Biology, Ecology and Management of Brown Marmorated Stink Bug in Orchard Crops, Small Fruit, Grapes, Vegetables and Ornamentals

Tracy C. Leskey, USDA-ARS, Appalachian Fruit Research Station, Kearneysville, WV 25430 USA

USDA-NIFA SCRI #2011-51181-30937

Building A Collaborative Team and Identifying Priorities

Grower And Consultant Experiences

Tree Fruit Grower

- Extreme damage to tree fruit and small fruit crops. May go out of business if things continue.

Crop Consultant

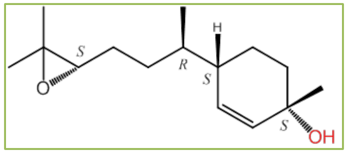
- Relying on mid- and late-season pyrethroids, creating a treadmill effect.
- Need a monitoring tools and control options that do not disrupt beneficials.

Organic Grower

- Severe damage on a range of fruiting vegetables including snap peas, green beans, heirloom and hybrid tomatoes, peppers, and raspberries. May have to stop growing particular crops.

Research Priorities

Studies of BMSB Biology, Behavior and Ecology



Identification of Aggregation Pheromone

Identification of Effective Biological Control Agents

Identification of Effective Insecticides

Standardized Sampling/Monitoring Techniques

Landscape-Level Threat To Crops

USDA-NIFA SCRI CAP

Specialty Crop Research Initiative

FY 2011 Request for Applications

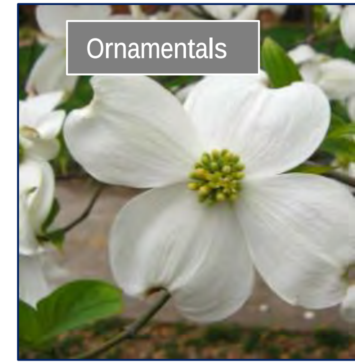
APPLICATION DEADLINE: January 31, 2011

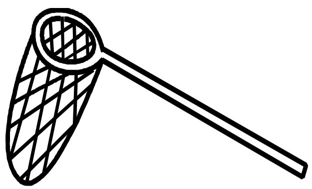
USDA U.S. Department of Agriculture
National Institute of Food and Agriculture

- Bring together a multi-state, multi-institutional, trans-disciplinary team to integrate scientific discoveries with practical application; and provide complementary extension efforts to bring science-based information to relevant audiences.

- Reduce duplication of efforts and integrate activities among individuals, institutions, states, and regions.

Broad Expertise Needed For Project





IPM

Insect Behavior

Horticulture

Field Ecology

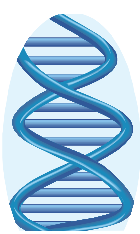
Biological Control

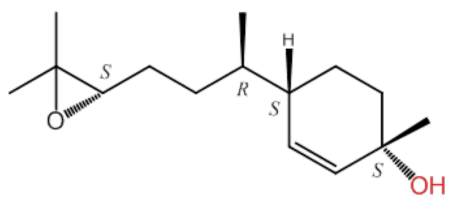
Economics

Taxonomy

Chemical Ecology

Plant Pathology





Molecular Genetics

Sociology

Host Plant Resistance

Extension/ Outreach

BMSB SCRI CAP Team

Tracy C. Leskey
Doo-Hyung Lee
Kim Hoelmer
Aijun Zhang
Ashot Khrimian
Christine Dieckhoff
Rob Morrison
Jana Lee
Peter Landolt

Tom Kuhar
Chris Bergh
Doug Pfeiffer
Eric Day

Carrie Koplinka-Loehr
Steve Young

Greg Krawczyk
Shelby Fleischer
Michael Saunders
Gary Felton
John Tooker
David Biddinger
Jayson Harper
Steve Jacobs

Jay Brunner
Betsy Beers
Doug Walsh

Arthur Agnello

George Hamilton
Anne Nielsen
Cesar Rodriguez-Saona
Dean Polk

Jim Walgenbach
Mark Abney
George Kennedy

Peter Shearer
Vaughn Walton
Silvia Rondon
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Nik Wiman
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Cerruti Hooks
Galen Dively
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Holly Martinson
Mike Raupp
Paula Shrewsbury
Leslie Pick
Ray St. Leger
Bryan Butler
Gerry Brust
Karen Rane
Amanda Buchanan
Guihua Chen
Dennis van Englesdorp
Dilip Venugopal

Joanne Whalen
Brian Kunkel

BMSB SCRI CAP Objectives

- As the threat to U.S. agriculture posed by spreading BMSB populations continues to increase, there is no established detection method, treatment threshold, or control strategy for BMSB in any cropping system.

- Therefore, we propose to:
- (1) establish biology and phenology of BMSB in specialty crops;
- (2) develop monitoring and management tools for BMSB;
- (3) establish effective management programs for BMSB in specialty crops;
- (4) integrate stakeholder input and research findings to form and deliver practical outcomes.

Notification of Award

Biology, Ecology, and Management of Brown Marmorated Stink Bug in Orchard Crops, Small Fruit, Grapes, Vegetables, and Ornamentals

The review panel grouped proposals into one of the relative categories below. The percentage indicates the final distribution of proposals in each category.

Recommended for Funding:

Outstanding %	18
High Priority %	26
Medium Priority %	18
Low Priority %	22

Not Recommended for Funding:

Some Merit %	14
Do Not Fund %	4

Original Project	(2011-2014)	$5,739,966
Renewal Project	(2014-2016)	$5,158,928
Total Project	(2011-2016)	$10,898,894

This proposal was placed in : Outstanding and ranked as : 1

Specialty Crop Research Initiative - PANEL SUMMARY

The panel decision regarding your proposal is based on the input provided by the reviews and the collected expertise and judgment of the individual panel members. This panel summary reflects the consensus opinion of the panel regarding your proposal.

Proposal Number: 2011-01413 Project Director: Leskey

Proposal Title: Biology, Ecology, and Management of Brown Marmorated Stink Bug in Orchard Crops, Small Fruit, Grapes, Vegetables, and Ornamentals

Positive Aspects of the Proposal
The review panel felt this is an important issue that needs to be urgently addressed. The research and extension team is impressive and with adequate expertise, with as much experience as can be expected when dealing with a relatively new pest. There is evidence of strong stakeholder and political support, as well as a strong advisory panel. The team is well organized, which made the panel confident that this team can be successful.

The proposal covers several disciplines and aspires to integrate them in a systems approach. This proposal should produce valuable information currently lacking, about the biology, extent of damage, and the efficacy of a wide array of management strategies in a potentially large number of commodities. The panel liked that the team included a list of potential limitations and pitfalls, and reasonable ways to address them if necessary.

Progress Made By BMSB SCRI CAP Team

Established BMSB Risk, Phenology, and Damage Symptoms in Specialty Crops

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Accepted for publication 20 April 2012. Published 23 May 2012.

The Pest Potential of Brown Marmorated Stink Bug on Vegetable Crops

Thomas P. Kuhar and **Katherine L. Kamminga,** Department of Entomology, Virginia Tech, Blacksburg, VA 24061; **Joanne Whalen**, Department of Entomology and Wildlife Ecology, University of Delaware, Newark, DE 19716; **Galen P. Dively, Gerald Brust,** and **Cerruti R. R. Hooks,** Department of Entomology, University of Maryland, College Park, MD 20742; **George Hamilton,** Department of Entomology, Rutgers University, New Brunswick, NJ 08901; and **D. Ames Herbert,** Virginia Tech Tidewater Agricultural Research and Extension Center, Suffolk, VA 23437

Corresponding author: Thomas P. Kuhar. tkuhar@vt.edu

Kuhar, T. P., Kamminga, K. L., Whalen, J., Dively, G. P., Brust, G., Hooks, C. R. R., Hamilton, G., and Herbert, D. A. 2012. The pest potential of brown marmorated stink bug on vegetable crops. Online. Plant Health Progress doi:10.1094/PHP-2012-0523-01-BR.

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Fig. 1), is an invasive insect from east Asia that was first reported in the USA near Allentown, PA, in the late 1990s (3). Since that time, the pest has spread rapidly across the United States, although significant pest densities and concomitant crop damage have largely remained centered in the mid-Atlantic from New Jersey to Virginia (2). The insect is highly polyphagous (1) and has been reported as a serious pest of tree fruit in the United States (4,2), but its damage and risk to vegetable crops has not been well documented to date. Herein, we report our observations from the mid-Atlantic United States on the relative pest risk that *H. halys* poses to vegetable crops.


Fig. 5. Severe infestations of brown marmorated stink bug can result in total loss of fruiting vegetable crops.


Fig. 6. Brown marmorated stink bug feeding scars on tomato fruit.


Fig. 7. Spongy area left by stink bug feeding on bell pepper.

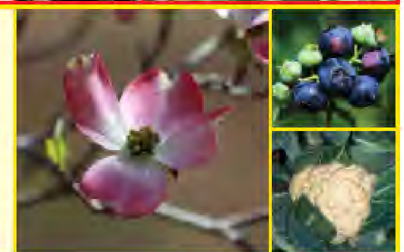

Fig. 8. Brown marmorated stink bug feeding scars on bell pepper.


Fig. 9. Brown marmorated stink bug feeding injury on eggplant.


Fig. 10. Brown marmorated stink bug feeding injury on okra.

Specialty Crops at Risk to BMSB Damage

HIGH RISK	apple, Asian pear, beans (green, pole, snap), bee-bee tree, edamame, eggplant, European pear, grape[1], hazelnut, Japanese pagoda tree, nectarine, okra, peach[2], Peking tree lilac, pepper, redbud, sweet corn, Swiss chard, tomato
MODERATE RISK	apricot, asparagus, blueberries[1,3], broccoli, cauliflower, cherry[2], collard, cucumber, flowering dogwood, horseradish, lima bean, littleleaf linden, serviceberry, tomatillo
LOW RISK	blackgum, carrot, cranberries, garlic, ginkgo, greens, Japanese maple, kohlrabi, kousa dogwood, leeks, lettuce, many gymnosperms, onion, potato, spinach, sweet potato, turnip
UNKNOWN	almond, citrus, hops, kiwi, olive, pistachio, plum, strawberries, walnut
HOSTS — Non-Specialty Crop BMSB Hosts Contributing to Specialty Crops Risk	field corn, soybean



1—Potential risk of taint/contamination. 2—Additional risk potential due to bark feeding. 3—Considered moderate-high risk.

About BMSB

The brown marmorated stink bug, *Halyomorpha halys* (Stål), is a voracious eater that damages fruit, vegetable, and ornamental crops in North America. With funding from USDA's Specialty Crop Research Initiative, our team of more than 50 researchers is uncovering the pest's secrets to find management solutions that will protect our food, our environment, and our farms.

Learn more at **StopBMSB.org**.

USDA

Stop BMSB

Funded by USDA-NIFA SCRI Coordinated Agricultural Project, grant #2011-51181-30937. Image credits—sweet corn: Joe Zlomek; eggplant: Howard F. Schwartz, Colorado State University, Bugwood.org; apple, carrots: morguefile.com/creative/bekahboo42; flowering dogwood: Richard Floyd, Creative Ideas LLC, Bugwood.org; blueberries, cauliflower: Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org; ginkgo: Jan Samanek, State Phytosanitary Administration, Bugwood.org; cranberries: Cjboffoli (CC-BY-3.0). Printed May 2015.

Host Plants of BMSB Includes >170 Records

made by collaborating researchers

Biology, ecology, and management of brown marmorated stink bug in specialty crops

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Host Plants of the Brown Marmorated Stink Bug in the U.S.

Print this page

A publication of the Brown Marmorated Stink Bug IPM Working Group in conjunction with the Northeastern IPM Center

Contributing authors (in alphabetical order):
Erik Bergmann, Karen M. Bernhard, Gary Bernon, Matthew Bickerton, Stanton Gill, Chris Gonzales, George C. Hamilton, Chris Hedstrom, Katherine Kamminga, Carrie Koplinka-Loehr, Greg Krawczyk, Thomas P. Kuhar, Brian Kunkel, Jana Lee, Tracy C. Leskey, Holly Martinson, Anne L. Nielsen, Michael Raupp, Peter Shearer, Paula Shrewsbury, Jim Walgenbach, Joanne Whalen, and Nik Wiman

Brown marmorated stink bug adults feeding through the bark of an elm tree (Ulmus sp.) (photo: M. Raupp)

Since its initial discovery in eastern Pennsylvania in the mid-1990s, the invasive brown marmorated stink bug (BMSB, *Halyomorpha halys* [Heteroptera: Pentatomidae]) has become a conspicuous insect in residential areas and farms in the mid-Atlantic U.S. As part of several ongoing research projects, entomologists have been observing which plants this insect typically uses for food and reproduction in its new environment. BMSB is a tree-loving bug but has a very broad host plant range. We have observed it on hundreds of plant species in Delaware, Maryland, New Jersey, North Carolina, Oregon, Pennsylvania, Virginia, and West Virginia.

In the spring, BMSB adults emerge from overwintering sites and become active during warm sunny days. During this time, adult bugs can be found on virtually any plant that exposes them to the sun. Trees, shrubs, and ornamental plants that are near BMSB overwintering shelters often serve as the best places to observe early bug activity. Tall plants and trees tend to have more bugs on them than plants lower to the ground. As adult bug activity increases throughout the month of May and as mating, egg laying, and nymphal development occurs throughout the summer, BMSB can be found on a wide range of plant species (Table 1). Plants bearing reproductive structures, such as fruiting bodies, buds, and pods, tend to have more bugs than plants without these parts. Furthermore, BMSB prefers certain species of plants more than others, often at particular times during the growing season. These plants, listed in boldface in Table 1, may provide the most suitable habitat and/or nutrition for BMSB. The list of host plants for this bug will undoubtedly grow as the pest spreads to new regions.

Table 1. Plants hosting BMSB adults and immature stages in the United States. Plant species in bold represent those with the highest densities of bugs in a given habitat.

Habitat*	Genus	Species	Common Name	Image
Orn.	*Abelia*	*× grandiflora*	glossy abelia	
Agric.	*Abelmoschus*	*esculentus*	okra	
Orn.	*Acer*	*buergerianum*	trident maple	📷
Orn.	*Acer*	*circinatum*	vine maple	
Orn.	*Acer*	*japonicum*	Amur (Japanese Downy) maple	

Insecticide Efficacy and Management Programs

Effective Short-Term Mitigation Strategies adopted on >85,000 acres of specialty crops

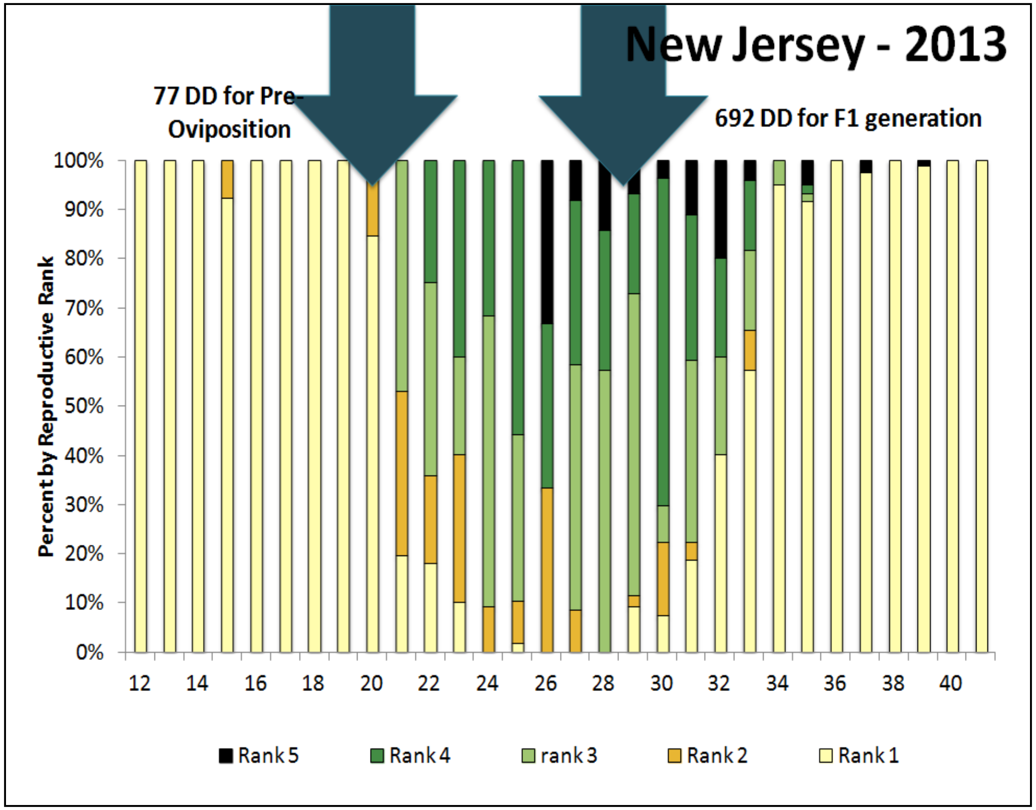
Table 2. Lethality index of each candidate insecticide as well as the initial efficacy rating and the change in efficacy over the 7-d trial

Rank	Insecticide	Class[a]	Lethality index	Initial efficacy[b] (E_0)	Efficacy change[c] (E_7 - E_0)
1	Dimethoate	O	93.3	High	Stable
2	Malathion	O	92.5	High	Stable
3	Bifenthrin	P	91.5	High	Stable
4	Methidathion	O	90.4	High	Stable
5	Endosulfan	—	90.4	Moderate	Increasing
6	Methomyl	C	90.1	High	Stable
7	Chlorpyrifos	O	89.0	Moderate	Increasing
8	Acephate	O	87.5	Moderate	Increasing
9	Fenpropathrin	P	78.3	High	Stable
10	Permethrin	P	77.1	High	Stable
11	Dinotefuran	N	67.3	High	Stable
12	Kaolin clay + Thiamethoxam	—	66.7	High	Stable
13	Gamma-cyhalothrin	P	64.2	High	Decreasing
14	Formetanate HCl	C	63.5	Moderate	Stable
15	Thiamethoxam	N	56.3	High	Stable
16	Clothianidin	N	55.6	High	Stable
17	Beta-cyfluthrin	P	54.8	High	Decreasing
18	Lambda-cyhalothrin	P	52.9	High	Decreasing
19	Zeta-cypermethrin	P	52.1	High	Decreasing
20	Cyfluthrin	P	49	High	Decreasing
21	Oxamyl	C	46.8	Moderate	Stable
22	Esfenvalerate	P	43.3	Moderate	Decreasing
23	Imidacloprid	N	39.2	Moderate	Increasing
24	Tolfenpyrad (SC)	—	36.5	Moderate	Increasing
25	Tolfenpyrad (EC)	—	33.3	Moderate	Decreasing
26	Pyrifluquinazon	—	28.3	Low	Increasing
27	Kaolin clay	—	23.1	Low	Increasing
28	Diazinon	O	20.4	Low	Increasing
29	Phosmet	O	20.0	Low	Increasing
30	Acetamiprid	N	18.8	High	Decreasing
31	Thiacloprid	N	18.3	Moderate	Stable
32	Abamectin	—	16.3	Low	Increasing
33	Indoxacarb	—	11.3	Low	Increasing
34	Spirotetramat	—	9.8	Low	Increasing
35	Carbaryl	C	9.0	Low	Increasing
36	Flonicamid	—	7.7	Low	Increasing
37	Cyantraniliprole	—	1.7	Low	Stable

[a] C, carbamates; N, neonicotinoids; O, organophosphates; P, pyrethroids; —, others; EC, emulsifiable concentrate; SC, suspension con-

Voltinism – Generations Per Year

ONE generation per year in northerly locations, and TWO in the Mid-Atlantic and Pacific Northwest



Overwintering Ecology in the Natural Landscape

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Characterization of Overwintering Sites of the Invasive Brown Marmorated Stink Bug in Natural Landscapes Using Human Surveyors and Detector Canines

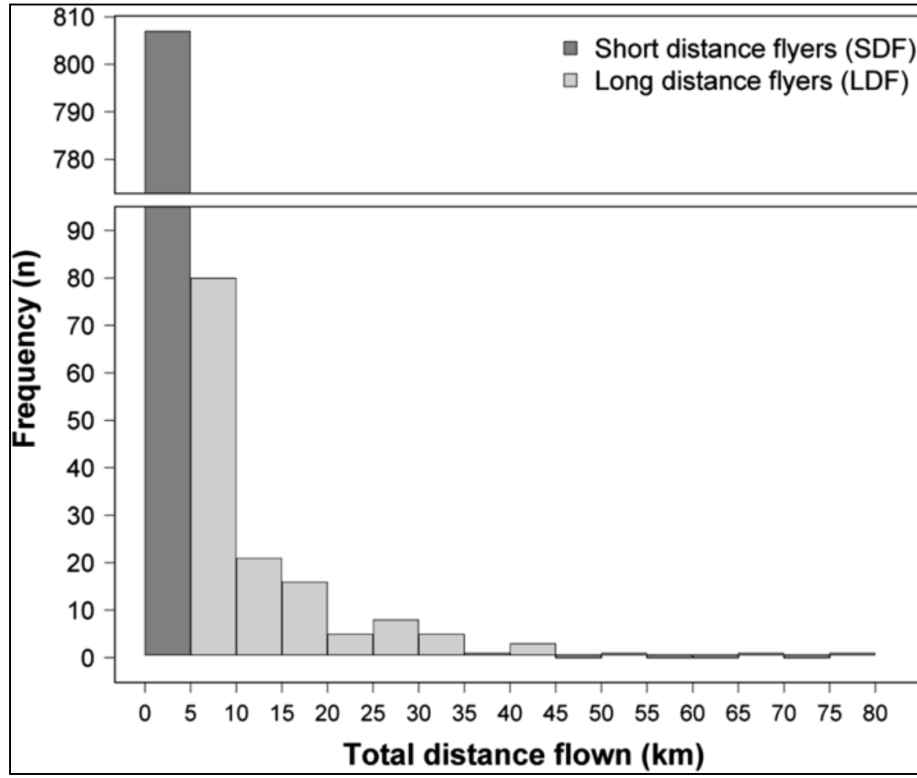
Doo-Hyung Lee[1*¤], John P. Cullum[2], Jennifer L. Anderson[3], Jodi L. Daugherty[3], Lisa M. Beckett[3], Tracy C. Leskey[1]

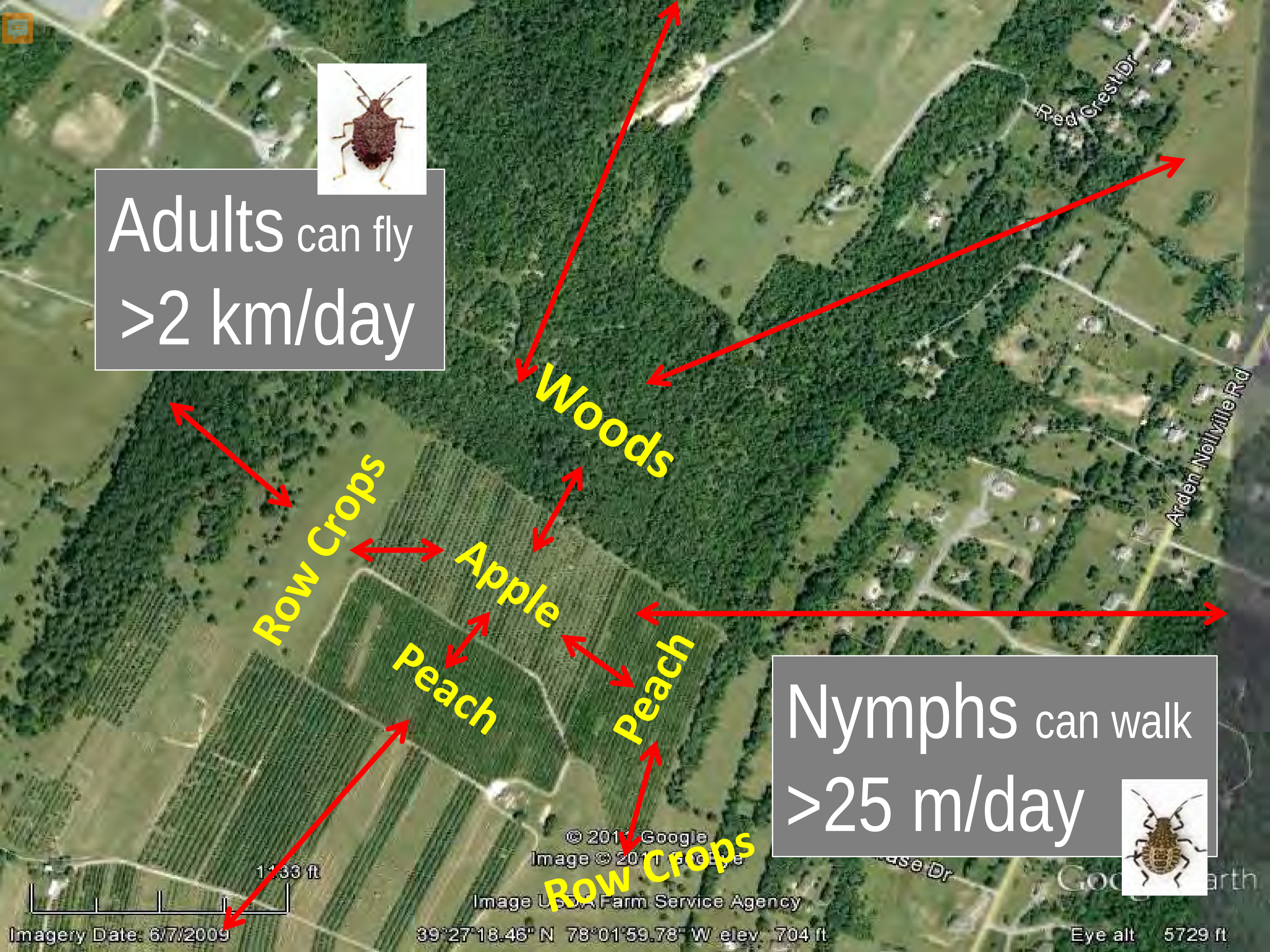
1 U.S. Department of Agriculture – Agricultural Research Service, Appalachian Fruit Research Station, Kearneysville, West Virginia, United States of America, 2 Department of Entomology, Virginia Tech, Winchester, Virginia, United States of America, 3 U.S. Department of Agriculture – Animal and Plant Health Inspection Service, National Detector Dog Training Center, Newnan, Georgia, United States of America

Dispersal Capacity of Adults and Nymphs

Factors affecting flight capacity of brown marmorated stink bug, Halyomorpha halys *(Hemiptera: Pentatomidae)*

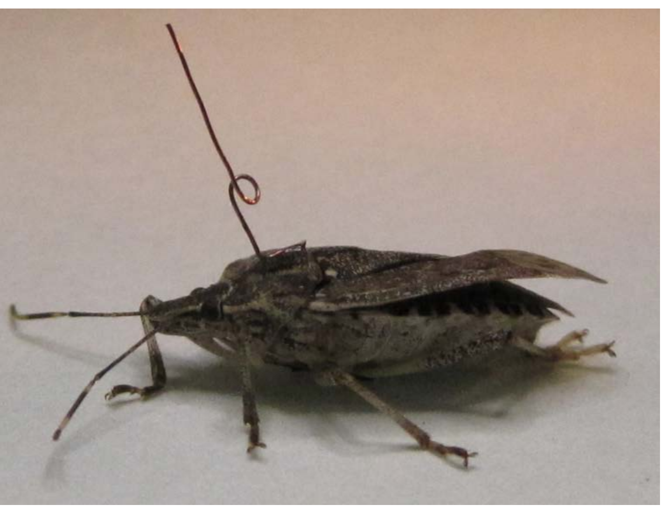
Nik G. Wiman, Vaughn M. Walton, Peter W. Shearer, Silvia I. Rondon & Jana C. Lee





Adults can fly
>2 km/day
Woods
Row Crops
Apple
Peach
Peach
Row Crops
Nymphs can walk
>25 m/day
Red Crest Dr
Arden Nollville Rd
1133 ft
Imagery Date: 6/7/2009
39°27'18.46" N 78°01'59.78" W elev 704 ft
Eye alt 5729 ft

Identifying Risk Factors For Spread and Establishment



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Landscape Factors Facilitating the Invasive Dynamics and Distribution of the Brown Marmorated Stink Bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), after Arrival in the United States

Adam M. Wallner[1]*, George C. Hamilton[2], Anne L. Nielsen[2], Noel Hahn[2], Edwin J. Green[3], Cesar R. Rodriguez-Saona[2]

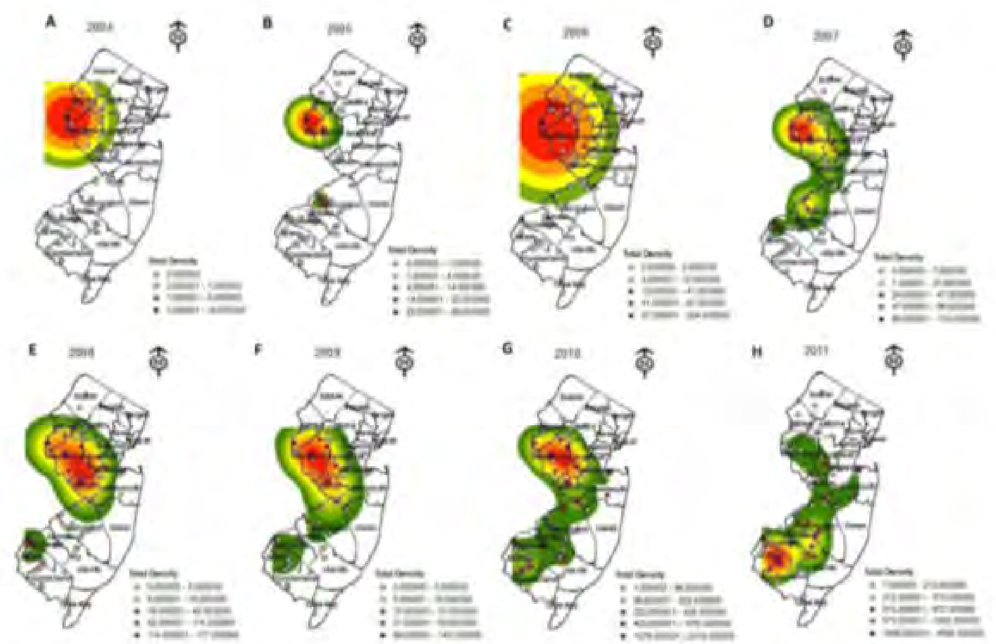

Figure 2. Kernel Density Estimation (KDE) graphs of the density of *Halyomorpha halys* captured from black light traps placed throughout New Jersey from (A) 2004, (B) 2005, (C) 2006, (D) 2007, (E) 2008, (F) 2009, (G) 2010, (H) 2011. KDE are based on actual and predicted density of *H. halys* where green reflects lowest population density, orange moderate to high population density, and red predicts highest population of *H. halys*. Total density of *H. halys'* for year black lights were monitored is also provided.
doi:10.1371/journal.pone.0095691.g002

BMSB can be monitored successfully throughout the U.S. season-long using pheromone-baited traps

Discovery of the Aggregation Pheromone of the Brown Marmorated Stink Bug (*Halyomorpha halys*) through the Creation of Stereoisomeric Libraries of 1-Bisabolen-3-ols

Ashot Khrimian,*[†] Aijun Zhang,[†] Donald C. Weber,[†] Hsiao-Yung Ho,[‡] Jeffrey R. Aldrich,[†,§] Karl E. Vermillion,[⊥] Maxime A. Siegler,[‖] Shyam Shirali,[†] Filadelfo Guzman,[†] and Tracy C. Leskey[∇]

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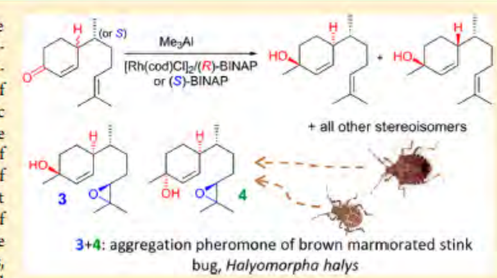
Supporting Information

ABSTRACT: We describe a novel and straightforward route to all stereoisomers of 1,10-bisaboladien-3-ol and 10,11-epoxy-1-bisabolen-3-ol via the rhodium-catalyzed asymmetric addition of trimethylaluminum to diastereomeric mixtures of cyclohex-2-enones **1** and **2**. The detailed stereoisomeric structures of many natural sesquiterpenes with the bisabolane skeleton were previously unknown because of the absence of stereoselective syntheses of individual stereoisomers. Several of the bisabolenols are pheromones of economically important pentatomid bug species. Single-crystal X-ray crystallography of underivatized triol **13** provided unequivocal proof of the relative and absolute configurations. Two of the epoxides, (3S,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol (3), and



Attraction of the Invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) to Traps Baited with Semiochemical Stimuli Across the United States

TRACY C. LESKEY,[1,2] ARTHUR AGNELLO,[3] J. CHRISTOPHER BERGH,[4] GALEN P. DIVELY,[5] GEORGE C. HAMILTON,[6] PETER JENTSCH,[7] ASHOT KHRIMIAN,[8] GRZEGORZ KRAWCZYK,[9] THOMAS P. KUHAR,[10] DOO-HYUNG LEE,[11] WILLIAM R. MORRISON III,[1] DEAN F. POLK,[12] CESAR RODRIGUEZ-SAONA,[6] PETER W. SHEARER,[13] BRENT D. SHORT,[1] PAULA M. SHREWSBURY,[5] JAMES F. WALGENBACH,[14] DONALD C. WEBER,[8] CELESTE WELTY,[15] JOANNE WHALEN,[16] NIK WIMAN,[17] AND FARUQUE ZAMAN[18]

Gut Symbionts, Transcriptome, and Salivary Proteins

Novel Approaches for Management

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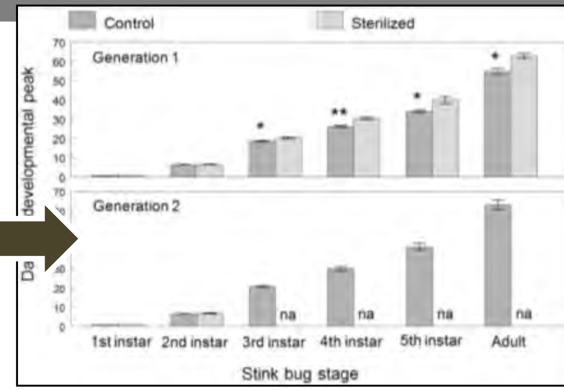
The Importance of Gut Symbionts in the Development of the Brown Marmorated Stink Bug, *Halyomorpha halys* (Stål)

Christopher M. Taylor*, Peter L. Coffey, Bridget D. DeLay, Galen P. Dively

University of Maryland, Department of Entomology, College Park, Maryland, United States of America



RESEARCH ARTICLE Open Access

Rapid transcriptome sequencing of an invasive pest, the brown marmorated stink bug *Halyomorpha halys*

Panagiotis Ioannidis[1,4], Yong Lu[2], Nikhil Kumar[1], Todd Creasy[1,5], Sean Daugherty[1], Marcus C Chibucos[1,3], Joshua Orvis[1], Amol Shetty[1], Sandra Ott[1], Melissa Flowers[1], Naomi Sengamalay[1], Luke J Tallon[1], Leslie Pick[2] and Julie C Dunning Hotopp[1,3*]

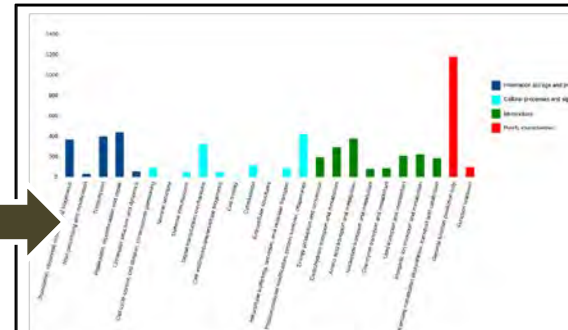


Figure 3. Transcript functional categories. The NCBI Cluster of Orthologous Groups (COG) database was used to classify the predicted proteins in the 13,211 representative transcripts. Assignment of COG categories showed that a large number of ORFs belonged to categories of proteins whose functions are poorly characterized, namely those that have general function prediction only and those

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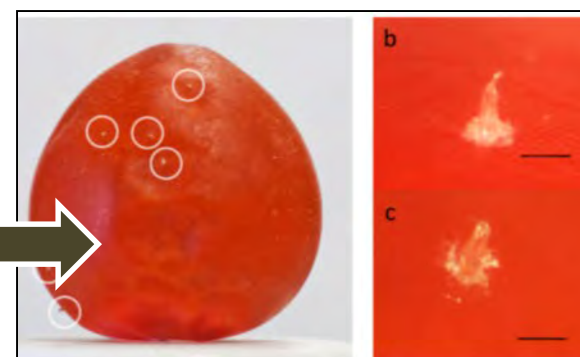
Insights into the Saliva of the Brown Marmorated Stink Bug *Halyomorpha halys* (Hemiptera: Pentatomidae)

Michelle Peiffer, Gary W. Felton*

Department of Entomology, Penn State University, University Park, Pennsylvania, United States of America



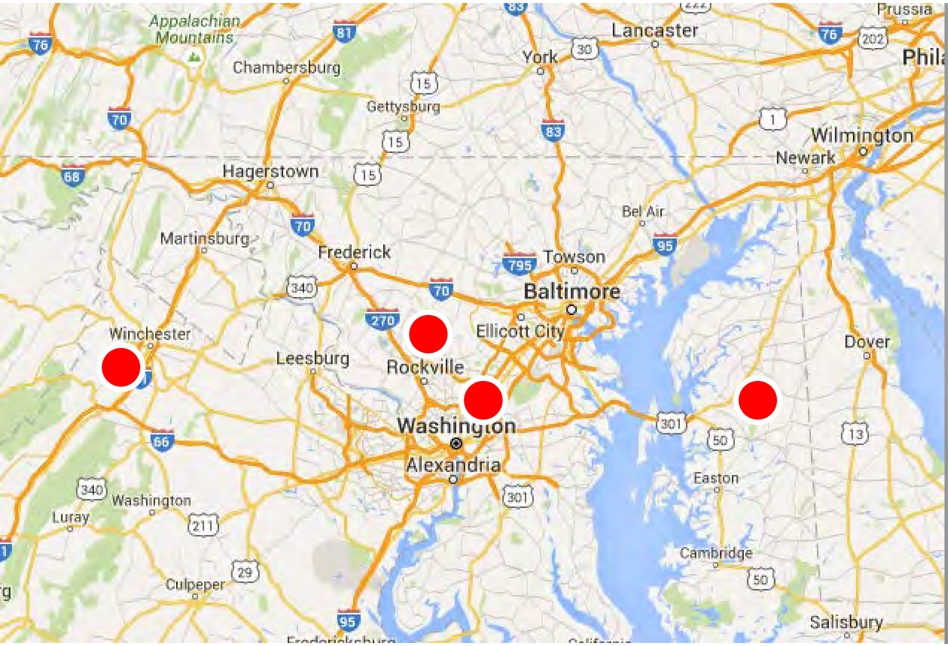
Biological Control Offers Long-Term Landscape-Level Solutions

Native Predators and Parasites

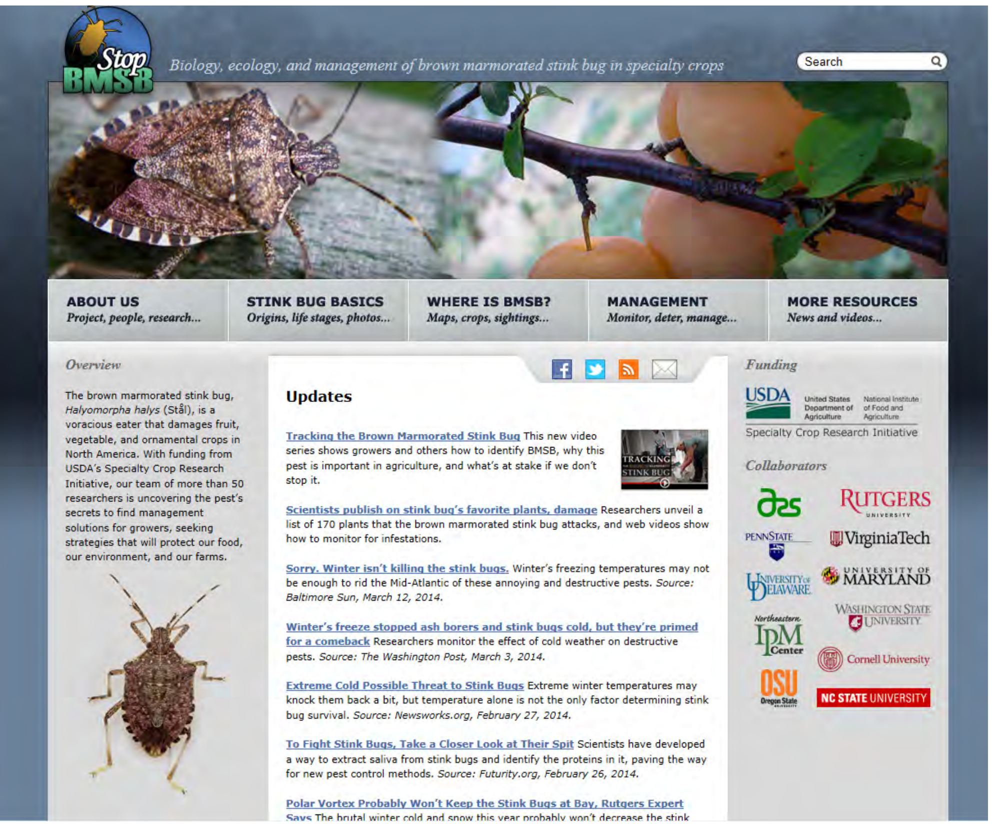
Classical Biological Control

Biological Control Game Changer?

Trissolcus japonicus found in MD in 2014 and MD, VA and OR in 2015



BMSB Outreach Efforts include >50,000 stakeholder contacts, >150,000 via online efforts, and millions more through popular press

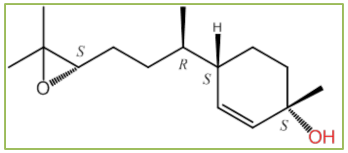


Key Personnel Trained

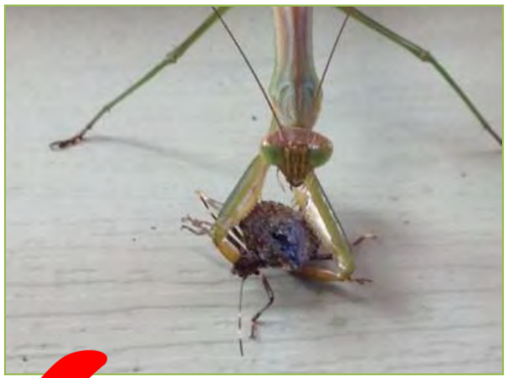
Undergraduates and H.S.	Graduate Students	Post-Docs and Visiting Scholars	Technical Staff
147	39	30	43

Research Priorities

Studies of BMSB Biology, Behavior and Ecology



Identification of Aggregation Pheromone



Identification of Effective Biological Control Agents

Identification of Effective Insecticides

Standardized Sampling/Monitoring Techniques

Pending Questions

- Invasion ecology and pest status? *Establishment in other regions of the country – southeast is rapidly increasing, west coast areas and continued pressure in the mid-Atlantic and conversely, areas where it seems limited – Eastern coastal plains, northern locations. Influence of abiotic factors (high/low temperature, daylength, humidity). Multiple introductions?*
- Phenology and impact on other specialty crops? *Hops, olive, kiwi, citrus, nut crops (almond, pecan, walnut, pistachio), and tomato. (strawberry and plum?). Adult vs nymphal contribution and damage diagnostics for numerous crops*
- Biology and population ecology in various regions? *Diapause, voltinism, reproduction, model validation and refinement? Methods developed, but not well characterized yet.*
- Early spring biology and ecology? *What happens when they leave an overwintering site? Reproduction? Feeding? Dispersal and fate?*
- Mid season biology and ecology? *What triggers movement between hosts? Host quality? Volatiles? Etc.*
- Late season biology and ecology? *What triggers dispersal from hosts to an overwintering site? What behavioral events?*
- Contribution of wild and non-specialty crop hosts on overall populations? *Influence of acceptable hosts and their density on overall populations.*
- Optimized methods for rearing BMSB colonies? *Food, conditions, identifying issues (pathogens).*
- Conventional and organic insecticides for specialty crops? *Identifying insecticides for additional specialty crops (nut crops, citrus, olives). Impacts on beneficials?*
- Non-neonic programs? *If regulatory changes occur, how will we manage in their absence?*
- Optimization of pheromone lures for monitoring and management? *Improved synthetic pathways for main component, optimized ratio of pheromone/synergist, release rates, distance of response, management (attract and kill, baited trap crops)*
- Key native natural enemies and their conservation in different regions and cropping system? *Vary across regions and near crops, how to best promote and conserve them*
- Impact of *T. japonicus*? Did it survive, distribution, biology and ecology, impact on natives?
- Optimized trapping methods for various specialty crops? *Different trap types may be best for different specialty crops*
- Fungal pathogens? *Can we overcome the difficulty for fungi penetrating cuticle and potential for defensive compounds to reduce viability?*
- Cultural Techniques? *Exclusion, host removal?*
- Incorporating and integrating tools into a single crop and across crops? *Some orchard crops (apples, peaches) are working on this, but much more to do.*
- Development and validation of tools in other specialty crops? *Fruiting vegetable crops and many others.*
- Farmscape-level managment? *Based on identified risk factors, can we integrate tools and improve management (host removal and natural enemy promotion/conservation, attract-and-kill, for example).*
- Area-wide management? *Implementing landscape-level management tactics (T. japonicus, for example) to reduce overall populations and decrease grower-level inputs into specialty crop production.*
- Resistance management ? *Establish baseline levels and monitor potential development in different area of US.*
- Economics of BMSB? *Programs with integrated tools? Production of pheromone depending on synthetic pathway, loading, ratios, etc. Cost of and potential ROI for conventional tactics and classical biological control program, Damage estimates over time?*
- Longitudinal grower surveys? *Adoption of new tactics and technology, mitigation of damage due to knowledge (identification of adults and nymphs)?*
- Sustained delivery of information? *As new information is generated, integrate with existing and utilize at a national level.*
- Connection with and feedback from longtime and new stakeholders? *As new information is generated, integrate with existing and utilize at a national level.*

Pending Questions

- Invasion ecology and pest status? *Establishment in other regions and continuing pressure in existing range. Influence of abiotic factors (temperature, daylength, humidity). Multiple introductions?*
- Non-neonic programs? *If regulatory changes occur, how will we manage in their absence?*
- IPM Programs? *Based on identified risk factors, can we integrate tools and improve management (decision support tools, host removal, natural enemy promotion/conservation, attract-and-kill).*
- Area-wide management? *Implementing landscape-level management tactics (T. japonicus, for example) to reduce overall populations and decrease grower-level inputs into specialty crop production.*
- Sustained delivery of information? *As new information is generated, integrate with existing and utilize at a national level.*

Future Project Directions

- Continued cooperative, collaborative and integrated approach to research and Extension on a national level.
- Developing IPM-based strategies including trap-based treatment thresholds, border sprays, cultural control, behavioral control, etc.
- Strong emphasis on long-term, landscape-level solutions including conservation biological control as well as classical biological control.

Acknowledgements

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- Collaborating Growers, Extension Agents and Crop Consultants
- Collaborating Commercial Companies