit & vegetable convention. Hershey, PA.

Kuhar, T. March 1, 2019. Integrated pest management approaches for vegetables. Central Virginia Vegetable Producer's Meeting. Stanardsville, VA

Kuhar, T. February 26, 2019. Integrated pest management approaches for vegetables. Northern Piedmont 2019 Winter Vegetable School. Warrenton, VA.

Kuhar, T. Jan 23-24, 2019. Update on snap bean and tomato pest management. Eastern Shore Ag Conference. Melfa, VA.

Kuhar, T. Dec 13, 2019. Update on vegetable pest management. Northern Neck Vegetable Growers Annual Meeting. Warsaw, VA.

Leskey, TC. 2019. Damage symptoms, monitoring techniques and management strategies for the invasive brown marmorated stink bug in tree fruit. Invasive species workshop. Utah State University. Spanish Forks, UT.

Lowenstein, DM. April 4, 2019. BMSB and status of samurai wasp. Pear IPM meeting. Oregon State University Southern Oregon Research and Extension Center. Central Point, OR.

Marshall, AT, and EH Beers. January 9-11, 2019. One flew over the shade net: Developing stink bug exclusion tactics. 93rd Annual Orchard Pest & Disease Management Conference. Portland Hilton. Portland, OR.

Milnes, JM. Jan. 15, 2019. Samurai wasp potential to keep BMSB in check. North Central Washington Stone Fruit Day. Wenatchee Convention Center. Wenatchee, WA.

Milnes, JM. Jan. 15, 2020. Pests of concern: Spotted lanternfly and BMSB. G. S. Long, INC 2020 Annual Growers Meeting, Yakima Convention Center. Yakima, WA.

Milnes, JM. Nov. 25, 2019. I like small parasitoids and I cannot lie. Scarabs: The Bug Society, Woodland Park Zoo. Seattle, WA.

Milnes, JM. Oct. 30, 2019. The good, the bad, and the bug ugly: An introduction to the world of biological control of BMSB. Yakima WSU Extension Center. Union Gap, WA.

Pote, J, C Guimond, J Maas, and L Gut. December 2019. Poster: Exploring the influence of variety on experienced BMSB damage in Michigan apple systems. Michigan State Horticultural Society. Grand Rapids, MI.

Quinn, NF, TC Leskey, and JC Bergh. January 29-31, 2019. Samurai wasp: Update on an important new natural enemy of brown marmorated stink bug. Mid-Atlantic Fruit and Vegetable Convention. Hershey, PA

Rijal, J. September 5, 2019. Monitoring and control of brown marmorated stink bug (BMSB). CAPCA Educational Seminar. Sacramento, CA

Rijal, J. November 12, 2019. Plant bug and stink bug of concern in almonds. Tree and Vine Conference and Expo. Pacific Nut Producer Magazine. Turlock, CA

Rijal, JP. July 30, 2019. Biology, monitoring and management of brown marmorated stink bug (BMSB) in almond and peach orchards. Wilbur-Ellis PCAs meeting. Hughson, CA.

Rijal, JP. July 12, 2019. Brown marmorated stink bug (BMSB) activity in CA crops – peach, almond. San Joaquin Agricultural Commissioner's CE Seminar. Ripon, CA.

Rijal, JP. Nov. 3-5, 2019. Brown marmorated stink bug (BMSB): Pest ID, crop damage, monitoring, and management. Annual Conference of California Pest Control Advisors. Reno, NV

Rijal, JP. August 12, 2019. Brown marmorated stink bug field damage and ID. Extension Field Meeting. Turlock, CA

Rijal, JP. January 30, 2019. Brown marmorated stink bug infestation in local peach orchards and tools for monitoring and management. North San Joaquin Valley Cling Peach Day, Modesto, CA

Rijal, JP. February 5, 2019. Invasive pests (BMSB, spotted lanternfly, spotted wing drosophila) to watch for in the vines in 2019. Annual Grape Day, Lodi Wine Grape Commission. Lodi, CA

Schumm, Z. July 9, 2019. Brown marmorated stink bug feeding on tart cherry. Grower Field Day. USU Extension and Utah State Horticultural Association, Santaquin, UT. (50 attendees)

Schumm, Z. R., Holthouse, M. C., Berdahl, E., Morgan, K., and Hall, S. July 3, 11, and 18, 2019. Invasive insect surveying and collection methods. Wasatch Gardens Education Programs. Salt Lake City, UT. (41 attendees)

Schumm, Z.R. June 15, 2019. Pioneer Park Farmer's Market Extension Booth. Salt Lake City, UT. (223 attendees)

Shrewsbury, PM. February 2019. IPM of key insect pests in nurseries and landscapes. 2019 Chesapeake Green – An annual horticulture symposium, MD Nursery, Landscape, and Greenhouse Association. Linthicum Heights, MD. (250 attendees)

Shrewsbury, PM. January 2019. Bugs, aphids, adelgids, thrips. Advanced landscape IPM short course. Department of Entomology, University of Maryland. College Park, MD. (59 attendees)

Shrewsbury, PM. January 2019. Demonstration of Hemiptera pests – laboratory. Advanced landscape IPM short course. Department of Entomology, University of Maryland. (25 attendees)

Shrewsbury, PM. January 2019. Insect pests of ornamentals (1 day – lectures and lab). Continuing professional education short course. Rutgers University. New Brunswick, NJ. (30 attendees)

Spears L. June 5, 2019. Biological control of brown marmorated stink bug. Utah Association of County Agricultural Agents. West Jordan, UT. (5 agents)

Spears L. January 24, 2019. Invasive insect update. Utah State Horticultural Association. Spanish Fork, UT. (80 producers)

Spears L. February 21, 2019. Invasive insect update. Utah Urban and Small Farms Conference, West Valley, UT. (40 producers)

Spears L. May 7, 2019. Invasive pest surveys, research, and outreach. Seasonal Inspectors, Utah Department of Agriculture and Food. Salt Lake City, UT. (20 seasonal inspectors)

Spears L. May 1, 2019. The search for the samurai wasp. Master Gardener Guest Lecture (2 locations) (30 Master Gardeners)

Spears, L. July 9, 2019. Trapping for brown marmorated stink bug. Grower Field Day. USU Extension and Utah State Horticultural Association. Santaquin, UT. (50 attendees)

Szücs, M, J Wilson, J Pote, and L Gut. December 2019. Poster: Augmentative releases of the Samurai wasp, a natural enemy of brown marmorated stink bugs. Michigan State Horticultural Society. Grand Rapids, MI.

Talamas, E, and K Hoelmer. Jan. 31-Feb. 2, 2019 Workshop on identification of parasitoids of BMSB. Gainesville FL.

Talamas, E, and K Hoelmer. April 10-11, 2019. European workshop on identification of parasitoids of BMSB. Montferrier-sur-Lez, France.

Thompson, B, and JF Walgenbach. 2019. Managing scales and stink bugs. NC Peach Society Annual Meeting. Carthage, NC. Jan 22, 2019.

USDA-ARS. August 2019. Vegetable pests: overview of chemical ecology and biological control activities at Beltsville. Presentation for visiting Korean RDA scientists.

UDSA-ARS BIIRU Biological Control booth. 2019. Presented information on BMSB and *Trissolcus japonicus*. AgDay. University of Delaware.

Alston, D. February 12, 2019. Brown marmorated stink bug: a new invasive pest to Utah. Utah Pest Control and Lawncare Association. Layton, UT.

Walgenbach, JF, EC Ogburn, SC Schoof. 2019. What’s new with the stink bug? Southeastern Apple Growers Meeting. Asheville, NC. Jan 9, 2019

Walgenbach, JF. 2019. Tree fruit insect update. Wilkes/Alexander Tree Fruit Meeting. Wilksboro, NC. March 5, 2019.

Walgenbach, JF. 2019. Augmentation and conservation biological control in vegetables. Southeast Regional Fruit and Vegetable Conference, Savannah, GA. Jan 11, 2019.

Walgenbach, JF. 2019. Tree fruit insects: identification, biology and management. Avery County Tree Fruit Meeting. March 3, 2019.

Walgenbach, JF. 2019. Good bugs, bad bugs and new bugs. Transylvania County Master Gardeners. March 20, 2019.

Walgenbach, JF. 2019. BMSB trapping studies. Henderson County Apple Twilight Tour, Edneyville, NC May 7, 2019.

Welty, C. January 16, 2019. Brown marmorated stink bug: Biocontrol progress. Ohio Produce Network, Annual Conference of the Ohio Produce Growers & Marketers Association. Dublin, OH.

Welty, C. January 8, 2019. Brown marmorated stink bug: Biocontrol progress. Kentucky Fruit and Vegetable Conference. Lexington, KY.

Welty, C. March 26, 2019. Brown marmorated stink bug biocontrol progress. Webinar program on invasive pest management, produced by the Ohio IPM Program. Columbus, OH.

Wilson, JK. December 2019. Brown Marmorated Stink Bug: 2019 Report. Poster Session, Great Lakes EXPO. Grand Rapids, MI.

Wiman, N. January 8, 2019. Management of BMSB in Pacific Northwest orchard crops. Chamberlin Agriculture annual grower meeting. Hood River, OR.

Wiman, N. January 8, 2019. Brown Marmorated Stink Bug. Chemical Applicators Short Course. Wilsonville, OR.

Wiman, N. November 15, 2019. Hazelnut pest management: filbertworm, brown marmorated stink bug, and Pacific flatheaded borer. Corteva Agriscience Hazelnut Day. Salem, OR.

Wiman, NG. December 11, 2019. Status and management tools for BMSB in Pacific Northwest orchard crops. Washington State Tree Fruit Association Annual Meeting. Wenatchee, WA.

News, Print, Broadcast

WLOS TV, Asheville, NC. Experts warn WNC residents to expect lots of stink bugs. Interview with J. Walgenbach. https://wlos.com/news/local/experts-warn-wnc-residents-to-expect-lots-of-stink-bugs

Star Tribune: New crop of pests invade—Warmer, wetter climate attracts invasive insects to Minnesota's orchards and fields. Jennifer Bjorhus, Star Tribune OCTOBER 26, 2019. http://www.startribune.com/a-new-crop-of-invasive-bugs-threatens-minnesota-s-orchards-and-fields/563385312/

Nielsen, AL interview on Fox News "BMSB Overwintering"

Virginia Tech. Research featured in article entitled, "Stink Bugs Stay Out: Study Measures Gaps Needed for Invasion", popular periodical Entomology Today, published online by the Entomological Society of America, February 13, 2019. https://entomologytoday.org/2019/02/13/stink-bugs-stay-out-study-shows-size-gaps-needed-brown-marmorated-stink-bug-invasion/

Leveraged funding/complimentary resources

Alston, D, and L Spears. 2019-2022. Searching for the samurai wasp and promoting native parasitoid wasps for biological control of the invasive brown marmorated stink bug. Submitted to Utah Department of Agriculture and Food. $45,358.

Beers, E. H. 2019. Integrated control of brown marmorated stink bug. CP-19-105. Washington Tree Fruit Research Commission (WTFRC). 2019-2021. Total: $299,694.

Beers, E. H. 2017. Biological Control of Brown Marmorated Stink Bug. Project #18AN011. Washington State Commission on Pesticide Registration (WSCPR). 2018-2019. $21,851.

Bergh, JC. 2019. Tracking the establishment of *Trissolcus japonicus* in Virginia. Virginia Department of Agriculture and Consumer Services Specialty Crop Block Grant, $15,626

Hepler, JR. 2019. Extreme Polyphagy: Querying the gut contents of brown marmorated stink bug. USDA-AFRI pre-doctoral grant. 2019-2020. $119,667.

Pagani, MJ. Received a Virginia Tech Fralin Undergraduate Research Fellowship for project entitled: *Halyomorpha halys* feeding impact on industrial hemp yield and quality. $1,000

Pagani, MJ. The presence and influence of the brown marmorated stink bug on industrial hemp. Virginia Academy of Science Undergraduate Research Grant 2019. $750

Spears, LR, R Davis, M Murray, J Gunnell, K Wagner, and RA Ramirez. 2019-2020. Invasive pest outreach. USDA-APHIS-PPQ (Plant Protection Act 7721). $49,995.

Spears, LR and C Nischwitz. 2019-2020. Specialty crop commodity survey. USDA-APHIS-PPQ (Plant Protection Act 7721). $17,000.

Spears, LR and DG Alston. 2019-2020. Survey for native and introduced natural enemies of brown marmorated stink bug, *Halyomorpha halys*. USDA-APHIS-PPQ (CAPS). $6,545.

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

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

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

Walgenbach, JF, EC Ogburn and SC Schoof. 2019. Attract and Kill for managing brown marmorated stink bug. NCDA&CS Specialty Crop Block Grant Program. $127,595.

Welty, C and J Jasinski. 2019 Streamlined monitoring for spotted wing Drosophila and brown marmorated stink bug. $3,070. Ohio Vegetable & Small Fruit Research & Development Program. March-December 2019.

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Research

OXFORD

Ecology and Behavior

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

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Abstract

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

Short Communication

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Short Communication

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Baseline Toxicity of the Insecticides Bifenthrin and Thiamethoxam on *Halyomorpha halys* (Hemiptera: Pentatomidae) Collected From the Eastern United States

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Subject Editor: Troy Anderson

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Abstract

Brown marmorated stink bug, *Halyomorpha halys* (Stål), is an invasive species in the United States that attacks a wide variety of agricultural commodities including fruits, vegetables, agronomic crops, and ornamental plants. Populations of *H. halys* adults were collected from four and six states in 2017 and 2018, respectively, and tested using topical applications to establish baseline levels of susceptibility to two commonly used insecticides, bifenthrin and thiamethoxam. A Probit-estimated (95% fiducial limits) LD_{50} and LD_{99} of 2.64 g AI/L (1.2–3.84 g AI/L) and 84.96 g AI/L (35.76–716.16 g AI/L) for bifenthrin, and a LD_{50} and LD_{99} of 0.05 g AI/liter (1.14E-5–0.27 g AI/L) and 150.11 g AI/L (27.35–761,867 g AI/L) for thiamethoxam, respectively. These baseline levels can be used for future insecticide resistance monitoring in *H. halys*.

Key words: Chemical control, insecticide resistance, stink bug, pyrethroids, neonicotinoids

Brown marmorated stink bug, *Halyomorpha halys* (Stål), is an invasive species from Asia that was first detected in the United States in the 1990s in Pennsylvania (Hoebeke and Carter 2003), and has since become established in much of the continental United States as well as Europe, where it has become a significant pest of tree fruit, vegetables, tree nuts, and other crops (Rice et al. 2014, Haye et al. 2015, Leskey and Nielsen 2018). Despite encouraging progress with regards to biological control and integrated pest management (Leskey and Nielsen 2018), insecticides are the most commonly used tools to control this pest on high value horticultural crops, particularly pyrethroids and neonicotinoids (Kuhar and Kamminga 2017). Their use has increased substantially in the eastern United States during the past 8–10 yr that this pest has increased in importance. For instance, Leskey et al. (2012b) reported that some tree fruit growers in the mid-Atlantic United States increased the number of insecticide applications nearly fourfold from 2010 to 2011 to combat *H. halys*. Although pyrethroids and neonicotinoids, such as bifenthrin and thiamethoxam, respectively, have been quite efficacious at controlling *H. halys* (Kuhar and Kamminga 2017), good stewardship dictates that resistance monitoring programs be implemented to detect changes in the susceptibility of populations to these groups of insecticides. Detection of changes in susceptibility of field populations can denote the need for alternative control measures. Bioassays for field-resistance monitoring requires the establishment of reliable susceptible toxicity baselines and/or discernable doses, as a standard of control. This information is currently lacking for *H. halys*. The goal of this project was to obtain baseline data on the susceptibility of *H. halys* adults from multiple populations in the mid-Atlantic United States to bifenthrin and thiamethoxam, two commonly used insecticides to control them. While so doing, we also tested the hypothesis that no sex-related differences in insecticide susceptibility exist.

Materials and Methods

Bioassays

Collections of *H. halys* adults were made in September 2017 from four states (NC, OH, PA, VA) and six states (NJ, NY, NC, OH, PA, VA) in 2018 for bioassays. Adults were separated by sex and exposed individually to bifenthrin (Brigade 2EC, 25.1% bifenthrin, FMC Corporation, Philadelphia, PA) and thiamethoxam

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Taxonomic Paper

New record of *Trissolcus solocis* (Hymenoptera: Scelionidae) parasitising *Halyomorpha halys* (Hemiptera: Pentatomidae) in the United States of America

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Abstract

Background

A parasitoid wasp, *Trissolcus solocis* Johnson, was recorded parasitising eggs of the invasive stink bug *Halyomorpha halys* (Stål), in the United States. This is the first record of this species parasitising eggs of *H. halys*.

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Taxonomic Paper

First record of *Trissolcus basalis* (Hymenoptera: Scelionidae) parasitizing *Halyomorpha halys* (Hemiptera: Pentatomidae) in the United States

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Abstract

Background

A parasitoid wasp, *Trissolcus basalis* (Wollaston), was recorded parasitizing eggs of the invasive stink bug *Halyomorpha halys* (Stål) in the United States. This is the first record of this species parasitizing fresh and frozen eggs of *H. halys* in the United States.

PROSPECTS FOR INTEGRATED PEST MANAGEMENT OF BROWN MARMORATED STINK BUG IN WASHINGTON TREE FRUITS

Elizabeth H. Beers, Adrian Marshall, Jim Hepler and Josh Milnes, Tree Fruit Research & Extension Center, 1100 N. Western Ave., Wenatchee, Washington, USA there is grave concern that the brown mamorated stink bug will disrupt decades of progress in IPM in tree fruits, and force producers to return to a regimen of broad-spectrum, non-selective insecticide use

Keywords: invasive species, biological control, landscape ecology

Elizabeth Beers Adrian Marshall Jim Hepler Josh Milnes

Brown marmorated stink bug (BMSB, *Halyomorpha halys*) is one of several new invasive pests that threaten tree fruit production in the western US. Based on the experience in the eastern US, there is grave concern that this pest will disrupt decades of progress in IPM, and force producers to return to a regimen of broad-spectrum, non-selective insecticide use.

The western US has had over 20 years of warning as BMSB has gradually spread across the US from the original find in Pennsylvania (Leskey *et al.*, 2012). However, microsatellite analysis (Valentin *et al.*, 2017, Xu *et al.*, 2014) indicates that western populations are the result of multiple independent introductions from Asia and the eastern US.

Since its initial detection, research efforts in the eastern US have been launched to meet the challenge of this new pest by establishing the fundamentals of BMSB biology, ecology and management. Previous Asian literature was also made available to English-speaking researchers by Lee *et al.* (2013), who translated and reviewed many formerly inaccessible studies. Despite this progress, re-establishing IPM in eastern orchards has proven difficult. Similar challenges are predicted for the west.

Invasive pests of tree fruits – past and present

Invasive pests are often considered the "new reality" for tree fruits, but in fact, they are also our old reality. Two more recent arrivals, BMSB and spotted wing drosophila (*Drosophila suzukii*), currently receive high levels of attention. However, a glance at the list of tree fruit pests not native to western North America includes almost all significant pests we deal with today (Table 1). In this sense, the invasion of BMSB is business as usual.

The longer an invasive pest has been in a new area, the greater the opportunity for study and finding pest management solutions. However, those solutions may still represent only a temporary truce in the ongoing and dynamic interaction of pest and crop. A notable example is codling moth (*Cydia pomonella*), the key pest of pome fruits in western North America (if not the world). This species has held key pest status for well over a century in Washington. The first 'solution' to the problem was the arsenical pesticides. These were followed by DDT and then by the organophosphates, but resistance occurred to a greater or lesser extent to all of these groups. In the early 1990s, both sterile insect release (Dyck *et al.*, 1993) and mating disruption for codling moth were implemented (Brunner *et al.*, 2002). Both of these novel and non-insecticidal methods of control have strengths and weaknesses, and future improvements are likely. In contrast, we still struggle with another invader, pear psylla (*Cacopsylla pyricola*), in a cycle of new insecticide introductions followed by resistance. Familiarity with a pest does not a guarantee a permanent solution.

The arrival of a new invasive pest initiates a somewhat predictable sequence of events (Figure 1). The east has already passed through all the early stages of the invasion sequence. Here in the west we are in the Expansion/Crop Damage

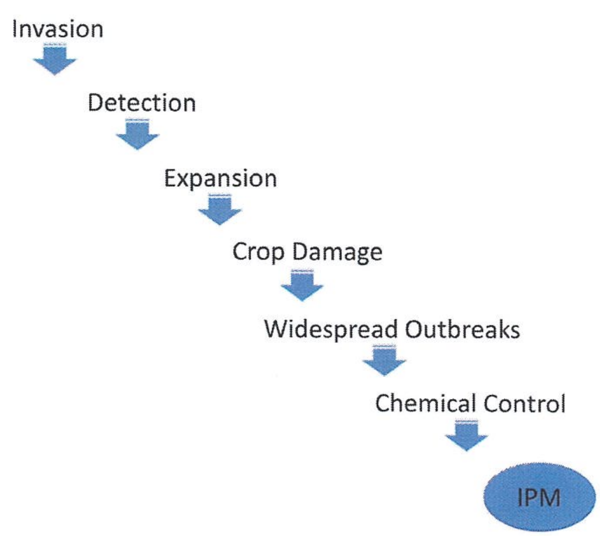

Figure 1. Stages of IPM following invasion of a new pest species.

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Effect of pre-harvest exposures to adult *Halyomorpha halys* (Hemiptera: Pentatomidae) on feeding injury to apple cultivars at harvest and during post-harvest cold storage

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ABSTRACT

The effect of exposing apples to brown marmorated stink bug, *Halyomorpha halys*, for discrete intervals before harvest and of post-harvest cold storage on feeding injury expression was evaluated in 2011 and 2012. Individual apples from four cultivars in experimental orchards in Virginia and West Virginia, USA were caged soon after fruit set to protect them from insect injury. During each of the four weeks preceding harvest of each cultivar, five adult *H. halys* were placed in a subset of cages for 7-days, then removed. Control fruit were not exposed. The proportion of injured fruit and the number of external injuries was evaluated at harvest, after which the fruit were held in cold storage for about 5 weeks, followed by assessments of the proportion of fruit injured and the number of external and internal injuries. Most exposure timings resulted in external injury at harvest, but fruit exposed closer to harvest tended to show less injury than those exposed earlier. Fruit from all cultivars showed external injury at harvest, with variation in the proportion of injured fruit among them. The proportion of injured fruit and the number of external injuries tended to increase during post-harvest cold storage in some, but not all cultivars. The number of external injuries at harvest and after cold storage underrepresented the number of internal injuries. Results are discussed in the relation to the length of pre-harvest protection required to mitigate fruit injury from *H. halys*.

1. Introduction

The invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), has impacted tree fruit production in several Mid-Atlantic States in the USA since its initial outbreak in 2010 (Leskey et al., 2012a). Subsequently, it has invaded tree fruit production regions in other parts of the USA and Europe, where it is causing increasing issues or concerns (Haye et al., 2015; Leskey and Nielsen, 2018). Injury to apples from feeding by the brown stink bug, *Euschistus servus* (Say) (Leskey et al., 2009; Brown and Short, 2010) and *H. halys* (Joseph et al., 2015; Acebes-Doria et al., 2016) is first manifest as a tiny discolored dot at the stylet insertion point, which may be undetectable to the untrained eye or without magnification and which is not considered economic injury *per se*. These injuries can progress into defects that can cause economic losses and that are much more apparent, including shallow, often discolored depressions or deformations on the fruit surface and, in the flesh, discrete areas of brown necrosis that tend to be associated with external injuries. Unlike the native stink bug species, both nymphs and adults of *H. halys* feed on and can cause economic injury to fruit (Acebes-Doria et al., 2016).

In the Mid-Atlantic region, adult *H. halys* emerge from overwintering sites between about mid-April and mid-June (Bergh et al., 2017), resulting in overlapping generations (Nielsen et al., 2016) and the presence of adults and/or nymphs during much of the fruiting period of orchard crops (Bakken et al., 2015; Leskey et al., 2015). Highest captures of *H. halys* in black pyramid traps deployed adjacent to agricultural crop fields, including tree fruit orchards, and baited with its aggregation pheromone (Khrimian et al., 2014) and a pheromone synergist (Weber et al., 2014) typically occur from late August through much of September (Leskey et al., 2015), prior to the mass dispersal of adults to

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ORIGINAL RESEARCH
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Plant Stimuli and Their Impact on Brown Marmorated Stink Bug Dispersal and Host Selection

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A diverse diet in polyphagous insects satisfies changing nutritional needs but the choice of host plant may vary throughout the insect and plant life cycle. The behaviors associated with host choice in the immature stages may differ from the egg laying site chosen by the mother. To evaluate this for an important agricultural pest, we looked at host choice over two growing seasons for the invasive *Halyomorpha halys*. *H. halys* has a host breadth of over 170 known species in its invaded range and adults can satisfy nutritional needs through a strong dispersal capacity. Nymphs are more limited in their ability to choose host plants and we investigated if they make a choice that differs from the source plant (to simulate maternal choice) and characterized volatile organic compounds that are present during attraction. In a mark-release-recapture experiment we quantified dispersal and host choice by nymphs to four common vegetable hosts throughout the growing season. Applying an attraction index to quantify host choice we identified that nymphs switch host plants depending on host phenology. Plants with maturing fruits were most attractive. Volatile organic compounds were collected from host plants during the same time period. Multivariate and correlation analyses categorized phenol, undecane, decanal, and caryophyllene as compounds associated with host plants during peak attractive periods. Thus, the availability of suitable food and associated olfactory cues appears to be influencing the spatiotemporal distribution of *H. halys* within the agroecosystem. Exploiting dispersal behavior and olfactory cues may be used to help increase the effectiveness and efficiency of current management practices for this severe and widespread pest.

Keywords: phenology, volatile, attraction, mark-release-recapture, nymph

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INTRODUCTION

Organisms make many "decisions" during their life to maximize reproductive success, which often are at the cost of compromises. Such decisions may encompass how much to invest in growth relative to defense, mate attraction, spatiotemporal reproduction choices, and whether to disperse in search of resources or to hide from endangerment. Most herbivorous arthropods are considered "specialists" because they specialize in obtaining resources from a narrow range of plant species (Strong et al., 1984). For these specialists, appropriate host selection is essential and chemical cues from host plants may provide the information in order to make such host selection decisions (Dicke, 2000). Herbivore host-choice decisions are largely determined by the mothers, which

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Research

Host Kairomones Influence Searching Behavior of *Trissolcus japonicus* (Hymenoptera: Scelionidae), a Parasitoid of *Halyomorpha halys* (Heteroptera: Pentatomidae)

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Abstract

The brown marmorated stink bug, *Halyomorpha halys* (Stål), is a highly polyphagous species native to Asia that has become a serious invasive agricultural and nuisance pest across North America and Europe. Classical biological control host range evaluations have revealed egg parasitoid *Trissolcus japonicus* (Ashmead) to be the primary candidate biocontrol agent for field release against *H. halys*. However, these evaluations only provide us with the physiological host range of *T. japonicus*. Other *Trissolcus* species have demonstrated that contact kairomones from different host species elicit varied responses in the parasitoids' host foraging behaviors. To assess *T. japonicus* response to host kairomones, mated naive females were exposed to leaf surfaces contaminated with adult kairomones from its preferred host, *H. halys*, or from a native nontarget host, *Podisus maculiventris* (Say) (Heteroptera: Pentatomidae). Red maple, apple, and soybean were used as plant substrate treatments. The wasp's residence time on the leaf surface, linear walking velocity, and angular walking velocity were observed and measured using Noldus EthoVision XT tracking software. Within each leaf treatment, *T. japonicus* displayed stronger behavioral responses on leaves contaminated with contact kairomones from *H. halys*. The parasitoid resided on *H. halys* contaminated leaves for approximately twice as a long as it did on *P. maculiventris* contaminated leaves. Further, both species' kairomones elicited significant decreases in parasitoid walking velocity on all tested substrate types. Overall, our study suggests that kairomone-based behavioral studies can be used to further evaluate the host specificity of *T. japonicus* and can be an invaluable supplement to classical biocontrol host range testing regimes.

Key words: Samurai wasp, biological control, brown marmorated stink bug, host specificity, parasitoid-host interactions.

Native to eastern Asia, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), the brown marmorated stink bug, has become a serious invasive pest in North America and Europe (Hoebeke and Carter 2003, Wermelinger et al. 2008, Rice et al. 2014). Since its initial discovery in 1996 in Allentown, Pennsylvania, *H. halys* is now found in 44 U.S. states, and is considered an agricultural pest in 23 of them (NE IPM 2019). *Halyomorpha halys* adverse effects on agriculture are facilitated by its ability to feed on the fruiting bodies of a vast variety of plants (Lee et al. 2013). Current management regimes for *H. halys* primarily involve broad-spectrum insecticide application to at-risk crops within agricultural systems (Hamilton et al. 2018). Unfortunately, this insecticide use is disruptive and unsustainable, as growers must perform multiple applications per growing season (Blaauw et al. 2015).

One promising alternative management strategy for *H. halys* currently being investigated is classical biological control. Foreign exploration for natural enemies of *H. halys* in its native range of China yielded the discovery of *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), an egg parasitoid which is now considered the primary candidate biological control agent (Yang et al. 2009, Talamas et al. 2013). Due to its high levels of *H. halys* parasitism, *T. japonicus* is recognized as the predominant egg parasitoid of *H. halys* in China, and for this reason, is currently the subject of rigorous quarantine experimentation in several USDA-ARS, state, and university laboratories (Zhang et al. 2017). Surprisingly,

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Brief Communications

OXFORD

First Report of Brown Marmorated Stink Bug (Hemiptera: Pentatomidae) Associated With *Cannabis sativa* (Rosales: Cannabaceae) in the United States

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Abstract

Brown marmorated stink bug, *Halyomorpha halys* (Stål), is a highly polyphagous pest in North America and Europe. Herein, we report our observations of this invasive stink bug on grain hemp (*Cannabis sativa*) in Virginia, which to our knowledge, is the first published report of *H. halys* associated with that crop. Effects of damage to hemp plants from this insect are unknown, so studies were initiated in 2018 to investigate further. Bugs were caged in varying densities for several weeks on seed heads of grain variety industrial hemp in field plots to document damage appearance and yield effects. Seeds were removed from plants in the laboratory, counted, and weighed to assess differences between treatments. In another study, bugs were reared on hemp seed heads in a lab setting from the second instar stage to adulthood. We found that bugs developed successfully to adulthood. Although further studies are needed, it appears that at this time, *H. halys* may not be a threat to yield and quality of industrial hemp.

Key words: stink bug, first report, industrial hemp

The brown marmorated stink bug, *Halyomorpha halys* (Stål), is an invasive species from east Asia (Lee et al. 2013) that likely entered the United States in the mid-1990s, first detected in eastern Pennsylvania (Hoebeke and Carter 2003). Since the early 2000s, *H. halys* has spread throughout much of the United States, has established in Canada and several European countries, and has become a significant agricultural pest (Haye et al. 2015, Leskey and Nielsen 2018). *Halyomorpha halys* is a highly polyphagous pest with a broad host range of over 170 plant species including a wide array of agriculturally important crops (Leskey and Nielsen 2018). In our examination of the literature, there is currently no documentation of *H. halys* feeding on industrial hemp, *Cannabis sativa* L. (Lago and Stanford 1989, McPartland et al. 2000). Herein, we report our observations of this invasive stink bug on grain variety industrial hemp (*C. sativa*) in Virginia. In September of 2016, one of the co-authors (T.P.K.) inspected a research planting of industrial hemp at Virginia Tech's Kentland Farm in Whitethorne, VA (37.196106N, −80.580221W). At time of inspection, plants were mature with fully developed seed heads and numerous *H. halys* adults were observed feeding on seeds (Fig. 1). Since initial observations in 2016, *H. halys* has remained the most commonly observed stink bug species on grain/fiber hemp at this location in 2017 and 2018. Nymphs, adults, and eggs of this species have been found on plants (Figs. 2 and 3). On 28 August 2018, we received laboratory colony *H. halys* egg masses from USDA-ARS in Beltsville, MD. On 7 September 2018, we placed 28 second instars into a cage containing a potted *C. sativa* plant along with fresh field-harvested seed heads of *C. sativa*. Survival and development of *H. halys* was assessed comparatively against corn (*Zea mays*), a known suitable host plant (Kuhar et al. 2012); this was evaluated in four cages (n = 4) for each host plant type. The study was terminated on 8 October 2018 when there were no remaining live insects in cages. Nymphs successfully completed development on both *Z. mays* and *C. sativa* with an average of 24% (2, 10, 4, and 1 stink bugs developing to adult stage) and 66% (20, 23, 23, and 9 stink bugs developing to adult stage), respectively, which is similar, if not higher, to other published studies of *H. halys* development on various beans, seeds, carrot, or tree fruit (Nielsen et al. 2008, Medal et al. 2012, Acebes-Doria et al. 2016, Dingha and Jackai 2016); Nielsen et al. (2008) observed 52.5% of *H. halys* nymphs on a diet of beans and peanuts and Dingha and Jackai (2016) reported 60–80% survival of *H. halys* nymphs on carrot, green beans, princess tree leaves, and various seeds. Given the developmental success on *C. sativa* compared with *Z. mays*, it appears that *C. sativa* may be a suitable host plant for *H. halys*. More evaluations are needed on reproductive ability to understand the suitability of *C. sativa* as a host for *H. halys*.

So far, the authors have not been able to detect any qualitative or quantitative effects of brown marmorated stink bug feeding

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Short Communication

Short Communication

OXFORD

Responses of Overwintering *Halyomorpha halys* (Hemiptera: Pentatomidae) to Dead Conspecifics

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Abstract

Overwintering brown marmorated stink bugs (*Halyomorpha halys*) (Stål) are a notable domestic nuisance. In addition to disruptive activity, dead individuals remain in homes, sometimes in large numbers. To better understand the effects of these remains on overwintering behavior, adult *H. halys* were subjected to several experiments to test their responses to dead conspecifics. In non-tactile tests of individuals exposed to groups of dead conspecifics, *H. halys* did not respond to 1-yr-old desiccated dead conspecifics, but avoided corpses that were freshly killed. In tactile tests of individuals exposed to groups of dead conspecifics, *H. halys* joined those corpse aggregations significantly more often than not, and preferred corpses to cotton when given a choice. In tests of exposure of overwintering individuals to fresh dead conspecifics over the course of a winter, no necrophagy or evidence of survival advantage was observed, but overall females had higher survival rates than males.

Key words: diapause, home invasion, brown marmorated stink bug, necrophagy, aggregation

The brown marmorated stink bug (*Halyomorpha halys*) (Stål), is a significant invasive agricultural pest (Leskey et al. 2012, Haye et al. 2015, Leskey and Nielsen 2018), and a notable domestic nuisance pest due to its habit of overwintering in human dwellings. One homeowner counted over 26,000 individuals in his home in a single year (Inkley 2012).

In addition to the fall search for harborage, *H. halys* may leave their harborage and become active in homes through winter and spring, likely in response to poor nutritional state (Funayama 2012, Skillman et al. 2018). During active periods, some become trapped and die in window frames, light fixtures, and ventilation systems. Predation by web-building spiders (Morrison et al. 2017) also leaves corpses. Others die in harborage, as overwintering temperatures affect mortality (Cira et al. 2016, Taylor et al. 2017), as does desiccation. The authors have searched many attics, crawl spaces, barns, and sheds for overwintering *H. halys*, and frequently find corpses therein, particularly in hard to reach spaces. While *H. halys* decomposition rates in these contexts are unknown, one author has found corpses lasting over 5 yr in their attic.

Halyomorpha halys aggregate using antennae and a tactile response to live conspecifics (Toyama et al. 2006). *Halyomorpha halys* also release an alarm pheromone when disturbed. The pheromone, (*E*)-2-decenal (Zhang et al. 2018), is highly volatile, and will not persist in a corpse. However, the possibility of cues or survival advantage for *H. halys* from dead conspecifics exists. There is precedent for other overwintering heteropterans having responses to recently dead conspecifics. Specifically, boxelder bugs, *Leptocoris trivittata* (Say) (Hemiptera: Rhopalidae), have been shown to increase survivorship through conspecific necrophagy during overwintering (Brown and Norris 2004), with a majority of individuals engaging in the behavior, often soon after introduction of corpses. *Halyomorpha halys* have been observed engaging in cannibalism in lab-reared colonies (Medal et al. 2012), but this was on freshly molted individuals.

This article collects several exploratory studies investigating the responses of overwintering *H. halys* to dead conspecifics, in order to identify the potential importance of their many corpses. It includes tests of tactile and non-tactile responses to *H. halys* corpses, as well as overwintering survival in the presence of fresh dead conspecifics.

Methods

All experiments were conducted in a basement frequently occupied by overwintering *H. halys* in a residence in Blacksburg, VA. The space was monitored and kept at 10°C, with two rooms kept in complete darkness. Live test subjects were collected in western and southwestern Virginia during fall overwintering seasons from the sides of buildings, or in winter from settled aggregations in homes and barns. These insects were allowed at least 48 h to resettle before

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Research

Household and Structural Insects

OXFORD

Size Restrictions on the Passage of Overwintering *Halyomorpha halys* (Hemiptera: Pentatomidae) Through Openings

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Abstract

Intentional and unintentional openings in a building's envelope provide opportunities for unwanted pests to enter buildings. The brown marmorated stink bug, *Halyomorpha halys* (Stål), is one such pest, causing a significant domestic winter nuisance in many locations. One important means of pest control is exclusion, or blocking openings through which they can enter, although some openings are intentional and cannot be completely blocked without putting a building at risk. To help understand what size openings are relevant to entry, adult *H. halys* ready for overwintering were driven out of heated boxes through openings designed to limit passage by their lateral pronotal and dorsoventral dimensions. Pronotally limited holes of 8 mm wide were passed by only one female (3.3% of those tested), and no females and only one male (3.3%) passed through 7-mm-wide holes. For dorsoventrally limited slits, few (13%) of females passed through 4-mm-high slits, and no individuals passed through 3-mm-high slits. Dorsoventral heights and pronotal widths of 930 individuals collected in Virginia were measured. Females were consistently larger, with pronota averaging 8.33 mm wide to the males' 7.47 mm and heights at the point of leg movement restriction averaging 4.03 mm to the males' 3.50 mm. Based on experimental data and size data, we conclude that most *H. halys* individuals will be excluded by slits smaller than 3 mm and holes smaller than 7 mm.

Key words: diapause, home invasion, brown marmorated stink bug, urban pest, building envelope

The brown marmorated stink bug, *Halyomorpha halys* (Stål), is a major agricultural pest and a significant domestic nuisance pest (Leskey et al. 2012, Rice et al. 2014, Leskey and Nielsen 2018). It has achieved its nuisance status because of its habit of using human-built structures as refuges while in winter diapause. Every fall, these insects arrive at houses and sheds. They crawl around the exteriors while searching for entry points and may quickly enter when doors and windows are opened. In spring, they exit, triggered at least in part by the depletion of their fat bodies (Skillman et al. 2018). Throughout the colder months, individuals may exit their hiding places and move around indoors. This can be disturbing to human occupants, particularly in the cases of large infestations, as there can be tens of thousands of *H. halys* in a single house (Inkley 2012).

There are many methods to reduce pest pressure in buildings, and several have been applied for *H. halys* control. Indoors, a variety of light traps are commercially available, though a simple setup of a lamp over a pan of soapy water may be most effective (Aigner and Kuhar 2014). The application of pesticides and the use of traps on building exteriors have been shown to help reduce pressure (Watanabe et al. 1994). Pesticide-treated screens applied to windows may also be effective (Mooneyham et al. 2016). However, with the exception of treated screens, these methods are separate from the building, and only treated screens are related to exclusion.

The Asian ladybird beetle, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), is a winter nuisance pest in similar ways to *H. halys*, and the sizes of these insects relevant to exclusion have been studied. Nalepa (2009) found that *Ha. axyridis* was unable to traverse 2-mm openings, but mostly passed through 3-mm openings. This information has found its way into some exclusion guidelines, which recommend 1.6-mm (1/16 in) mesh installation over openings

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Experimental assessment of the biosafety of *Trissolcus japonicus* in New Zealand, prior to the anticipated arrival of the invasive pest *Halyomorpha halys*

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Abstract Despite numerous interceptions at the border, the brown marmorated stink bug (BMSB), *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), is not yet established in New Zealand. Nevertheless, a classical biocontrol programme using the egg parasitoid *Trissolcus japonicus* Ashmead (Hymenoptera: Scelionidae) has been initiated in anticipation of its likely arrival. The potential host range of the parasitoid in New Zealand was investigated by importing parasitised BMSB eggs into quarantine from Newark, DE, USA. Egg masses of seven species of Pentatomidae, including one sub-species, were individually exposed to naïve mated female *T. japonicus* in no-choice laboratory experiments. The results showed that predatory *Cermatulus nasalis nasalis*, *C. nasalis hudsoni* and *Oechalia schellenbergii*, and the phytophagous *Monteithiella humeralis*, *Dictyotus caenosus*, *Glaucias amyoti*, and *Cuspicona simplex* are all within the physiological host range of *T. japonicus*, although not all appeared to be equally susceptible to parasitism. No development or emergence of *T. japonicus* from eggs of the cosmopolitan pentatomid plant pest *Nezara viridula* were observed. The likely ecological consequences of releasing *T. japonicus* in New Zealand are discussed, as is the subsequent decision of New Zealand's Environmental Protection Authority to approve release of the parasitoid once BMSB arrives in New Zealand.

Keywords Fundamental host range · Host specificity · No-choice test · Non-target impacts · Risk assessment · Proactive biocontrol

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Introduction

The brown marmorated stink bug (BMSB), *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), is an invasive temperate/subtropical pest of many horticultural crops. It is native to China, Japan, Korea, and Taiwan, but has successfully established in the USA and Chile, and Europe including Russia (Haye et al. 2015a; Gapon 2016; Faúndez and Rider 2017; Leskey and Nielsen 2018). BMSB is a major economic threat

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Research

Effects of Aggregation Lure and Tree Species on *Halyomorpha halys* (Hemiptera: Pentatomidae) Seasonal Oviposition

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Abstract

The brown marmorated stink bug, *Halyomorpha halys* (Stål), is a polyphagous pest that feeds on a wide variety of agricultural commodities including tree fruits, berries, vegetables, field crops, and ornamental trees and shrubs. Accurate knowledge of where *H. halys* lays eggs is critical to optimize the potential release of *Trissolcus japonicus* (Ashmead), a scelionid egg parasitoid native to the same host region as *H. halys*. Ideally, parasitoids should be released in and around areas with high host density. In southwestern Virginia in 2017 and 2018, we searched trees for egg masses in an urban environment and nonmanaged wooded border environment. We also evaluated the effects of a commercial aggregation lure on the number of eggs being deposited. This aggregation lure, when combined with methyl (*E,E,Z*)-2,4,6-decatrienoate (MDT), has been shown to attract both adult and nymph *H. halys* and its effects on egg laying were not known. Results of this study showed no difference between the number of eggs laid on trees with and without lures. Catalpa trees, *Catalpa bignonioides* Walter, had the most egg masses throughout the course of the study; however, the redbud, *Cercis canadensis* L., had similar numbers in the late July and August. There was an overall trend with more eggs masses found on trees with fruiting structures present. This information can provide insight on where and when to make augmentative releases of egg parasitoids for *H. halys*.

Keywords: Brown marmorated stink bug, ornamental host, aggregation lure, oviposition

Native to East Asia, *Halyomorpha halys* (Stål) is an invasive stink bug pest that is rapidly spreading throughout North America and Europe (Haye et al. 2015, Leskey and Nielsen 2018). Since its arrival in the United States in the 1990s (Hoebeke and Carter 2003), from a population likely originating from Beijing, China (Xu et al. 2014), *H. halys* has caused millions of dollars of economic loss to a variety of commodities including tree fruit, vegetables and row crops (Leskey et al. 2012, Rice et al. 2014).

The accelerated rate of its spread and the extent of the economic damage it causes is due, in part, to a host range of over 170 plants (Leskey and Nielsen 2018). The ability to feed on a variety of hosts enables *H. halys* to move from one plant to the next as fruiting structures and more suitable food become available (Zobel et al. 2016). High numbers of *H. halys* adults seek shelter in human dwellings and buildings, then move to suitable host plants in the spring to begin feeding and reproduction (Bergmann et al. 2016). Knowing what plants *H. halys* is primarily feeding and ovipositing on in the landscape is useful for monitoring and developing crop-specific scouting plans in new regions (Bakken et al. 2015).

In this study, we surveyed host trees in Montgomery County, Virginia that *H. halys* may deposit eggs on over its reproductive period (May through late Aug/early Sep). Tree species were chosen based on a prior study exploring the range of tree hosts in this geographic area (Bakken et al. 2015) and the predominance of each species in the landscape. To determine if these ovipositional trends could be manipulated by semiochemicals, commercial *H. halys* aggregation pheromone lures were added to half of the trees. It is not known whether lures influence *H. halys* oviposition preference. The results of this study may augment biological control efforts for *H. halys*, in particular, adventive populations of the egg parasitoid *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae). This species is capable of parasitizing *H. halys* egg masses in its native range at rates of almost 80% (Yang et al. 2015). This parasitoid has been detected in several states in the United States (Talamas et al. 2015, Herlihy et al. 2016, Hedstrom et al. 2017, Hoelmer and Tatman 2017), and efforts to distribute field-collected and lab-reared *T. japonicus* are in progress at the time of this manuscript. Thus, knowledge of where

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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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The Discovery of *Trissolcus japonicus* (Hymenoptera: Scelionidae) in Michigan

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Abstract

The invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is a pest of growing economic importance in the United States, the control of which currently relies on pesticide applications. Biological control could provide sustainable and long-term control but classical biological control agents have not yet been approved at the federal level. Adventive populations of a potential biological control agent, the Samurai wasp, *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), have been found in the United States, first in Maryland in 2014, expanding its range west to Ohio by 2017. *Trissolcus japonicus* is a highly effective parasitoid of *H. halys* eggs, but its redistribution and augmentative releases are restricted to states where it has been detected in the wild. To assess the presence of *T. japonicus* in Michigan and attack rates on *H. halys* by native natural enemies we deployed 189 *H. halys* egg masses at ten sites in lower Michigan between May and October in 2018. In addition, we deployed 51 native stink bug egg masses at the same sites to evaluate potential non-target effects of *T. japonicus* in the field, which were shown to occur in laboratory studies. We found *T. japonicus* in a single *H. halys* egg mass, which constitutes the first record of this Asian parasitoid in Michigan. Native predators and parasitoids caused minimal mortality of *H. halys* eggs and we did not find evidence of non-target effects of *T. japonicus* on native stink bug species. These findings open the door to initiation of a classical biological control program using an efficient, coevolved parasitoid from the native range of *H. halys*.

Keywords: Samurai wasp, brown marmorated stink bug, BMSB, biological control, sentinel egg masses, *Halyomorpha halys*

Invasive insects can cause significant economic damage to crops, especially in large monocultures (Bradshaw et al. 2016), potentially because they exist in their invaded ranges without their coevolved natural enemies (Roy et al. 2011). The brown marmorated stink bug, *Halyomorpha halys* (Stål), is an invasive pentatomid pest that was first detected in the United States in 1996 (Hoebeke and Carter 2003). It is capable of feeding on over 200 host plants, including many species of agricultural importance and has caused significant economic damage in the mid-Atlantic region (Leskey et al. 2012, Leskey and Nielsen 2018). Control of *H. halys* currently relies on pesticide applications, largely due to the absence of alternative control strategies like biological control agents (Rice et al. 2014). Native natural enemies have very limited impact on *H. halys* populations, with egg parasitoids attacking usually < 5% of egg masses (Abram et al. 2017, Dieckhoff et al. 2017). Thus, repeated applications of broad-spectrum insecticides over the growing season are necessary to control this pest in cropping areas, but given the vast host range of *H. halys*, populations can always persist in natural areas and recolonize crops. Biological control can suppress *H. halys* numbers across the landscape but to date no effective natural enemies have been found in Michigan.

Two parasitoid species that attack *H. halys* in its native range have been under consideration for release as classical biological control agents since 2007, with one, *Trissolcus japonicus* (Ashmead), undergoing host range testing. *Trissolcus japonicus* was found to develop on at least seven native stink bug species in Oregon (Hedstrom et al. 2017) and 15 native species in Michigan (Botch and Delfosse 2018), which would likely prevent its approval for field release. Nevertheless, *T. japonicus* found its own way into the United States, most likely from parasitized *H. halys* egg masses (Talamas et al. 2015b). Adventive populations were initially detected in Maryland (Talamas et

insects

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Article

Halyomorpha halys (Hemiptera: Pentatomidae) Genetic Diversity in North America and Europe

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Abstract: The brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), is an invasive species in North America and Europe that damages many different host plants. Substantial work has been conducted on the genetic diversity and invasion pathways of *H. halys* in some of the countries where it has been found, based on mitochondrial sequences. The main objective of the present study was to further explore the genetic diversity of invasive populations of *H. halys* exploiting both mitochondrial and nuclear markers. We used two molecular markers: the mitochondrial Cytochrome Oxidase I (*COI*) gene, an ideal standardized molecular marker for distinguishing closely related species, and the ribosomal Internal Transcribed Spacer 1 (ITS1), because only a few sequences of *H. halys* exist to this point in global databases. We used specimens from eight populations from Greece, Italy, Canada, and the US. Among the 14 haplotypes retrieved based on the *mtCOI* gene, two of them (H162–H163) were detected for the first time. These two haplotypes were found in specimens from Canada, Italy, and the US. Concerning the ITS1 region, 24 haplotypes were identified, with 15 being unique for a sampled population. In Greece and the US, 14 and 12 haplotypes were found, respectively, with 7 and 6 of them being unique for Greece and the US, respectively. Our analysis of the nuclear genes of *H. halys* indicates high genetic diversity of the invading populations in North America and Europe.

Keywords: brown marmorated stink bug; haplotype diversity; population genetics

1. Introduction

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is native to China, Japan, Korea, and Taiwan, and has recently become a global invasive species [1–3]. It was likely first found outside of its native range in Allentown, Pennsylvania in 1996 [4], and confirmed in 2001 in the United States [4] and subsequently in Canada [5], Europe [6–19], Russia, Abkhazia, Georgia [20], and South America [21]. Based on recent modelling approaches, as well as newly reported distribution points, its dispersal will likely continue in the coming years. The brown marmorated stink bug is considered a major biosecurity concern for Australia and New Zealand [22–24]. In the new regions of its introduction in North America and Europe, it has become a devastating pest, causing significant damage and economic loss, as well as creating nuisance to residents in rural and urban

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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Research

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Pest Management

Estimating Monitoring Trap Plume Reach and Trapping Area for Nymphal and Adult *Halyomorpha halys* (Hemiptera: Pentatomidae) in Crop and Non-crop Habitats

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Abstract

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae), the brown marmorated stink bug, is an invasive polyphagous insect that can cause serious economic injury to specialty and row crops in the United States and globally. To date, *H. halys* has been managed with repeated insecticide applications. While progress has been made toward development of trap-based monitoring tools to guide management decisions, little is known regarding the trapping area over which a single pheromone-baited trap captures *H. halys*. We conducted single trap, multiple distance mark-release-recapture experiments; results were used to estimate trapping area for nymphs and adults in sites without host plants present (open field) and for adults in sites with host plants present (apple orchard). Plume reach for pheromone-baited sticky traps was consistently estimated to be <3 m. Maximum dispersive distance in an open field devoid of host plants was estimated to be 40 m for nymphs and 120–130 m for adults resulting in trapping areas of 0.58 ha and 4.83–5.56 ha, respectively. When traps were deployed in association with host plants within the border row of an apple orchard, adult maximum dispersive distance and trapping area was reduced to 70 m and 1.67 ha, respectively. These results indicate that the behavioral response of *H. halys* to pheromonal stimuli is influenced by the presence of host plants and that trapping area for pheromone-baited traps will likely change relative to the cropping system in which it is deployed. Caution should be taken when extrapolating these results, because the measured values may differ in other crop systems.

Key words: brown marmorated stink bug, invasive species, dispersive distance, sampling area

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) is an invasive species native to Asia that has become a serious agricultural pest in parts of the United States and Europe. First reported in the United States in the 1990s (Leskey et al. 2012), *H. halys* is a highly polyphagous, landscape-level pest that has a broad host range of more than 170 plant species including orchard crops, small fruit, vegetables, field crops, and landscape and ornamental plants (Leskey and Nielsen 2018). In addition, *H. halys* is considered a severe nuisance pest for homeowners because adults disperse to and settle within residential buildings and other human-made structures to overwinter in large numbers (Inkley 2012, Lee et al. 2014a, Lee and Leskey 2015, Leskey and Nielsen 2018).

Within the last decade, substantial progress has been made toward development of monitoring and biosurveillance tools for *H. halys*. These include the identification of the two-component male-produced aggregation pheromone (3*S*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol and (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol by Khrimian et al. (2014) and methyl (2*E*,4*E*,6*Z*)-decatrienoate (MDT), a pheromone synergist (Weber et al. 2014), as well as behaviorally compatible trap designs (Morrison et al. 2015, Rice et al. 2018b). Combining pheromonal stimuli in traps enables season-long captures of both adults and nymphs (Leskey et al. 2015). Based on these results, a targeted study by Acebes-Doria et al. (2018) of two trap designs was conducted in locations with low, moderate, and high *H. halys* populations. The two traps were ground-deployed black pyramid traps and a clear sticky card affixed to the top of a wooden stake, both baited with lures containing low or high loading rates of the *H. halys* pheromone and pheromone synergist. Though clear sticky traps captured fewer adults and nymphs than pyramid traps, captures were strongly correlated between these two trap types at all

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Influence of harmonic radar tag attachment on nymphal *Halyomorpha halys* mobility, survivorship, and detectability

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Key words: brown marmorated stink bug, BMSB, dispersal, Hemiptera, movement, Pentatomidae, tracking

Abstract

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is a polyphagous invasive insect and currently one of the most threatening agricultural pests in the USA and globally. Nymphs are highly mobile, moving among host plants, and causing significant damage. Thus, understanding dispersal biology for all life stages is critical for the development of reliable monitoring and management programs. Here, we evaluated the influence of harmonic radar as a tool to study dispersal ecology of nymphal *H. halys*; we measured the impact of glues and tag attachment on survivorship and mobility in the laboratory and validated in the field that tagged and released nymphs could be tracked on baited and unbaited host and non-host plants using harmonic radar. In the laboratory, four glues were evaluated for attaching harmonic radar tags securely to nymphs, and survivorship with attached tags was measured. There were no significant differences in survivorship or vertical and horizontal movement among nymphs with tags affixed with the glue treatments compared with the untagged control. Based on numerically greater survivorship of nymphs with tags affixed with Loctite glass glue, a field validation study of tagged nymphs released in host (apple tree) and non-host (mowed grass) with or without *H. halys* pheromonal stimuli present revealed that nymphs could be successfully relocated using harmonic radar after 48 h. Among treatments, 83% of nymphs remained in baited and unbaited apple trees, 50% of nymphs remained in baited mowed grass plots, and in unbaited mowed grass plots, 17% of fifth instars, and 0% of fourth instars were retained. The absence of negative effects on mobility, survivorship, and field tracking validates that harmonic radar can be used to study dispersal ecology of nymphal *H. halys*.

Introduction

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is an invasive species native to China, Korea, Taiwan, and Japan (Lee et al., 2013a). It was first detected in the USA in the mid-1990s near Allentown, PA, and since has been detected in at least 40 states (Hoebeke & Carter, 2003; Leskey & Nielsen, 2018). Since its establishment, it has become a significant agricultural pest in the mid-Atlantic region (StopBMSB.org), and has caused damage to tree fruit, row crops, vegetables, and ornamentals (Leskey et al., 2012) with a reported host range of more than 170 plants (Leskey & Nielsen, 2018). Frequent applications of broad-spectrum insecticides by growers and changes in management practices have disrupted orchard ecosystems, lead to increased production costs, are broadly toxic to non-target arthropods, and cause a decline in natural enemies leading to outbreaks of secondary pests (Leskey et al., 2012). Development of successful and sustainable pest management

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Utilization of Insecticide Treated Nets as an Alternative Method to Monitor and Manage Brown Marmorated Stink Bug, Halyomorpha Halys (Stal)

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Introduction: The current recommendations to manage brown marmorated stink bug (BMSB) *Halyomorpha halys* (Stäl) (Hemiptera - Pentatomidae) continue to rely mostly on the judicious use of insecticide applications. Although, due to continuous improvement in our understanding of BMSB biology and behavior, we are a long way from the initial recommendations of multiple, calendar-based applications, broad spectrum insecticides still remain the most reliable and economical tool to control BMSB. Utilization of BMSB monitoring traps to better understand the movement of the bugs into orchards and the relative abundance of the pest helped in the decision process "if and when" the treatments are really necessary.

Biological control of BMSB in its native range in Asia is very effective and basically eliminates the need for the use of any insecticides against this particular species of stink bug. Our multi-year attempts to evaluate the complex of beneficial insects potentially capable to influence the BMSB populations around orchards resulted in mixed results. Generalist predators such as spiders, praying mantis, lacewings, assassin bugs, damsel bugs or even lady bugs are fully capable to feed on various BMSB instars, however, by their nature, their real practical impact is limited and they are not able to keep the BMSB population in orchards below levels that required chemical intervention. The North American native parasitic wasps, which are very effective in controlling native stink bugs are mostly not interested in feeding on BMSB eggs. Recent orchards observations conducted in PA identified some native parasitic wasps such as species from genera *Anastatus* spp., *Telenomus* spp., and *Trissolcus* spp. attempting to attack BMSB eggs, but their success ratio in parasitizing BMSB eggs was very low. The recent discovery of samurai wasp, *Trissolcus japonicus* (Ashmead), a BMSB specific parasitoid in Pennsylvania orchards provides a much better chance for successful biological control of this pest.

During last few seasons our research activities concentrated mostly on the development and validation of new approaches in effective BMSB monitoring systems and effective management strategies. The utilization of "ghost traps" and Attract and Kill (A&K) strategies proved very promising in reducing the reliance on pesticides to reduce fruit injury caused by BMSB. During the 2016 and 2017 seasons we started to evaluate the new ZeroFly® (D-Terence) nets (Vestergaard, Lausanne, Switzerland) baited with regular BMSB attractants as a potential tool for use in the A&K program. Insecticide treated nets placed between the orchard and the source of invading BMSB (e.g., woods) appear to be effective in capturing BMSB adults and nymphs. Disrupting the BMSB adult seasonal waddling behavior combined with utilization of the most effective insecticides can hopefully significantly reduce the reliance of repeatable insecticide applications as the main tool to manage BMSB.

Insecticides effective against BMSB such as pyrethroids, carbamates and neonicotinoids are detrimental to beneficial insects present in orchards. The recent shift back toward utilizing mating disruption and effective selective soft insecticides such as Altacor ®, Delegate®, or Cyd-X®, which are not effective against BMSB, if combined with the insecticide treated nets could potentially allow for an orchard system which will be much more friendly toward beneficial organisms such as parasitic wasps or predatory mites. The improvements in BMSB monitoring tools and alternative management strategies should provide better options for re-establishment and strengthening of integrated pest management strategies in Pennsylvania orchards.

During this project we evaluated and validated the options for the practical use of insecticide treated nets for the monitoring and potential control of brown marmorated stink bug. The research emphasis was placed on understanding the most effective and economical ways to incorporate

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Applications of Kaolin Protect Fruiting Vegetables from Brown Marmorated Stink Bug (Hemiptera: Pentatomidae)[1]

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Abstract The brown marmorated stink bug *Halyomorpha halys* (Stål) is a serious pest of many horticultural crops in the United States, and organic growers, in particular, have very few effective control options. We evaluated the efficacy of two commercially available natural products, kaolin and essential oils (rosemary oil and peppermint oil), to reduce *H. halys* feeding on tomato (*Solanum lycopersicum* L.) and pepper (*Capsicum anuum* L.). Laboratory choice tests were conducted assessing stink bug occurrence on a cherry tomato fruit placed atop a freshly picked *Paulownia tomentosa* (Thunberg) Steudel leaf that was treated with either kaolin or essential oils compared to an untreated control of the same food within the same cage. Significantly fewer *H. halys* nymphs and adults occurred on kaolin-treated fruit and leaves than an untreated control, whereas there was no significant difference between the essential oils and the control. In a field experiment, kaolin applications to peppers resulted in significantly less stink bug-injured fruit than the untreated control in all harvests. In one of two harvests in 2014 and in one of the three harvests in 2015, the essential oil treatment reduced the percentage of stink bug-injured fruit versus the untreated control. Natural repellents or deterrents such as kaolin have a great potential for reducing *H. halys* feeding in horticultural crops and may provide a management option in organic production systems.

Key Words repellents, deterrents, organic, pest management

Brown marmorated stink bug, *Halyomorpha halys* (Stål), is an invasive insect that has become a significant pest of tree fruit and various vegetables in the United States (Kuhar et al. 2012c, Rice et al. 2014, Leskey and Nielsen 2018). Among the vegetable crops attacked, peppers (*Capsicum annum* L.) can be heavily damaged if control measures are not taken (Kuhar et al. 2012a, 2012b, 2012c, 2013a, 2013b, 2013c, Philips et al. 2017). Insecticides including several pyrethroids, organophosphates, carbamates, and neonicotinoids can reduce *H. halys* densities and fruit damage (Nielsen et al. 2008, Leskey et al. 2012b, 2013, Kuhar and Kamminga 2017). However, virtually all of these insecticides are toxic to beneficial arthropod predators, parasitoids, and pollinators (Leskey et al. 2012b), and can lead to secondary pest outbreaks of aphids, mites, or scales in tree fruit and vegetables after repeated use, especially with pyrethroids (Kuhar et al. 2011, Leskey et al. 2012a).

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insects

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Article

Establishment in an Introduced Range: Dispersal Capacity and Winter Survival of *Trissolcus japonicus*, an Adventive Egg Parasitoid

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Abstract: The herbivorous brown marmorated stink bug, *Halyomorpha halys*, has spread globally, and one of its key parasitoids, *Trissolcus japonicus*, has recently been detected in the pest's introduced range. For an exotic natural enemy to impact its targeted host in a novel environment, it must disperse, locate hosts, and potentially be redistributed to susceptible sites. Through intentionally releasing *T. japonicus* across four Oregon eco-regions, we investigated an introduced parasitoid's dispersal capacity in urban sites and in two perennial crops, hazelnut and raspberry. In a second paired field and laboratory study, we investigated *T. japonicus* survival in different plant materials. Within three days of release, adult *T. japonicus* located host egg masses at 45% of sites and, one year later, were detected at 40% of release sites. Areas where released wasps survived winter were mostly urban or semi-natural. In commercial crop release experiments, we recovered the highest percentage of wasps in raspberry within 5 m of the release site but found no statistical difference in dispersal distance with some wasps dispersing up to 50 m. Adult parasitoids survived up to 16 weeks outdoors in the winter, with greater survival over time in bark compared to leaf litter. Wasp survival remained above 50% over the course of a simulated winter environment without precipitation. Our work affirms the continuation of *H. halys* parasitism by *T. japonicus* in novel environments and provides insight into the high population sizes necessary to survive winter and locate host egg masses the following season.

Keywords: biological control; invasion; overwinter; stink bug; raspberry; stink bug

1. Introduction

Invasive species continue to arrive in new habitats worldwide [1,2]. The entry of exotic pest species threatens existing crop production [3], forestry [4], and plant communities in urban areas [5]. Native arthropods and trophic webs are also affected by invasive species [6–8] through attempting and failing to reproduce in evolutionary traps [9] or displacement [10]. Costs of invasive species management and damage in the United States top 40 billion dollars [11], yet eradication and control efforts require more than financial resources to mitigate their effects on the environment and native species. The accidental entry and intentional release of non-native natural enemies connected to their invasive hosts [12–15] may contribute to pest suppression through biological control. When both the

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Biological and Microbial Control

Sensitivity of the Egg Parasitoid *Trissolcus japonicus* (Hymenoptera: Scelionidae) to Field and Laboratory-Applied Insecticide Residue

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Abstract

The spread of adventive *Trissolcus japonicus* (Ashmead, 1904) populations in North America is anticipated to increase biological control of *Halyomorpha halys* (Stål; Hemiptera: Pentatomidae), the brown marmorated stink bug. In an agricultural context, biological control will succeed if it can be integrated in an environment with insecticide applications. We investigated *T. japonicus* compatibility with nine conventional and organic insecticides commonly used in integrated pest management in perennial crops. Through evaluating mortality and longevity in field and laboratory trials, we determined that *T. japonicus* fares poorly when exposed to residues of neonicotinoids and pyrethroids. Spinosad resulted in the highest percentage of *T. japonicus* mortality, 100% in the laboratory and 97% in a field trial. The anthranilic diamide, chlorantraniliprole, had the lowest lethality, with no differences compared to an untreated control. *Trissolcus japonicus* survived insecticide applications in hazelnut orchards, and over 50% of wasps remained alive after contact with the anthranilic diamides, chlorantraniliprole and cyantraniliprole, the biopesticide *Chromobacterium*, and an untreated control. Our results indicate that *T. japonicus* is unlikely to survive and parasitize *H. halys* in settings that coincide with broad-spectrum insecticide application. Future *T. japonicus* redistributions could continue in orchards treated with anthranilic diamides and *Chromobacterium*. As *H. halys* is a landscape-level pest, orchards may also benefit from biological control if *T. japonicus* are released in unsprayed areas adjacent to agriculture and in urban sites.

Key words: integrated pest management, biological control, parasitoid, biopesticide

Invasive insects cost the U.S. economy over $70 billion dollars annually (Bradshaw et al. 2016). Management of invasive species often involves insecticides due to efficacy, quick action, and the absence of effective natural enemies. The exotic brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is a nuisance pest around homes and businesses and is an economic pest to farmers. In the past two decades, *H. halys* distribution has expanded from its native range in east Asia to North America (Hoebeke and Carter 2003, Gariepy et al. 2014), Europe (Wermelinger et al. 2008, Maistrello et al. 2014), and regions of Russia and the Republic of Georgia (Gapon 2016). Few options are available to manage *H. halys*. Chemical control can manage *H. halys* at high populations (Leskey et al. 2012, 2014; Short et al. 2017), but *H. halys* damage to crops can persist even after chemical applications.

Growers who manage *H. halys* must balance production practices with existing integrated pest management (IPM) of other pathogens and arthropods that cause damage. Crops susceptible to *H. halys* feeding sometimes have additional primary pests. In hazelnut, eastern filbert blight, caused by the fungus *Anisogramma anomala* (Peck), and the key pest filbertworm, *Cydia latiferreana* (Walsingham 1879) (Lepidoptera: Tortricidae) are two critical concerns that typically necessitate one to three annual fungicide and insecticide applications (AliNiazee 1997, Mehlenbacher and Olsen 1997). In small fruits, *H. halys* is typically a less important pest compared to *Drosophila suzukii* (Matsamura, 1931) (Diptera: Drosophilidae), which presents a major challenge to production and is frequently managed with insecticides (van Timmeren and Isaacs 2013). Toxicity of insecticides on arthropod predators (Roubos et al. 2014) and long-distance movement by *H. halys* (Wiman et al. 2015) reduce the efficacy of insecticides as the sole management strategy. The adventive arrival of *Trissolcus japonicus* (Ashmead, 1904), an egg parasitoid of *H. halys*, to North America (Talamas et al. 2015) provides an opportunity for IPM to include biological control. Since 2015, *T. japonicus* has been recorded in 11 states with established

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RESEARCH ARTICLE

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Parasitism of frozen *Halyomorpha halys* eggs by *Trissolcus japonicus*: applications for rearing and experimentation

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ABSTRACT
The brown marmorated stink bug, *Halyomorpha halys* (Stål), has become a well-known pest to growers and homeowners since its 1996 introduction to the United States. A classical biocontrol programme is under development using the egg parasitoid *Trissolcus japonicus*. Widespread implementation of biocontrol requires efficient mass rearing, which is constrained by the availability of fresh *H. halys* eggs. In this study, parasitism rate, developmental time, sex ratio and size were compared between wasps reared on fresh versus frozen, newly laid (<1 d old) versus variably aged (0–3 d old), and frozen egg masses stored ≤4 y. Frozen eggs yielded 56–65% fewer wasps, with parasitism rate decreasing 1–3% per month stored. Parasitism rate, sex ratio and developmental time were comparable between newly laid and variably aged eggs. Freezing eggs for any duration did not affect sex ratio or weight of emerged wasps, but delayed emergence 5–6 d. To simulate deployment of sentinel eggs in the field, we incubated frozen eggs at 20°C and 30°C for 1–9 d before exposing them to *T. japonicus*, then evaluated parasitism trends. *Trissolcus japonicus* parasitism rate decreased 5–8% per day incubated, unhatched wasps increased 9% per day incubated and sex ratio was not impacted. Variably aged, frozen and longer stored eggs can be used for *T. japonicus* rearing and experimentation without affecting emerged wasp sex ratio or size within one generation, but have lower parasitism and slower development. Frozen sentinel eggs are effective <3–5 d, especially in hot conditions.

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Biocontrol; samurai wasp; parasitoid; stink bug; BMSB; host acceptance

Introduction

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), has become a well-known pest to growers and homeowners since its introduction to the United States in 1996 (Hoebeke & Carter, 2003). Subsequently, the insect was introduced to Canada (Fogain & Graff, 2011), Europe (Wermelinger, Wyniger, & Forster, 2008) and South America (Fáundez & Rider, 2017) in just over 20 years. It has >170 known host plants including economically important crops and ornamentals (Bergmann et al., 2013). *Halyomorpha halys* nymphs and adults can disperse quickly by walking (Lee,

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Trissolcus japonicus (Hymenoptera: Scelionidae) Causes Low Levels of Parasitism in Three North American Pentatomids Under Field Conditions

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Abstract

Trissolcus japonicus (Ashmead), an Asian parasitoid of *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), was first detected in North America in 2014. Although testing in quarantine facilities as a candidate for classical biological control is ongoing, adventive populations have appeared in multiple sites in the United States, Canada, and Europe. Extensive laboratory testing of *T. japonicus* against other North American pentatomids and *H. halys* has revealed a higher rate of parasitism of *H. halys*, but not complete host specificity. However, laboratory tests are necessarily artificial, in which many host finding and acceptance cues may be circumvented. We offered sentinel egg masses of three native pentatomid (Hemiptera: Pentatomidae) pest species (*Chinavia hilaris* (Say), *Euschistus conspersus* Uhler, and *Chlorochroa ligata* (Say)) in a field paired-host assay in an area with a well-established adventive population of *T. japonicus* near Vancouver, WA. Overall, 67% of the *H. halys* egg masses were parasitized by *T. japonicus* during the 2-yr study. Despite the 'worst case' scenario for a field test (close proximity of the paired egg masses), the rate of parasitism (% eggs producing adult wasps) on all three native species was significantly less (0.4–8%) than that on *H. halys* eggs (77%). The levels of successful parasitism of *T. japonicus* of the three species are *C. hilaris* > *E. conspersus* > *C. ligata*. The potential impact of *T. japonicus* on these pentatomids is probably minimal.

Key words: classical biological control, parasitoid, invasive species

Classical biological control, involving the importation and release of a natural enemy from the native range of an exotic pest, has long been considered an ideal management tactic. If successful, the exotic pest may be suppressed to the point where control measures, especially pesticides, can be reduced or eliminated. There are numerous examples of successful introductions resulting in substantial control of the target pest without further intervention (DeBach 1962, Caltagirone 1981, Van Driesche and Hoddle 2017). However, the potential for imported natural enemies to significantly harm nontarget species has become increasingly controversial (Howarth 1983, 1991; Simberloff and Stiling 1996; Follett and Duan 2000; Louda et al. 2003b; Bigler et al. 2006; Messing and Wright 2006; Van Lenteren et al. 2006). Concerns about these possible nontarget effects have led to stricter regulations regarding the release of nonnative natural enemies (Babendreier et al. 2006). At least 25 countries require host range testing to predict nontarget effects (Van Lenteren et al. 2003), and the granting of approval for release is biased toward natural enemies with narrow host ranges (Louda et al. 2003a).

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), exhibited rapid population growth in its introduced ranges in the United States and Europe. This success, coupled with the poor performance of indigenous natural enemies (Haye et al. 2015, Herlihy et al. 2016, Ogburn et al. 2016, Abram et al. 2017, Dieckhoff et al. 2017), is consistent with the 'enemy release hypothesis' (Ogburn et al. 2016, Heimpel and Mills 2017, Hamilton et al. 2018). Fundamentally, classical biological control seeks to reverse the effects of this phenomenon by restoring the biotic pressure absent in the pest's invaded range (Hoddle 2004).

Trissolcus japonicus (Ashmead), a scelionid egg parasitoid of *H. halys*, is considered an important natural enemy in the latter's native range (Yang et al. 2009, Zhang et al. 2017). When its potential as a biological control agent was recognized, *T. japonicus* was imported from Asia to quarantine facilities in the United States to assess its physiological host range (Lara et al. 2016, Abram et al. 2017, Hedstrom et al. 2017, Botch and Delfosse 2018, Buffington et al. 2018). Recently, studies of its ecological host range were performed in its native range of northern China (Zhang et al. 2017). Both lines of research revealed a high degree of association between *T. japonicus* and *H. halys*, although it also attacks other pentatomid species in multiple genera. However, the relevance of these studies to North American ecosystems is limited by the artificial conditions of quarantine experiments and the differences

Research Article

SCI

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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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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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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

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Biological and Microbial Control

Impact of Temperature Storage Conditions of *Halyomorpha halys* (Hemiptera: Pentatomidae) Eggs on Parasitism by *Anastatus reduvii* (Hymenoptera: Eupelmidae)

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Abstract

Brown marmorated stink bug, *Halyomorpha halys* Stål, is an invasive species of Asian origin that is an important agricultural pest in the eastern United States. Sentinel egg masses are tools used to assess the impact of natural enemies on *H. halys* populations. To determine the effect of host egg age and storage conditions on their susceptibility to parasitism, *H. halys* eggs were stored at different temperatures for different lengths of time and then exposed to *Anastatus reduvii* (Howard), a native natural enemy of *H. halys* occurring in eastern North America. For eggs stored at 15, 20, and 25°C and then exposed to *A. reduvii*, the number of host eggs from which parasitoid offspring emerged declined with age of eggs. Control eggs (exposed to parasitoids without being stored) and those eggs stored for only 5.5 degree-days (DD) (=0.5 days) at 25°C yielded the highest percentage of parasitoids at 88.2 and 88.3%, respectively. For eggs stored at 20 and 25°C for 7.3 DD to about 36 DD, offspring emerged from about 58 to 73% of eggs, and total parasitism (emerged + unemerged parasitoids) ranged from about 70 to 80%. Parasitoid emergence was significantly lower for host eggs stored at 15°C for comparable times at 20 and 25°C. Stink bugs nymphs hatched from <0.6% of all eggs. Parasitoid-induced host egg abortion was an important component of egg mortality caused by *A. reduvii*, with underdeveloped stink bug nymphs, undifferentiated cell contents, and parasitoid host feeding occurring across all storage treatments.

Key words: brown marmorated stink bug, egg parasitoid, native natural enemy, parasitoid-induced host egg abortion

The brown marmorated stink bug (*Halyomorpha halys* Stål) was accidentally introduced into the mid-Atlantic region of the United States from Asia in the 1990s, and has spread throughout the region causing crop damage and increased control costs for many specialty crop producers (Hoebeke and Carter 2003, Leskey et al. 2012). Understanding the ecology of this exotic pest has been a priority in efforts to develop management strategies, including research into the role of predators and parasitoids on *H. halys* populations in its introduced range. The deployment of *H. halys* sentinel egg masses has been widely used to identify and estimate the impact of native natural enemies on *H. halys* populations in a diversity of managed and non-managed habitats (e.g., Haye et al. 2015, Cornelius et al. 2016, Herlihy et al. 2016, Morrison et al. 2016, Ogburn et al. 2016, Abram et al. 2017, Dieckhoff et al. 2017, Jones et al. 2017, Zhang et al. 2017, Pezzini et al. 2018). They have also been used to detect non-native parasitoids in the stink bug's invaded range, such as *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae) (Talamas et al. 2015, Milnes et al. 2016, Abram et al. 2019, Kaser et al. 2019).

Halyomorpha halys sentinel egg masses will continue to be an important tool used in assessing parasitism and predation of stink bug eggs, to provide baseline data and indications of parasitoid population changes, and to monitor for exotic parasitoids and *T. japonicus* population expansion. Using eggs of uniform age that exhibit a consistent response to parasitism and/or predation is important in interpreting results from sentinel egg deployment. The suitability of host eggs for successful parasitism often declines with age of the egg (Spínola-Filho et al. 2014, Yang et al. 2018, Stahl et al. 2019), and for this reason *H. halys* eggs no more than 48 h old have been commonly used in sentinel egg studies. However, it is often a challenge to maintain stink bug colonies of sufficient size to produce enough fresh *H. halys* egg masses of uniform age to deploy

Utilizing the Samurai Wasp as a Potential Control Tool Against Brown Marmorated Stink Bug

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Introduction: Since the 2010 season, several successful IPM programs in Pennsylvania fruit orchards were disrupted due to the severe outbreak of the brown marmorated stink bug (BMSB) *Halyomorpha halys* (Stål) (Heteroptera – Pentatomidae). While research conducted on BMSB monitoring strategies and alternative management methods has helped decrease the number of insecticide sprays throughout the season, broad-spectrum insecticides continue to be the most effective control measure against BMSB. Use of such products has led to outbreaks of secondary pests, such as mites, wooly apple aphid and San Jose scale. In addition, the effects of these insecticides on BMSB natural enemies have not been thoroughly investigated under orchard conditions. It is crucial to understand where and when populations of natural enemies are present to create strategies that may aid their effectiveness in BMSB control.

Effective biological control of BMSB is likely to come from several natural enemies over different life stages of the pest. Research throughout the Mid-Atlantic has shown both native predatory and parasitic insects and spiders attacking BMSB. While generalist predators are important in agricultural ecosystems, this group of beneficial organisms does not provide specific control of one pest species and often can attack one another, highlighting the importance of research on more specific natural enemies. Parasitic wasps are one of the best candidates for more specific control of BMSB, as they can attack the eggs of stink bugs, killing bugs before they hatch and start causing damage. Parasitic wasps (e.g. *Anastatus* spp., *Telenomus* spp., and *Trissolcus* spp.) which attack native stink bug species have demonstrated the ability to also attack and kill BMSB eggs. In addition, populations of the samurai wasp (*Trissolcus japonicus* Ashmead), a highly successful parasitoid of BMSB in Asia, have been recently found in several U. S. states, including the first detection on sticky traps in Pennsylvania during the 2017 season. During the 2016 and 2017 field seasons we found species from the same three genre of native egg parasitoids attacking BMSB eggs in Pennsylvania. In 2018, we also found the samurai wasp attacking sentinel and wild BMSB eggs for the first time in Pennsylvania. With the samurai wasp being present in Pennsylvania fruit orchards, this parasitoid has now become an important candidate for potential biological control of BMSB alongside its native "cousins."

Although the numbers of parasitoids emerging from sentinel egg masses have been relatively low, it is promising that these wasps are able to attack BMSB. Research has shown that parasitoid species often prefer the host from which they have emerged. Over time, it is possible that some native parasitoid species will be able to further adapt to feeding on BMSB eggs. Research sites in Pennsylvania, due to likely being the earliest locations where BMSB arrived providing native parasitoids the longest amount of time to adapt, provide additional unique opportunities for this study. Also, understanding how native parasitoids may co-adapt to impact BMSB in the presence of the highly adapted samurai wasp provides an even further interesting aspect of parasitoid interactions. It is currently unknown if the samurai wasp will be able to outcompete native parasitoids, or if it will only attack BMSB in specific landscapes, leaving other landscape categories open for native wasps.

To research these interactions, specifically if native parasitoids are adapting to BMSB and if the small adventive populations of the samurai wasp will survive in Pennsylvania conditions, it is important to know where and when they can be found. Some studies have demonstrated that different parasitoid species are found only in certain habitats. For example, one parasitoid species that may be detected in soy may not be found in the woods. Due to low relative captures of these parasitoids, however, population presence across different habitats and throughout the season continues to be an area that is not understood well. Additionally, investigating how these different species find BMSB throughout the landscape may aid in the understanding of why species may reside in these different habitats. The priorities of the first year of the project were to detect new populations of the samurai wasp, to evaluate the habitats and seasonality of populations of native parasitoid species attacking stink bug eggs in Pennsylvania commercial orchard conditions, and to establish colonies of egg parasitoids.

continued on page 20

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RESEARCH ARTICLE

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Surveys of stink bug egg parasitism in Asia, Europe and North America, morphological taxonomy, and molecular analysis reveal the Holarctic distribution of *Acroclisoides sinicus* (Huang & Liao) (Hymenoptera, Pteromalidae)

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Impact of *Nosema maddoxi* on the survival, development, and female fecundity of *Halyomorpha halys*

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ABSTRACT

Nosema maddoxi Becnel, Solter, Hajek, Huang, Sanscrainte, & Estep, a microsporidian species native to the United States, has been found infecting the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål). Microsporidian infections in insects often shorten lifespans, decrease fecundity, prolong development, and stunt growth. This study was conducted to determine the impact of *N. maddoxi* on *H. halys* fitness. Adult females (2 doses) and nymphs (1 dose) drank suspensions of *N. maddoxi* spores to promote infection. Adult females receiving a high dose died faster than the controls. *Nosema maddoxi* infections impacted female egg production and egg viability at both doses compared with the controls. Infections were transmitted to 34.9% of adult males caged with infected females. As the number of days after inoculation increased, infection intensity (# spores found within an infected individual) for both adult treatments transitioned from low-intensity to high-intensity. Infected nymphs died significantly sooner than the controls. Of the treated nymphs, 55.9% died before molting into the fourth instar and only 26.5% eclosed to adults. Nymphal development rate and size were not impacted by *N. maddoxi* infection. These results indicate that *N. maddoxi* infection can negatively impact the lifespan of adult females, female fecundity, egg viability, and nymphal survival, which we hypothesize would negatively impact *H. halys* population densities.

1. Introduction

Microsporidia are intracellular, obligate fungal parasites that usually cause chronic infections in insect hosts that can shorten lifespans, decrease fecundity, prolong development, and stunt growth (Becnel and Andreadis, 2014; Hoch and Solter, 2018). These fitness costs can become obvious when microsporidia infect laboratory colonies where transmission is often enhanced by containment, resulting in epizootics that can lead to colony decimation (Bjørnson and Oi, 2014; Hoch and Solter, 2018). Microsporidian infections can also reach high prevalence in colonies of social insects that often exhibit localized aggregation, which can enhance transmission (Solter, 2014). However, microsporidian species can also reach high prevalence in field populations of diverse insects, especially when host populations are abundant; infection is often density-dependent and can negatively impact such field populations (Andreadis, 1984; Lewis et al., 2009; van Frankenhuyzen et al., 2011; Bjørnson and Oi, 2014).

Microsporidia are well known from the major insect orders Diptera, Lepidoptera and Coleoptera, but relatively few (approximately 20) microsporidian species have been described from hosts in the order Hemiptera (Hajek et al., 2017). However, the microsporidian *Nosema maddoxi* Becnel, Solter, Hajek, Huang, Sanscrainte, & Estep, was recently described as a systemic pathogen of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), in North America (Hajek et al., 2017). In 1968, Joseph Maddox first discovered this microsporidian parasitizing native green stink bugs, *Chinavia hilaris* (Say), in Illinois (Maddoxm, 1979), before *H. halys* was discovered in Pennsylvania in 1996 (Hoebeke and Carter, 2003; Hajek et al., 2017). Therefore, this pathogen is assumed to be native to North America.

Halyomorpha halys was introduced from Asia and is a major pest of fruit and vegetables in the United States (Leskey and Nielsen, 2018). Its management has mostly been dependent on insecticides, with some integrated pest management (IPM) strategies and releases of egg parasitoids (Abram et al., 2017). Bioassays have been conducted demonstrating susceptibility of *H. halys* to isolates of the acute fungal pathogens *Beauveria bassiana* (Bals.-Criv.) Vuill. and *Metarhizium anisopliae* (Metchnikoff) Sorokin, including commercially available formulations of *B. bassiana* (Gouli et al., 2012; Parker et al., 2015). To

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Nosema maddoxi (Microsporidia: Nosematidae) in Brown Marmorated Stink Bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), Populations in the United States

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Highlights

- *Nosema maddoxi* is an entomopathogen infecting *Halyomorpha halys* in the US.
- *Nosema maddoxi* has a wide distribution in *Halyomorpha halys* populations in the US.
- *Nosema maddoxi* infection in *Halyomorpha halys* populations is variable and seasonal.

Abstract

In 2017, *Nosema maddoxi* Becnel, Solter, Hajek, Huang, Sanscrainte, & Estep (Microsporidia: Nosematidae) was described as a pathogen of the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). This study focused on the phenology, distribution, and prevalence of N. maddoxi infections in *H. halys* populations in the United States. Collections of *H. halys* from three sites in 2018 were evaluated for the seasonality of

N. maddoxi infections. Prevalence of infection in spring, after *H. halys* adults overwintered, averaged 37.5 ± 18.9% (peaking at 60.0% in one site) followed by lower infection prevalence during two summer collections (9.7 ± 4.1% and 7.3 ± 2.4%). Collections of H. halys from 31 sites in 11 states in 2017 and 2018 were evaluated and N. maddoxi was found in every state sampled, averaging 18.9 ± 4.3% infection (range: 0.0–52.0%). Prevalence of low-intensity infections was higher than high-intensity infections in both the phenology study (low-intensity infections = 69.3%, high-intensity infection = 30.7%) and the distribution study (low-intensity infections = 62.4%, high-intensity infections = 37.6%). Internal melanized tissues within infected *H. halys* adults are visible as brown spots through the abdominal cuticle and this physical sign can help indicate *N. maddoxi* infection: 74.2% of *H. halys* with these spots were infected; however, 30.0% of *H. halys* adults that did not have spots were infected. Based on this study, this pathogen is widely distributed throughout *H. halys* populations in the US, and infection prevalence is variable among sites and is seasonal, with the highest infection levels occurring when *H. halys* adults are aggregated.

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Short Communication

Sampling Methods for Adventive *Trissolcus japonicus* (Hymenoptera: Scelionidae) in a Wild Tree Host of *Halyomorpha halys* (Hemiptera: Pentatomidae)

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Abstract

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) is an invasive pest that has established in much of the United States. Adventive populations of an effective Asian egg parasitoid of *H. halys*, *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), have been detected in several states, including Virginia, and its geographic range is expanding. Documenting changes in its distribution and abundance have thus become key research priorities. For these specific purposes, surveillance of *T. japonicus* over large geographic areas using sentinel *H. halys* egg masses may not be optimally efficient, and examination of alternative sampling tactics is warranted. In 2016, sentinel *H. halys* egg masses were deployed as vertical transects in the canopy of female *Ailanthus altissima* (Mill.) Swingle (Sapindales: Simaroubaceae) in Virginia. A brief follow-up study in 2016 using yellow sticky traps deployed in the same trees yielded captures of *T. japonicus*, leading to a comparison of vertical transects of sentinel eggs and yellow sticky traps in 2017. Both methods yielded *T. japonicus* detections only in the middle and upper tree canopies, whereas other known *H. halys* parasitoids were detected in the lower, middle, or upper canopies. Based on this information, a method for deploying yellow sticky traps in the middle canopy of *H. halys* host trees was assessed in 2017, yielding *T. japonicus* captures. A comparison of estimated time inputs revealed that traps were more efficient than sentinel eggs in this regard. Results are discussed in relation to the utility of each sampling method to address specific questions about the range expansion and ecology of *T. japonicus*.

Key words: biological control, parasitoids, invasive species, monitoring

Brown marmorated stink bug, *Halyomoprha halys* (Stål) (Hemiptera: Pentatomidae), is a polyphagous agricultural and nuisance pest from Asia that continues to cause significant crop protection issues in the United States (www.stopbmsb.org, Leskey and Nielsen 2018). Its management has relied heavily on broad spectrum insecticides, which can mitigate crop injury but have incited secondary pest outbreaks (Rice et al. 2014) and do not adequately reduce its populations in the surrounding landscape. Consequently, there is much interest in biological control to regulate *H. halys* populations in crop and noncrop habitats. Some indigenous natural enemies attack *H. halys* but have not regulated its populations sufficiently (Abram et al. 2017). In Asia, the egg parasitoid, *Trissolcus japonicus* (Ashmead) (Hymenoptera: Scelionidae), is a key natural enemy of *H. halys* (Yang et al. 2009, Zhang et al. 2017) and has been evaluated in quarantine in the United States since 2007 (Talamas et al. 2015). An adventive population of *T. japonicus* was detected in Maryland in 2014 (Talamas et al. 2015); subsequent detections have been reported from Virginia, West Virginia, Maryland, Delaware, New York, New Jersey, Pennsylvania, Ohio, Michigan, Oregon, Washington, California, and Washington, DC. Consequently, documenting the spread of *T. japonicus* has become a major research objective.

To date, most field data on *H. halys* natural enemies have been derived from assessments of naturally laid egg masses or from sentinel egg masses deployed on host plants (reviewed in Abram et al. 2017). While these sampling methods can document egg predation and parasitism, they pose some challenges for determining the distribution and spread of *T. japonicus* across large geographic areas. Collection of naturally laid egg masses is time-consuming (Bakken et al. 2015) and the use of sentinel eggs requires maintaining a colony of *H. halys*. The acceptability of *H. halys* eggs to *T. japonicus* declines within a few days of oviposition (Qiu et al. 2007, Yang et al. 2018), and sentinel eggs are typically retrieved after 72 h. Moreover, sentinel eggs are vulnerable to predation during deployment (reviewed in Abram et al. 2017), and may underestimate parasitism (Jones

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Research

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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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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

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RESEARCH ARTICLE

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Molecular phylogeny of *Trissolcus* wasps (Hymenoptera, Scelionidae) associated with *Halyomorpha halys* (Hemiptera, Pentatomidae)

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Abstract

As the brown marmorated stink bug (*Halyomorpha halys*) has spread across the Northern Hemisphere, research on its egg parasitoids has increased accordingly. These studies have included species-level taxonomy, experimental assessments of host ranges in quarantine, and surveys to assess parasitism in the field. We here present a molecular phylogeny of *Trissolcus* that includes all species that have been reared from live *H. halys* eggs. Species-group concepts are discussed and revised in the light of the phylogenetic analyses. The analyses indicate that the ability to successfully parasitize *H. halys* eggs is not phylogenetically constrained, but the most effective parasitoids are all found in the *flavipes* species group.

Keywords

egg parasitoid, biological control, Pentatomoidea

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Research

Ecology and Behavior

Attractiveness of Pheromone Components With and Without the Synergist, Methyl (2*E*,4*E*,6*Z*)-2,4,6-Decatrienoate, to Brown Marmorated Stink Bug (Hemiptera: Pentatomidae)

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Abstract

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) is attracted to its male-produced aggregation pheromone, a ~3.5:1 mixture of (3*S*,6*S*,7*R*,10*S*)- and (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol (SSRS and RSRS respectively), and also to the pheromone of its Asian sympatric species *Plautia stali* Scott (Hemiptera: Pentatomidae), methyl (2*E*,4*E*,6*Z*)-2,4,6-decatrienoate (MDT). A stereoisomeric mixture of (7*R*) 10,11-epoxy-1-bisabolen-3-ols (= mixed murgantiols) is used together in commercialized products with MDT because the latter is a synergist for *H. halys* attraction to mixed murgantiols. However, the optimal ratio for MDT combination with mixed murgantiols, and the sensitivity of bug captures to variation in ratio of the two pheromone components, have not been tested to date. Using black pyramid traps at two sites (in Maryland and West Virginia, United States), different ratios of mixed murgantiols to MDT were tested over two entire seasons. Also, captures using various ratios of the two active pheromone stereoisomers were undertaken in month-long trials with and without MDT. Results showed that *H. halys* adult and nymphal captures were relatively insensitive to the ratio of synthetic pheromone (mixed murgantiols) to MDT, as long as each was present in the trap. Captures of adults and nymphs were responsive to the lure loading of the SSRS isomer, but relatively insensitive to levels of the minor component, RSRS. The relative insensitivity of *H. halys* to these attractant ratios gives flexibility to development of more cost-efficient synthesis and trapping as well as other semiochemical-based management tactics.

Key words: murgantiol, pheromone ratio, pheromone trap, monitoring, (3*S*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol, (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol

The invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), native to eastern Asia, has in the last 20 yr established pest populations in temperate North America (Northeastern IPM Center 2019), in Europe and the Caucasus (Haye et al. 2015, Haye and Wyniger 2019), and most recently in Chile (Faúndez and Rider 2017). In its original and introduced range, *H. halys* feeds on a wide diversity of wild and cultivated plants including many crops (Lee et al. 2013, Northeastern IPM Center 2019), and is a significant agricultural pest in the United States and Europe (Haye et al. 2015, Leskey and Nielsen 2018), in addition to its nuisance status as an invader of human structures for overwintering (Inkley 2012, Northeastern IPM Center 2019).

Following the invasion of *H. halys* into the United States, the pheromone of Asian sympatric species *Plautia stali* Scott (Hemiptera: Pentatomidae), methyl (2*E*,4*E*,6*Z*)-2,4,6-decatrienoate (hereinafter, MDT), discovered and deployed earlier in Japan (Sugie et al. 1996; Tada et al. 2001a,b), was the only attractant available, and attracted bugs almost exclusively in the late season (Aldrich et al. 2007, 2009; Funayama 2008; Khrimian et al. 2008; Leskey et al. 2012a,b). Khrimian et al. (2014) then discovered and synthesized both