Final Report

Project No. and Title: NE1944: Management of the Brown Marmorated Stink Bug
Period Covered: 10/01/2018 to 9/31/2023.

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Statement of Issue: The brown marmorated stink bug, *Halyomorpha halys* Stål (BMSB) is a highly polyphagous stink bug of Asian origin. In its native range of China, Korea, and Japan, it is considered a periodic agricultural pest of soybeans, tree fruit and various ornamental and vegetable crops. The brown marmorated stink bug is also a nuisance pest in these countries due to its overwintering behavior of entering enclosed structures such as residences in large numbers each fall. Since its introduction into the United States around 1996, it has spread to all but six states and the District of Columbia. *Halyomorpha halys* has also established populations in Canada, numerous European countries, South America, and potentially southern Africa. It has also been intercepted in other countries such as New Zealand and Australia. In the United States BMSB has become a homeowner nuisance wherever it has established and in the eastern United States *H. halys* become a severe agricultural pest on both conventional and organic farms with little (insecticide use) or no management options. *Halyomorpha halys* is an emerging pest in Southern and Midwestern United States. In the western United States growers in agricultural areas of California, Oregon, and Washington where BMSB is becoming established are also concerned about its impacts because it has been shown to be damaging tree and nuts crops in these areas. In the United States where BMSB is currently a pest, it also attacks a wider range of agricultural crops than in Asia. Currently, damage is seen in numerous vegetables, tree fruit and field crops, and in nurseries. Due to this, failure to address this issue on a regional/national basis will result in severe losses in a variety of cropping systems including peaches, apples, soybeans and peppers resulting in economic hardships by growers and potential farm failures.

Need: In 2010, in response to severe losses in the mid-Atlantic United States due to BMSB, Drs. Tracy Leskey (USDA ARS) and George Hamilton (Rutgers University) created the Brown Marmorated Stink Bug Working Group via a grant from the Northeastern IPM Center. The working group's goals were to bring together researchers, growers and others with the intent to discuss the situation and identify needs research and extension needs and priorities. The first meeting generated a long list of needs and priorities. They can be found at http://www.northeastipm.org/working-groups/bmsb-working-group/priorities-and-reports/. Due to continued funding from the Northeastern IPM Center, this group continues to meet and has grown to over 80 members from throughout the United States. Each time the group meets the list of priorities/needs are discussed and modified. As a priority is met it is removed. New priorities are added when needed. This proposal's objectives reflect current needs established by the working group and will be modified during the life of the project to reflect changes in priorities as identified by the working group.

A multi-state approach to this issue is warranted given the heavy losses incurred by agricultural producers in the eastern United States since 2010. In 2010, this insect's presence in mid-Atlantic apples

resulted in $37 million in losses (American/Western Fruit Grower 2011) and in the tree fruit growing regions of Virginia and West Virginia damage approached 90% (Leskey & Hamilton 2010). Organic producers in this area observed similar amounts of damage to numerous fruits and vegetables. In 2011 and 2012, comparable damage levels were again observed in these and other eastern states and crops (apples, pears, peaches, tomatoes, peppers, grapes, brambles sweet and field corn and soybeans) from Virginia to New York. As a result of the current multistate project (NEERA 1306) and several USDA grants (OREI – 1, SCRI – 2) obtained by its members progress has been made in the management of *H. halys* resulting in damage reductions in tree fruit and vegetables. However, these reductions continue to be the result of heavy insecticide use by growers and have resulted in outbreaks of secondary pests previously managed by natural enemies.

Continuing the current multi-state project to address the on-going needs currently identified by the BMSB working group and others will bring together researchers already working on this issue in the Northeast and other parts of the United States once a year to discuss, identify, and adjust research needs and priorities, and present progress updates. This approach will also allow participating researchers to coordinate their activities to avoid duplication. Finally, since this insect has spread throughout the United States, creating a multi-state project has the potential to bring together researchers from the northeast, from other geographic regions and from other cropping systems not present in the Northeast (cotton, nuts, etc.).

Justification: The brown marmorated stink bug was first observed in the United States in Allentown, PA around 1996 but was initially misidentified as a native pentatomid species. Following correct identification in 2001, it has been found in over 40 states. In several eastern states, its presence in agricultural crops has been confirmed in 2009 and was documented causing severe damage to apples, peaches, pears, peppers and tomatoes. In 2010, 2011 and 2012 damage by this insect was also observed in brambles, field corn, grapes, ornamentals, soybeans, and sweet corn.

Traditionally, management of stink bugs in soybeans, tree fruit and horticultural crops was accomplished through the use of targeted applications of organophosphate insecticides. However, with the passage of the Food Quality Protection Act in 1996, these materials have been slowly phased out resulting in increased damage by stink bugs in these crops. The addition of BMSB with its high rates of reproduction and survival puts these crops at greater risk. Many of the insecticides currently available to growers have variable effects (limited knockdown, recovery once treated, etc.) on resident populations and little or no residual effects on future invaders into treated fields and orchards. In the laboratory pyrethroid insecticides, the replacement for organophosphate insecticides in many cases, exhibit high levels of toxicity to the brown marmorated stink bug fifth instars and adults as do various neonicotinoid insecticides (imidacloprid and dinotefuran). Testing under field conditions has shown that pyrethroids such as bifenthrin to be the most efficacious. Prior to BMSB becoming a problem, pyrethroid use was discouraged in tree fruit and vegetables because of their negative effects to natural enemies. Today, due to the issues mentioned above, in many cases growers continue to rely on weekly applications of pyrethroids and neonicotinoids to manage BMSB thus abandoning 40 years of IPM program development. This use pattern has caused secondary outbreaks of pest such as the wooly apple aphid, San Jose scale and European red mites that were previously controlled by natural enemies putting growers on a "pesticide treadmill" that could lead to complete failures of management programs for BMSB and other pests.

In Asia, the brown marmorated stink bug is attacked by several egg parasitoids and one species of tachinid fly. However, as is customary with newly introduced species, natural enemies are rarely introduced at the same time. Two egg parasitoids and a tachinid fly have been observed attacking the brown marmorated stink bug in Delaware, Maryland, Pennsylvania, and New Jersey but are generalist natural enemies and therefore not specific to the brown marmorated stink bug. Several native predators, including minute pirate bugs, ladybugs and spiders do attack BMSB. However, as with native parasitoids

their impact has been limited. The use of microbial agents is another potential non-chemical control method. However, to date, screening for possible candidates with toxicity to the brown marmorated stink bug has had limited success. Exploration in Asia to find possible biological control agents has identified several potential parasitoids. One, *Trissolcus japonicus*, a highly effective egg parasitoid of BMSB in Asia, is currently in quarantine undergoing host specificity testing. In the last 3 years, naturally occurring populations of this parasitoid (i.e., genetically distinct from the strain in quarantine) have been found in several eastern states and in Oregon and Washington. These finding have resulted in the need to investigate in the field their impact on *H. halys* and other native stink bugs, and how best to use them for control of BMSB in agricultural situations.

In addition, wherever, the brown marmorated stink bug occurs it has become a severe residential nuisance pest. Currently, while progress has been made because of this multistate project there are still no adequate pest management alternatives to prevent overwintering brown marmorated stink bug adults from entering residences in areas where they occur. Current recommendations for caulking of windows and/or the sealing of cracks and voids in exterior walls, eaves, etc. and the limited use of insecticides on external building surfaces can provide limited control but are not 100% effective. Unfortunately, homeowners, commercial building managers and pest control professionals continue create their own potential solutions through the illegal insecticides in attics and blanket treatment of exterior surfaces and interior walls with insecticides. These practices pose health risks to homeowners, their families, and the environment.

Accomplishments: During the length of the project, the group has accomplished the following

- Refinement of BMSB monitoring methods using clear sticky traps
- Evaluation of landscape variables in different eco-zones on BMSB density
- Refinement of development models
- Evaluation of monitoring traps to access damage thresholds
- Evaluation of insecticide resistance
- Optimization of damage thresholds
- Evaluation of new insecticides for BMSB management
- Evaluation of BMSB impact in edamame
- Recovery and redistribution of Trissolcus japonicus in fruit orchards
- Refinement of management recommendations for fruit and vegetable growers

Impacts: Members of this project have been involved in several grants during the length of the multistate project. Most were members of the USDA SCRI grant entitled "Management of Brown Marmorated Stink Bug in US Specialty Crops and the USDA ARS Areawide Project targeting the management of BMSB. Both ended at the end of August 2021. Because of the work done by the participants, conventional and organic growers have a better understanding of how to manage BMSB populations and minimize damage. Initially, a grower's sole tactic was to spray crops on a calendar basis. This was especially true in tree fruit where growers sprayed one to two times per season prior to the appearance of BMSB. Today, because of the work done by members of the project, growers have methods they can use to monitor crops and as a result have refined their control strategies, resulting in reduced insecticide applications. While this should be considered progress, BMSB management tactics are still not optimal, and ongoing reliance on certain insecticides against it continue to result in secondary pest outbreaks. Because of this, work to develop more sustainable management methods needs to be continued.

Publications: During the length of thes project, the group has accomplished the following

1. Park, Y-L, K. Choi, J. Cullum, K.A. Hoelmer, D.C. Weber, W.R. Morrison, K.B. Rice, G. Krawczyk, S.J. Fleischer, S.J., G. Hamilton, D. Ludwick, A.L. Nielsen, J. Kaser, D. Polk, P.M. Shrewsbury, J.C.

Bergh, T.P. Kuhar, and T.C. Leskey, 2024. Landscape-scale spatiotemporal dynamics of Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) populations: Implications for spatially-based pest management. Pest Management Science. http://doi.org/10.1002/ps.7772

2. Gutiérrez I.J., J.F. Walgenbach, A. Acebes-Doria, A.M. Agnello, D.G. Alston, H. Andrews, J.C. Bergh, R. T. Bessin, B.R. Blaauw, G.D. Buntin, E.C. Burkness, J.P. Cullum, K.M. Daane, L.E. Fann, J. Fisher, P. Girod, L.J. Gut, G.C. Hamilton, K.A. Hoelmer, W.D. Hutchison, P.J. Jentsch, S.V. Joseph, G.G. Kennedy, G. Krawczyk, T.P. Kuhar, T.C. Leskey, A.L. Nielsen, D.K. Patel, H.D. Peterson, D.R. Reisig, J.P. Rijal, A.A. Sial, L.R. Spears, J.M. Stahl, K.M. Tatman, S.V. Taylor, G. Tillman, M.D. Toews, R.T. Villanueva, C. Welty, N.G. Wiman, J.K. Wilson, F.G. Zalom, G. Zhu and D.W. Crowder. 2022. Evaluating invasion risk and population dynamics of the brown marmorated stink bug across the conterminous USA. Pest Management Science. http://doi.org/10.1002/ps.7113
3. Leskey, T.C., H. Andrews, A. Bády, L. Benvenuto, I. Bernardinelli, B. Blaauw, P. Bortolotti, L. Bosco, E. Di Bella, G. Hamilton, T. Kuhar, D. Ludwick, L. Maistrello, G. Malossini, R. Nannini, L. Nixon, E. Pasqualini, M. Preti, B. Short, L. Spears, L. Tavella, G. Vétek, and N. Wiman. 2021. Refining pheromone lures for the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) through collaborative trials in the USA and Europe. J. Econ. Entomol. doi: 10.1093/jee/toab088
4. Quinn, N., E. Talamas. T. Leskey, and C. Bergh. 2021. Seasonal activity of *Trissolcus japonicus* and the effect of habitat type on detection frequency. Insects 12(2): 118. doi: 10.3390/insects12020118
5. Bergh, J.C., W.R. Morrison III, J.W. Stallrich, B.D. Short, J.P. Cullum, and T.C. Leskey. 2021. Border habitat effects on captures of *Halyomorpha halys* (Hemiptera: Pentatomidae) in pheromone traps and fruit injury at harvest in apple and peach orchards in the Mid-Atlantic, USA. Insects 12(5), 419; https://doi.org/10.3390/insects12050419
6. Sutton, K., H. Doughty, T. Kuhar, and S. Rideout. 2021. Evaluation of insecticides to control southern green stink bug in edamame, 2020. Arthropod Management Tests, Volume 46, Issue 1, 2021, tsab081, https://doi.org/10.1093/amt/tsab081
7. Lopez, L., T. Kuhar, S. Taylor, and K. Sutton. 2021. Biology and Management of Brown Marmorated Stink Bug in Mid Atlantic Soybean. Virginia Cooperative Extension Publication. No. ENTO-450NP. https://resources.ext.vt.edu/contentdetail?contentid=3212
8. Akotsen-Mensah, C., B. Blaauw, B.D. Short, T. Leskey, C. Bergh, D. Polk, and A. Nielsen. 2020. Using IPM-CPR as a management program for apple orchards. J. Econ. Entomol. 113(4):1894-1902.doi: 10.1093/jee/toaa087.
9. Ludwick, D., W.R. Morrison III, A.L. Acebes-Doria, A.M. Agnello, J.C. Bergh, M.L. Buffington, G.C. Hamilton, J.K. Harper, K.A. Hoelmer, G. Krawczyk, T.P. Kuhar, D.G. Pfeiffer, A.L. Nielsen, K.B. Rice, C. Rodriguez-Saona, P.W. Shearer, P.M. Shrewsbury, E.J. Talamas, J.F. Walgenbach, N.G. Wiman, and T.C. Leskey. 2020. Invasion of the brown marmorated stink bug (Hemiptera: Pentatomidae) into the USA: 14 Developing a national response to an invasive species crisis through collaborative research 15 and outreach efforts. J. of Integrated Pest Management 11(1): 4; 1–16. doi: 10.1093/jipm/pmaa001
10. Acebes-Doria, A., A. Agnello, D. Alston, H. Andrews, E. Beers, C. Bergh, and 32 others. 2020. 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. 113: 159-171
11. Acebes-Doria, A., Ludwig, D., Morrison, W., Agnello, A., Bergh, J.C., Buffington, M., Hamilton, G., Harper, J., Hoelmer, K., Krawczyk, G., Kuhar, T., Pfeiffer, D., Nielsen, A., Rice, K., Rodriguez-Saona, C., Shearer, P., Shrewsbury, P. Talamas, E., Walgenbach, J., Wiman, N., Leskey, T. 2020. Invasion of the brown marmorated stink bug (Hemiptera: Pentatomidae) into the USA: Developing a national response to an invasive species crisis through collaborative research and outreach efforts. Journal of Integrated Pest Management. doi.org/10.1093/jipm/pmaa001
12. Alford. A., et al. 2020. Baseline toxicity of the insecticides bifenthrin and thiamethoxam on Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) collected from the Eastern U.S.A. Journal of Economic Entomology. doi: 10.1093/jee/toz361

13. Bergh, C., S.V. Joseph, B. Short, M. Nita, and T. Leskey. 2019. 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. Crop Protection 124: article 104872
14. Blaauw, B.B., G. Hamilton, C. Rodriguez-Saona and A.L. Nielsen. 2019. Plant stimuli and their impact on brown marmorated stink bug dispersal and host selection. Frontiers in Ecology and Evolution doi: 10.3389/fevo.2019.00414.
15. Britt, K. E., M. K. Pagani, and T. P. Kuhar. 2019. First report of brown marmorated stink bug (Hemiptera: Pentatomidae) associated with Cannabis sativa (Rosales: Cannabaceae) in the United States. Journal of Integrated Pest Management, Volume 10, Issue 1, 2019, 17, https://doi.org/10.1093/jipm/pmz014
16. Chambers, B. D., T. C. Leskey, A. R. Pearce, and T. P. Kuhar. 2019. Responses of overwintering Halyomorpha halys (Hemiptera: Pentatomidae) to dead conspecifics. J. Econ. Entomol.112, Issue 3:1489–1492. https://doi.org/10.1093/jee/toz011
17. Hancock, T., D.-H. Lee, C. Bergh, W. Morrison III, and T. Leskey. 2019. 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. Agric. and Forest Entomol. 21: 99-180
18. Kuhar, T. P., J. A. Morehead, and A. J. Formella. 2019. Applications of kaolin protect fruiting vegetables from brown marmorated stink bug (Hemiptera: Pentatomidae). J. Entomol. Sci. 54(4):401-408 (2019). https://doi.org/10.18474/JES18-126
19. Morrison, W. III, B. Blaauw, B. Short, A. Nielsen, C. Bergh, G. Krawczyk, Y.-L. Park, B. Butler, A. Khrimian, and T. Leskey. 2019. Successful management of *Halyomorpha halys* (Hemiptera: Pentatomidae) in commercial apple orchards with an attract-and-kill strategy. Pest Manag. Sci. 75: 104-114
20. Quinn, N., E. Talamas, A.L. Acebes-Doria, T. Leskey, and C. 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
21. Quinn, N., E. Talamas, T. Leskey, and C. Bergh. 2019. Sampling methods for adventive *Trissolcus japonicus* (Hymenoptera: Scelionidae) in a wild tree host of *Halyomorpha halys* (Hemiptera: Pentatomidae). J. Econ. Entomol. 112: 1997-2000
22. Valentin, R., D.M. Fonseca, S. Gable, K. Kyle, G.C. Hamilton, A.L. Nielsen, and J.L. Lockwood. 2020. Moving eDNA surveys onto land: Strategies for active eDNA aggregation to detect invasive forest insects. Molecular Ecology Resources. dx.doi.org/10.1111/1755-0998.13151

Presentations:

Research

1. Dyer J.E., E.J. Talamas, T.C. Leskey, and J.C. Bergh. 2020. Sampling *Trissolcus japonicus* using yellow sticky traps: Does location in the tree canopy matter?" Entomological Society of America, November 11-25 2020. Virtual
2. Hadden, W.T., T.C. Leskey, and J.C. Bergh. 2020. Retention of *Halyomorpha halys* (Hemiptera: Pentatomidae) adults and nymphs on wild and cultivated host trees as a proxy for host acceptability at different points in the growing season. Entomological Society of America, November 11-25 2020. Virtual
3. Hamilton, G. and P. Girod. 2020. *Halyomorpha halys* in New Jersey: The more we know, the more we know we don't know? – Monitoring, adventive population of *Trissolcus japonicus* and biological control. Entomological Society of America Annual Meeting.
4. Dyer, J., E. Talamas, T. Leskey, and C. Bergh. 2020. Are captures of *Trissolcus japonicus* correlated with those of its host, *Halyomorpha halys*? Cumberland-Shenandoah Fruit Workers Conference, December 2-4, Winchester, Virginia. Virtual

5. Hadden, W., T. Leskey, and C. Bergh. 2020. Deciphering the seasonal host use patterns of *Halyomorpha halys* on select deciduous plants. Cumberland-Shenandoah Fruit Workers Conference, December 2-4, Winchester, Virginia. Virtual
6. Bergh, C., A. Edwards, C. MacRae, and N. Brandt. 2020. Re-distributing *Trissolcus japonicus* in Virginia: 2020 Update. Cumberland-Shenandoah Fruit Workers Conference, December 2-4, Winchester, Virginia. Virtual
7. McDougall, R., D. Ludwick, T. Leskey, G. Krawczyk, C. Bergh, Y.-L. Park, and A. Nielsen, 2020. Effects of land use on the natural enemies of brown marmorated stink bug (Halyomorpha halys). Cumberland-Shenandoah Fruit Workers Conference, December 2-4, Winchester, Virginia. Virtual
8. Ben-Zvi, Y., G. Hamilton and C. Hawkings. 2021. The effects of volatile organic compounds on host seeking behavior of *Trissolcus japonicus.* Entomological Society of America Annual Meeting.
9. Dyer, J.E., E.J. Talamas, T.C. Leskey, and J.C. Bergh. 2021. *Halyomorpha halys* egg mass abundance and detections of its egg parasitoid, *Trissolcus japonicus*, in wild host trees baited with aggregation pheromone. Symposium: Research Advances in Invasive Pests by Early-Career Scientists, Entomological Society of America Eastern Branch, March 22 – 24. Virtual
10. Kuhar, T. 2021. Update on BMSB from the Mid-Atlantic U.S. BMSB Virtual SCRI Stakeholder Advisory Panel Meeting, February 17, 2021 Virtual.
11. Kuhar, T. P. 2021. Insect pest response to vegetable soybean genotypes bred for commercial edamame production in Virginia. 2021 Soybean Breeders virtual workshop: Entomology and Breeding Innovation, February 22-24, 2021. https://www.soybase.org/meeting_presentations/soybean_breeders_workshop.
12. Sutton, K. Kuhar T.P., Rideout S., and Doughty H. 2021. Developing an IPM program for edamame in Virginia. Entomological Society of America Eastern Branch. March 23, 2021. Virtual.
13. Woobey, J., Ben-Zvi, Y., G. Hamilton and C. Hawkings. 2021. The influence of volatile organic compounds on the life stages of *Halyomorpha halys* and implications for biological control. Entomological Society of America Annual Meeting.

Extension

1. Kuhar, T. Fall Vegetable Pest Updates, VCE AG Today Virtual Meeting, October 29, 2020.
2. Kuhar, T. Fall Vegetable Pest Updates, Shenandoah Valley Vegetable Grower Virtual Meeting, October 29, 2020
3. Bergh, C. Virtual presentations to tree fruit producers in Virginia, West Virginia, and Maryland on March 31, April 7, April 14, April 21, April 28, May 5, May 12, May 19, and May 26, 2021
4. Bergh, C. In-person orchard meetings with tree fruit producers in Virginia on April 21, May 5, May 19, and June 2, 2021
5. Bergh, C. Public Open House at the Winchester AREC, August 14, 2021
6. Kuhar, T. Vegetable Production Meeting, Fancy Gap, VA, Jan 14, 2021
7. Kuhar, T. Chattanooga Elementary Schools – Invasive Species Chat with an Expert – Virtual – Feb 23, 2021.
8. Kuhar, T. Virginia Coop. Ext. In-service Training – Urban vegetable production, Virtual, March 3, 2021
9. Kuhar, T. VA Association of Biological Farming Conference, Roanoke, VA, March 18, 2021
10. Kuhar, T. Virginia Coop. Ext. In-service Training – Organic Vegetables, Virtual, March 22, 2021
11. Kuhar, T. Southside, VA vegetable Production - virtual meeting – VCE Joanne Jones, Sep 2, 2021
12. Kuhar, T. Southside, VA vegetable Production - meeting – Phenix, VA, Nov 17, 2021