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

Funding

USDA

United States Department of Agriculture

National Institute of Food and Agriculture

Specialty Crop Research Initiative

Grant #2011-01413-30937

Collaborating Institutions

University of Delaware

ars

Penn State

Rutgers, The State University of New Jersey

Northeastern IPM Center

Washington State University

Cornell University

Oregon State University

University of Maryland

Virginia Tech

NC State University

StopBMSB.org

Goals of the BMSB SCRI CAP Team

Our long-term goals for this project are to develop economically and environmentally sustainable pest management practices for the brown marmorated stink bug (BMSB), Halyomorpha halys (Stål), in specialty crops and to implement a coordinated, rapid delivery system to disseminate critical information generated from this project to specialty crop end-users.

Timeline and Funding

- Originally funded in 2011 for 3 years at $5.7 million. Funding from September 2011 – September 2014. Coincided with expiration of existing Farm Bill.

- Farm Bill passed and renewal application submitted in Spring 2014. Received two additional years of support. Funded in full with a 7% sequestration in second year. Total funding for renewal at $5.1 million.

- Matching costs through Year 4 (2015).

- Submitted and received final year funding. Grant ends August 31, 2016.

  Total project funding = $10,898,894.

Purpose of Stakeholder Advisory Panel

- The Stakeholder Advisory Panel (SAP) will meet annually to review project accomplishments, provide feedback on research plans, and guide the execution of objectives.
- The SAP will provide an overall assessment of the project and recommendations for future research and outreach efforts.
- Based on input from the SAP, we will modify objectives or procedures to ensure that the needs of specialty crop stakeholders are best served and the risk posed by BMSB is mitigated.
- Final (5^{th}!) meeting of BMSB SCRI CAP SAP.

Original Grant Objectives

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.

Renewal Grant Objectives

1. Expand current knowledge of BMSB biology, ecology and behavior in specialty crops.

2. Develop and refine monitoring and management tools for BMSB.

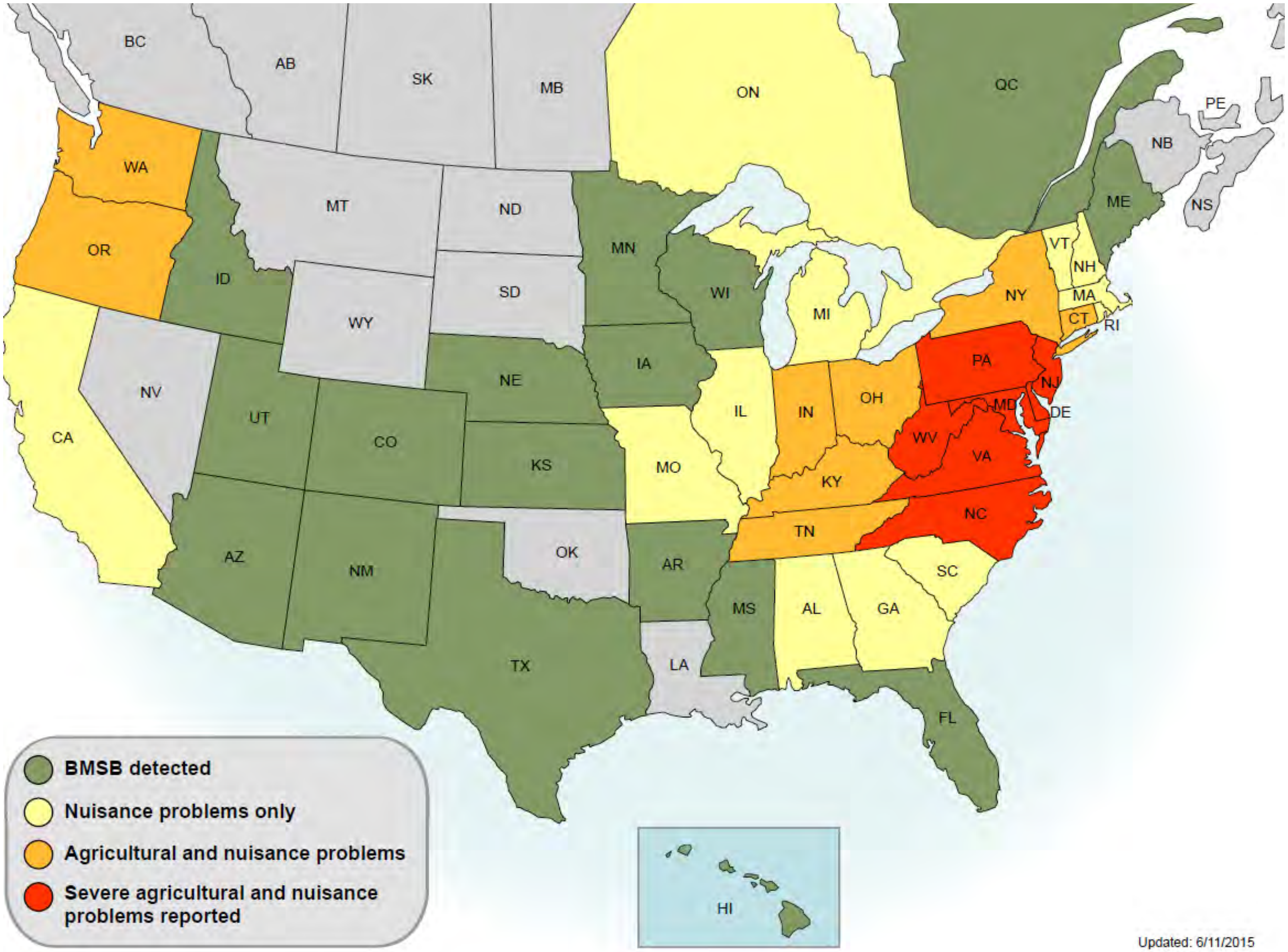
3. Improve existing BMSB management programs and transfer information to other at-risk specialty crops.

4. Integrate stakeholder input and research findings to form and deliver practical outcomes.

Regulatory Issues

- Section 18s for Tree Fruit
  - Renewal of Section 18 for Dinotefuran (easy to add new states)
  - Renewal of Section 18 for Bifenthrin (difficult to add new states)
- 2012 was the last year for endosulfan use in peaches. Apples through 2015.
- Uncertainty surrounding neonicotinoids and pollinators.
- Continued progress in host specificity screening for classical biological control program. *Trissolcus japonicus* found in MD, VA and WA. Christine Dieckhoff will provide an update today.

Current Distribution of BMSB in North America



BMSB SCRI Management

- Project Director
  - Tracy Leskey – USDA

- Institutional PDs
  - Tracy Leskey - USDA
  - Art Agnello – Cornell
  - George Hamilton – Rutgers
  - Greg Krawczyk – PSU
  - Joanne Whalen – UD
  - Cerruti Hooks – UMD
  - Jim Walgenbach – NCSU
  - Peter Shearer - OSU
  - Betsy Beers (replaced Jay Brunner) - WSU
  - Tom Kuhar (replaced Chris Bergh) – VT
  - Steve Young (replaced Carrie Koplinka-Loehr) – NE IPM Center

- Commodity Team Leadership
  - Chris Bergh – Orchard Crops
  - Tom Kuhar – Vegetables
  - Anne Nielsen (replaced Doug Pfeiffer) - Grapes
  - Cesar Rodriguez-Saona – Small Fruit
  - Paula Shrewsbury – Ornamentals

- Subobjective Leaders / Liaisons

- Project Support Assistant
  - Donna Joy hired in January 2014. Replaced Teresa Mersing.

Institutional Annual Reports

- Technical Summary of Progress
- Outlined Experimentation for Upcoming Period
- Barriers to Success
- Key Personnel Trained (post-docs, graduate students, undergrads)
- Research and Extension Products (talks, posters, workshops, publications)
- New/Leveraged Funding
- Media Contacts

Institutional Progress

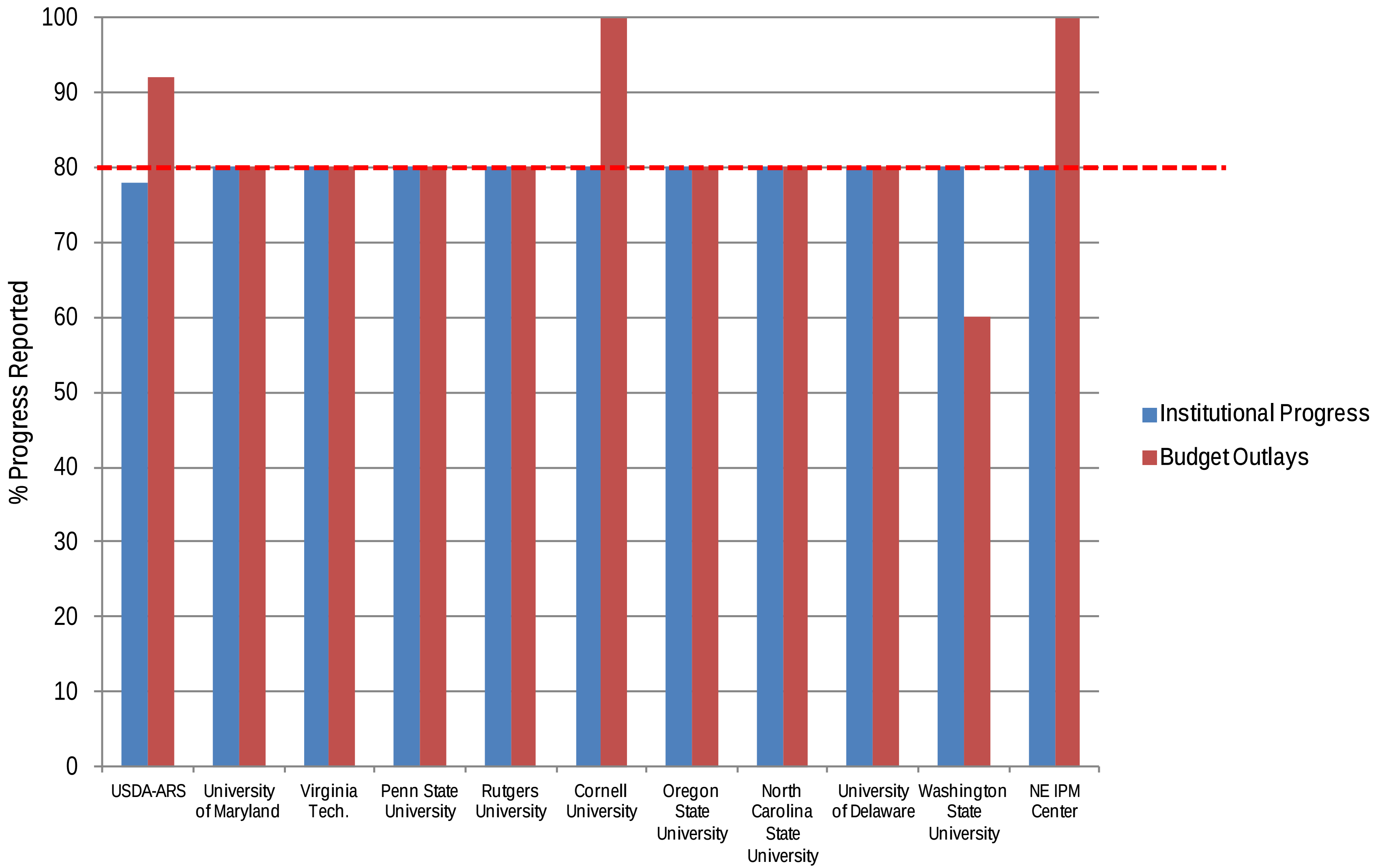
General Institutional Progress

- [ ] 0% (Project Under Development)
- [ ] 20% (Year 1 Objectives Completed)
- [x] 40% (Year 2 Objectives Completed)
- [ ] 60% (Year 3 Objectives Completed)
- [ ] 80% (Year 4 Objectives Completed)
- [ ] 100% (Project Close-Out Initiated)

Subaward Budget Outlays

- [ ] <20% of Project Total
- [ ] 20%-40% of Project Total
- [ ] 40%-60% of Project Total
- [ ] 60%-80% of Project Total
- [x] 80%-100% of Project Total
- [ ] Over Subaward Budget

Institutional Progress



Overall Project Progress

- Progress
  - Calculated based proposed effort x progress reported per institution. Then summed across ALL institutions.

$$\boxed{\Sigma \text{ (Proposed Institutional Effort) x (\% Accomplished)}}$$

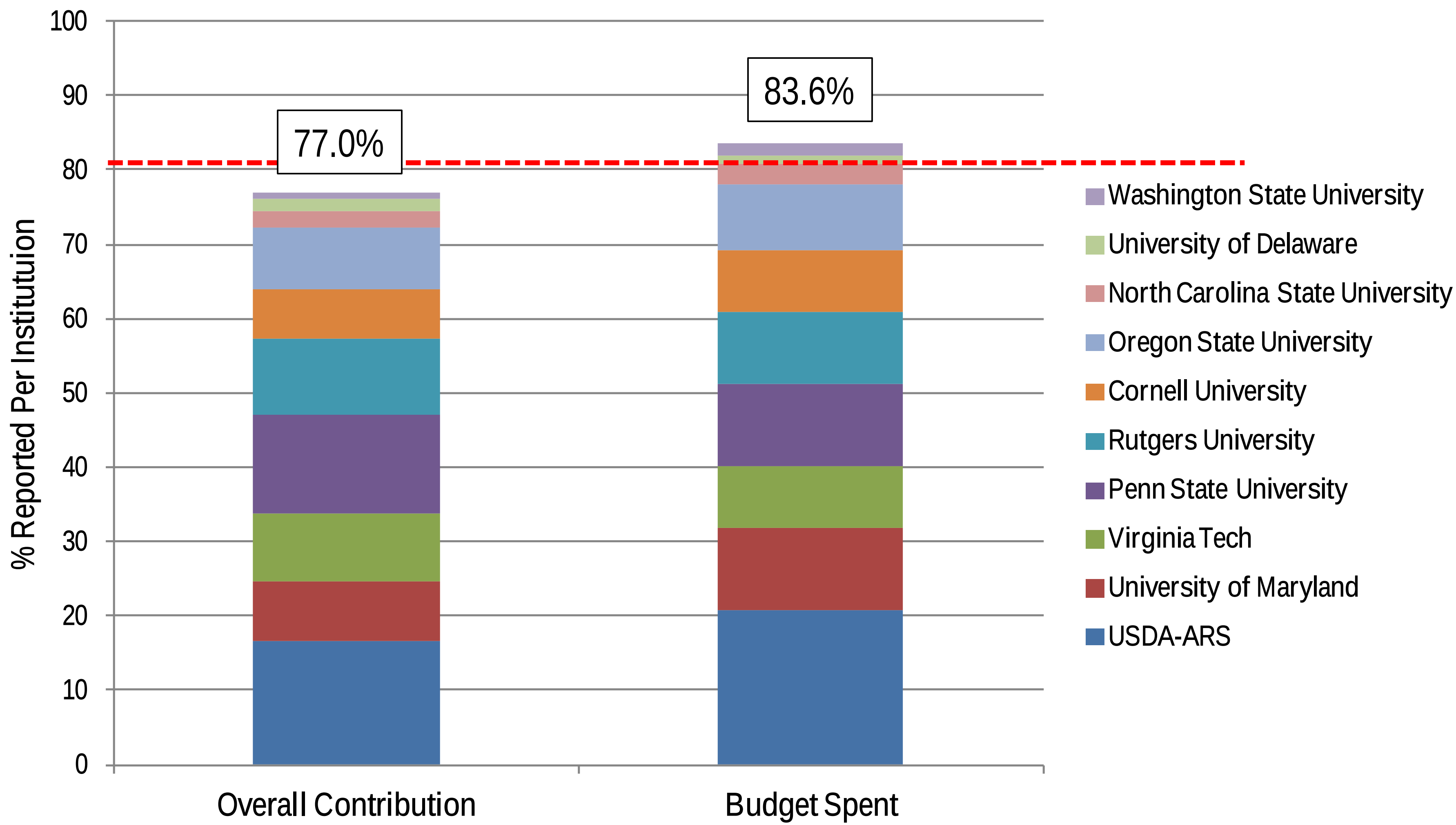
  - ex., Cornell
    - 8.47 (Proposed Effort) x 25.0 (% Accomplished) = 2.12 (toward overall progress)

- Budget Consumed
  - Calculated based proportional budget x subaward used per institution. Then summed across ALL institutions.

$$\boxed{\Sigma \text{ (Proportional Institutional Budget) x (\% Subaward consumed)}}$$

  - ex., Virginia Tech
    - 10.45 (proportion of budget) x 37.5 (consumed) = 3.92 (toward overall budget consumption)

Overall Project Progress



Individual Objective Progress

Progress Toward Accomplishment of Individual Objectives

1.1.1. (Leskey)

Determining voltinism characteristics of BMSB.

Categorical Progress

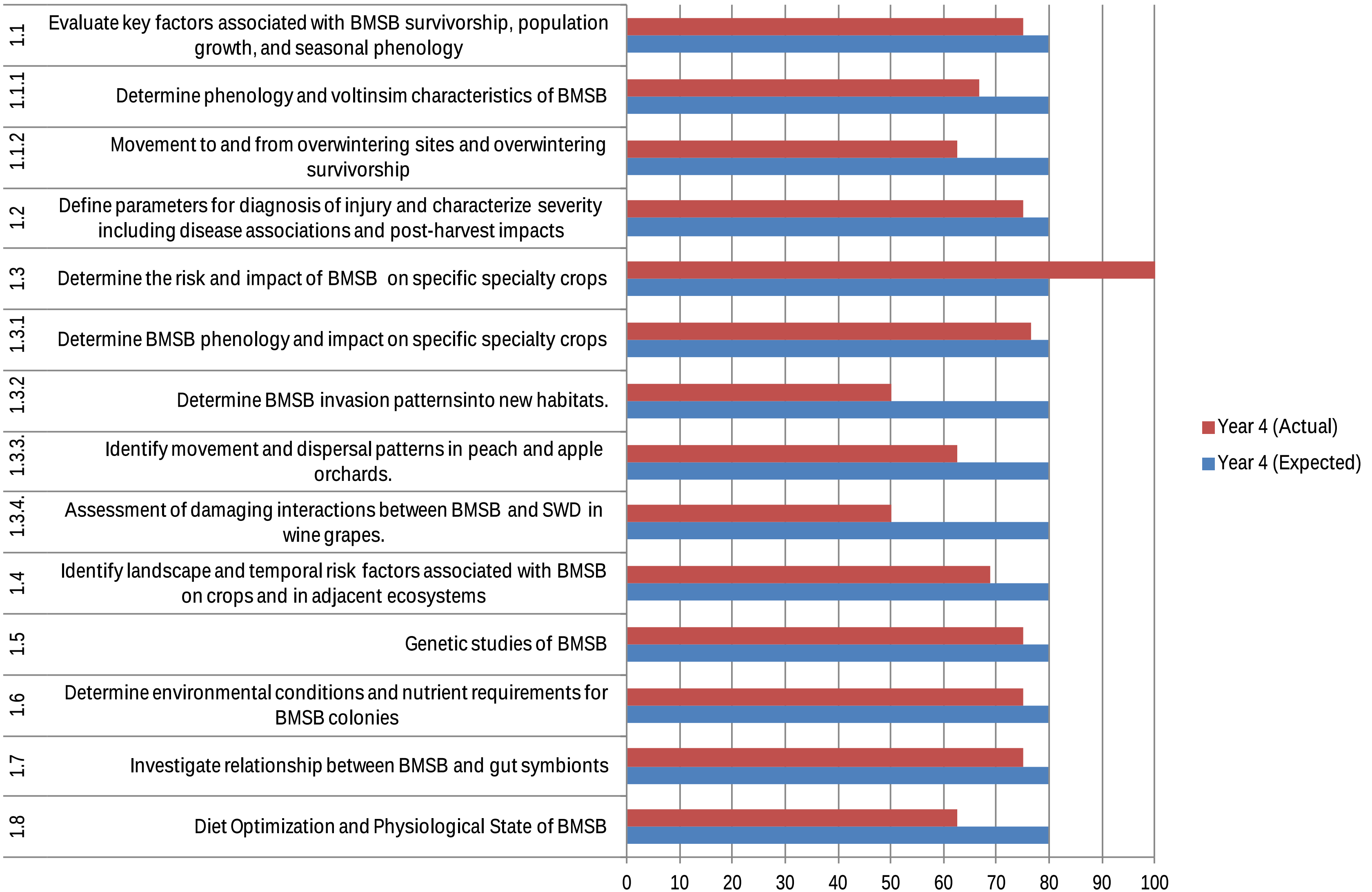
- ○ 0% (Under Development)
- ● 25% (Project Initiated)
- ○ 50% (Results Collected)
- ○ 75% (Data Analysis Completed)
- ○ 100% (Manuscript Completed)

Objective 1

- ORIGINAL   Establish biology and phenology of BMSB in specialty crops.

- RENEWAL   Expand knowledge of BMSB biology, ecology and behavior in specialty crops.

Objective 1. Establish biology and phenology of BMSB in specialty crops.



Objective 1 - Progress

- Sargent, C., H.M. Martinson, and M.J. Raupp. 2011. The Orient Express in Maryland: The Brown Marmorated Stink Bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). The Maryland Entomologist 5(3): 2-21. *Supports Original Obj. 1.3*
- Jentsch. P. 2012. The Unpredictable Brown Marmorated Stink Bug in New York State. NY Fruit Quarterly. 20(1): 11-15. *Supports Original Obj. 4.2*
- Kuhar, T.P., K.L. Kamminga, J. Whalen, G.P. Dively, G. Brust, C.R.R. Hooks, G. Hamilton, and D.A. Herbert. 2012. The pest potential of brown marmorated stink bug on vegetable crops. Online. Plant Health Progress doi:10.1094/PHP-2012-0523-01-BR *Supports Original Obj. 1.3.1*
- Leskey T.C., B.D. Short., B.B. Butler, and S.E. Wright. 2012. Impact of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) in mid-Atlantic tree fruit orchards in the United States: case studies of commercial management. Psyche. Article ID 535062, DOI:10.1155/2012/535062. *Supports Original Obj. 1.2.1*
- Martinson, H.M., P.M. Shrewsbury, and M.J. Raupp. 2013. Invasive stink bug wounds trees, liberates sugars, and facilitates native Hymenoptera. Annals of the Entomological Society of America 106: 47-52. *Supports Original Obj. 1.3*
- Timer, J., and M. Saunders. 2013. Meridic Diet for *Halyomorpha halys*. Journal of Entomological Science (accepted). *Supports Original Obj. 1.5*
- Bergh, J.C. 2013. Single insecticides targeting brown marmorated stink bug in apple, 2011. Arthropod Management Tests, Vol. 38: A2. Online publication. doi: 10.4182/amt.2013.A2
- Lee, D.-H., B.D. Short, S.V. Joseph, J.C. Bergh, and T.C. Leskey. 2013. Review of the biology, ecology, and management of *Halyomorpha halys* (Hemiptera: Pentatomidae) in China, Japan, and the Republic of Korea. Environmental Entomology 42: 627-641. *Supports Objective 1.1*
- Lee, D.-H., T.C. Leskey, and B.D. Short. 2014. Impacts of organic insecticides on the survivorship and mobility of brown marmorated stink bug (Hemiptera: Pentatomidae) in the laboratory. Florida Entomologist (In press) *Supports Original Obj. 2.2.1*
- Lee, D.-H., J.P. Cullum, J.L. Anderson, J.D. Daugherty, L.M. Beckett and T.C. Leskey. 2014. Characterization of overwintering sites of the invasive brown marmorated stink bug in natural landscapes using human surveyors and detector canines. PLOS ONE (DOI: 10.1371/journal.pone.0091575). *Supports Objective 1.1.2*
- Sargent, C., H. and M. J. Raupp. 2014. Traps and Trap Placement May Affect Location of Brown Marmorated Stink Bug (Hemiptera: Pentatomidae) and Increase Injury to Tomato Fruits in Home Gardens. (In Press) Environmental Entomology. *Supports Original Obj. 1.2.1.*
- Taylor, C.M, P.L. Coffey and G.P. Dively. 2014. The importance of gut symbionts in the development of the brown marmorated stink bug, *Halyomorpha halys* (Stål). PLOS One (in press). *Supports Original Obj. 1.5*
- Basnet, S., L.M. Maxey, C. Laub, T.P. Kuhar, and D.G. Pfeiffer. The stink bug (Hemiptera: Pentatomidae) community in primocane-bearing raspberries in southwestern Virginia. J. Entomol. Sci. (in press) *Supports Original Obj. 1.3.2*
- Peiffer, M., and G. Felton. 2014. Insights into saliva of the brown marmorated stink bug *Halyomorpha halys* (Hemiptera: Pentatomidae). PlosOne DOI: 10.1371/journal.pone.0088483 *Supports Original objective 2. 9 .*
- Xu J., D.M. Fonseca, G.C. Hamilton, K. A. Hoelmer, and A. L. Nielsen, 2014. Tracing the origin of US brown marmorated stink bugs, *Halyomorpha halys*. Biological Invasions 16:153-166. *Supports Original Objective 1.5*
- Wiman, N.G., V.M. Walton, P.W. Shearer, S.I. Rondon, J.C. Lee. 2014. Factors affecting flight capacity and invasive characteristics of brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae). J. Pest Science. (in press). *Supports Original Obj. 1.1.2*

Objective 1 - Progress

- Wallner, A.M., Hamilton, G.C., Nielsen, A.L., Hahn, N., Green, E., and Rodriguez-Saona, C.R. 2014. Landscape factors facilitating the invasive dynamics and distribution of the brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), after arrival in the United States. PLoS ONE (in press). <u>*Supports Original Obj. 1.4.*</u>
- Lee, D.-H., C.-G. Park, B.Y. Seo, G. Boiteau, C. Vincent, and T.C. Leskey. Detectability of *Halyomorpha halys* (Hemiptera: Pentatomidae) by portable harmonic radar in agricultural landscapes. Florida Entomologist (Submitted) <u>*Supports Objective 1.1.2*</u>
- DeLay, B.D., and W.O. Lamp. Bacterial symbionts on the invasive brown marmorated stink bug, *Halyomorpha halys*. Applied Environmental Microbiology (submitted). <u>*Supports Original Obj. 1.2.2.*</u>
- Joseph, S., J.W. Stallings, T.C. Leskey, G. Krawczyk, D. Polk, B. Butler, and J.C. Bergh. Spatial distribution of injury from brown marmorated stink bug (Hemiptera: Pentatomidae) at harvest in Mid-Atlantic apple orchards. For Journal of Economic Entomology. <u>*Supports Original Obj. 1.1.3*</u>
- Joseph, S., B.D. Short, T.C. Leskey, M. Nita, and J.C. Bergh. Injury to peaches and apples from brown marmorated stink bug (Hemiptera: Pentatomidae) following discrete exposure periods during the growing season. For Journal of Economic Entomology. <u>*Supports Original Obj. 1.1.3*</u>
- Zobel, E.S., G.P. Dively, and C.R. Hooks. In prep. Assessing the economic impact of brown marmorated stink bug on selected vegetable crops: relative attractiveness, reproductive suitability and plant injury. PLoS-One. <u>*Supports Original Obj. 1.3.1*</u>
- Wiman, N.G., V.M. Walton, P.W. Shearer, S.I. Rondon, J.C. Lee. Environmental controls on probing activity of brown marmorated stink bug, *Halyomorpha halys* (Stål). For PLOS ONE. <u>*Supports Original Obj. 1.3.1*</u>.
- Wiman, N.G., J. Parker, C. Rodriguez-Saona, and V.M. Walton. Characterizing damage and impacts of brown marmorated stink bug, *Halyomorpha halys* (Stål) on blueberries. For J. Econ. Entomol. <u>*Supports Original Obj. 1.2.1.*</u>
- Lee, D.-H., and T.C. Leskey. Dispersal capacity of foraging and overwintering *Halyomorpha halys* (Stål) populations. For Environmental Entomology. <u>*Supports Original 1.1.2.*</u>
- Martinson, H., Bergman, E. J. , P. M. Shrewsbury, and M. J. Raupp. In prep. Host phenology and colonization affect spatial patterns of *Halyomorpha halys* (Hemiptera: Pentatomidae). Ecological Entomology. <u>*Supports Original Obj. 1.3.1.*</u>
- Bergh, J.C. and T.C. Leskey. Emergence of overwintering brown marmorated stink bug from shelters deployed in natural settings. For Environmental Entomology. <u>*Supports Original Obj. 1.1.2.*</u>
- Acebes-Doria, A., T.C. Leskey, and J.C. Bergh. Effects of single and mixed diets on brown marmorated stink bug: Survivorship and development. For Environmental Entomology. <u>*Supports Original Obj. 1.1.1.*</u> Basnet, S., T.P. Kuhar, and D.G. Pfeiffer. BMSB varietal preference and injury to wine grapes in Virginia. For <u>*Plant Health Progress*</u> <u>*Supports Original Obj. 1.2.1.*</u>
- Basnet, S., T.P. Kuhar, and D.G. Pfeiffer. Phenology and population dynamics of BMSB in vineyards in Virginia. For J. Entomol. Sci. <u>*Supports Original Obj. 1.3.1.*</u>

Established BMSB Risk to and Phenology in Specialty Crops

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.

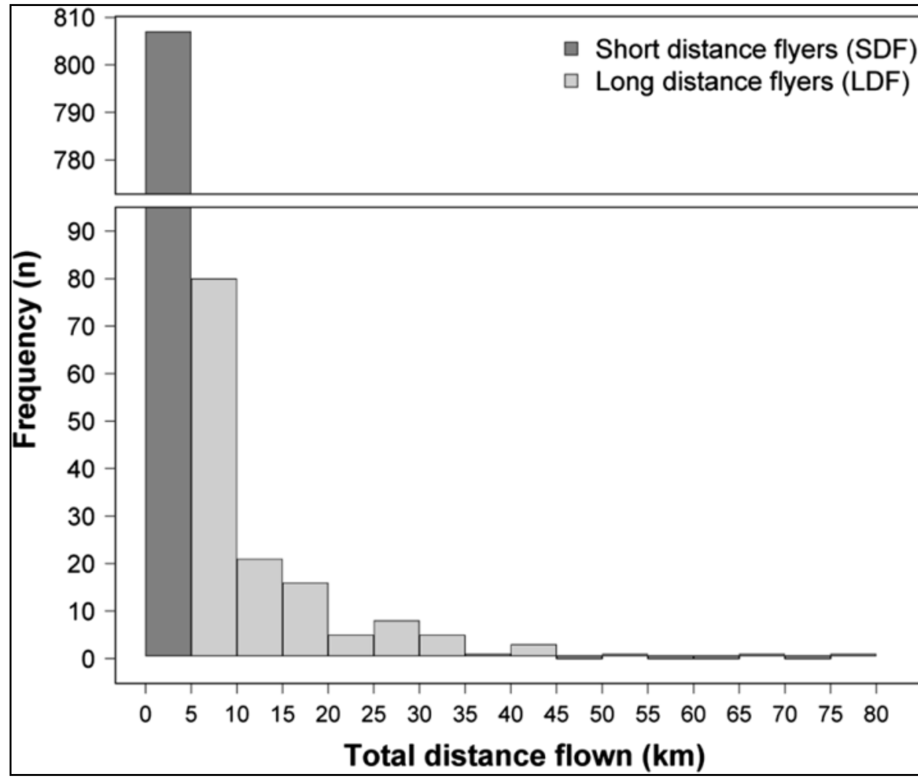
Fig. 9. Brown marmorated stink bug feeding injury on eggplant.

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

Dispersal Capacity

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



Overwintering Ecology in the Natural Landscape

OPEN ACCESS Freely available online

PLOS | ONE

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

Doo-Hyung Lee[1¤a], 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

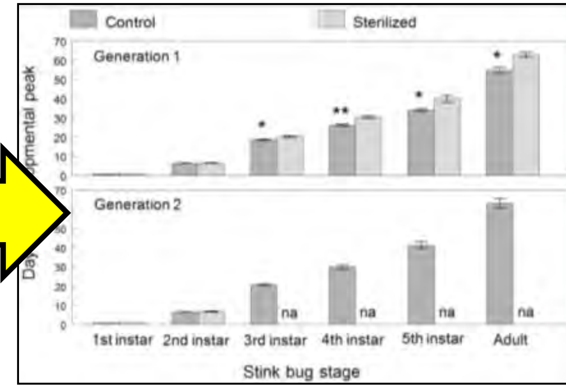
Gut Symbionts, Transcriptome, and Salivary Proteins

OPEN ACCESS Freely available online PLOS ONE

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*]

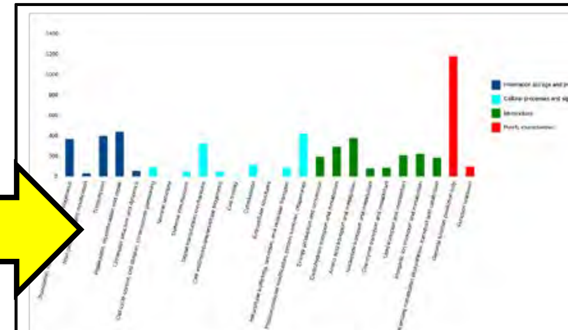


Figure 3. Transcript functional categories. The NCBI Cluster of Orthologous Groups (COG) database was used to classify the predicted proteins in the 13,211 representative transcripts. Assignment of COG categories showed that a large number of ORFs belonged to categories of proteins whose functions are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

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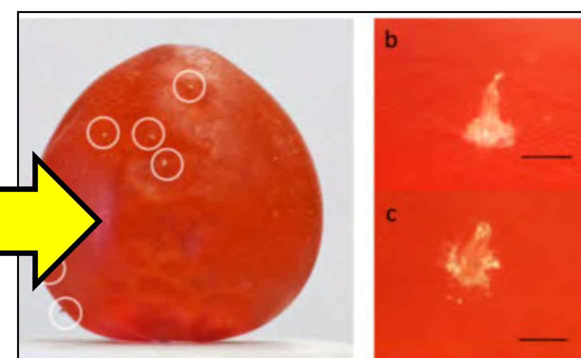
Insights into the Saliva of the Brown Marmorated Stink Bug *Halyomorpha halys* (Hemiptera: Pentatomidae)

Michelle Peiffer, Gary W. Felton*

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



Identified Risk Factors For Spread

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PLOS | ONE

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]

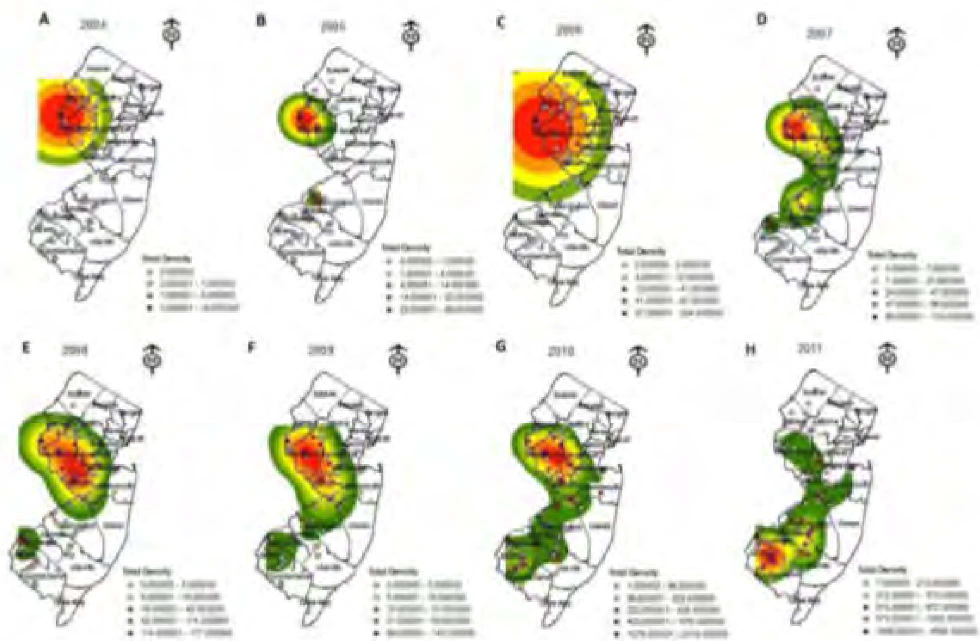
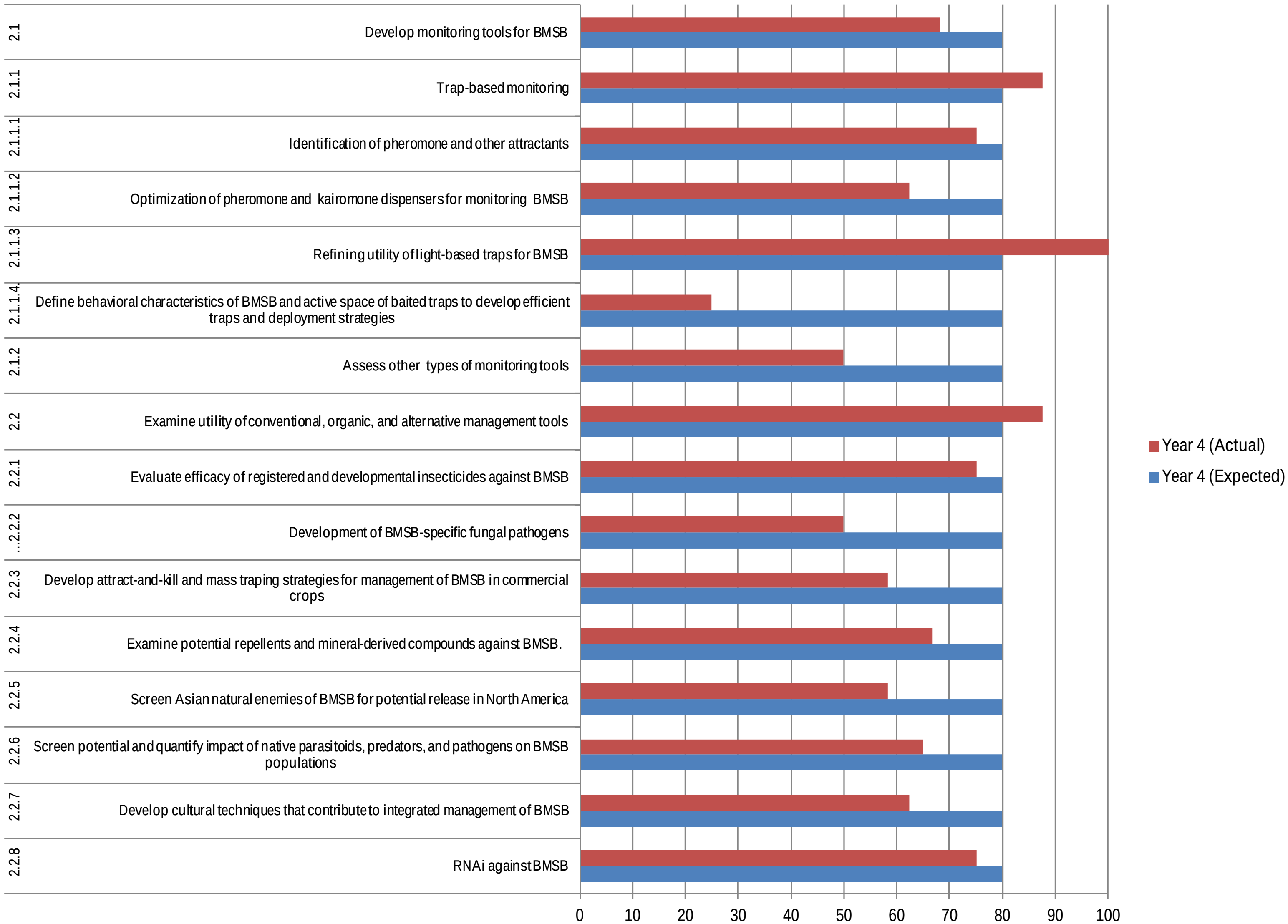


Figure 2. Kernel Density Estimation (KDE) graphs of the density of *Halymorpha halys* captured from black light traps placed throughout New Jersey from (A) 2004, (B) 2005, (C) 2006, (D) 2007, (E) 2008, (F) 2009, (G) 2010, (H) 2011. KDE are based on actual and predicted density of *H. halys* where green 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

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).*

Objective 2. Develop monitoring and management tools for BMSB.



Objective 2 - Progress

- Kamminga, K., T. Kuhar, A. Wimer and D. A. Herbert. 2012. Effects of the insect growth regulators novaluron and diflubenzuron on the brown marmorated stink bug. Online. Plant Health Progress doi:10.1094/PHP-2012-1212-01-RS. Supports Original Obj. 2.2.1
- Kuhar, T.P., K.L. Kamminga, J. Whalen, G.P. Dively, G. Brust, C.R.R. Hooks, G. Hamilton, and D.A. Herbert. 2012. The pest potential of 7. Leskey, T.C., D.-H. Lee, B.D. Short, and S.E. Wright. 2012. Impact of insecticides on the invasive Halyomorpha halys (Stål) (Hemiptera: Pentatomidae): analysis on the insecticide lethality. Journal of Economic Entomology. 105: 1726-1735. Supports Original Obj. 2.2.1
- Bergh, J.C. 2013. Alternate-row-middle applications of single insecticides targeting brown marmorated stink bug in apple, 2012. Arthropod Management Tests, Vol. 38: A3. Online publication doi: 10.4282/amt.2013. A3 Supports Original Obj. 2.2.1
- Bergh, J.C. 2013. Effect of an adjuvant on control of brown marmorated stink bug and other pests in apple, 2012. Arthropod Management Tests, Vol. 38: A4. Online publication. doi: 10.4182/amt.2013.A4. Supports Original Obj. 2.2.1
- Bergh, J.C. 2013. Single insecticides targeting brown marmorated stink bug in apple, 2011. Arthropod Management Tests, Vol. 38: A2. Online publication. doi: 10.4182/amt.2013.A2
- Hull, L.A., D. Biddinger, and G. Krawczyk. 2013. Large plot evaluations of various lepidopteran and brown marmorated stink bug tactics, 2012. Arthropod Management Tests, 38: Vol. 38: A9. Online publication. doi: 10.4182/amt.2013.A9 Supports Original Obj. 2.2.1
- Hull, L.A., G. Krawczyk, and D. Biddinger. 2013. Evaluations of products for internal Lepidoptera and brown marmorated stink bug control, 2012. Arthropod Management Tests, 38: Vol. 38: A7. Online publication. doi: 10.4182/amt.2013.A7 Supports Original Obj. 2.2.1
- Lee, D.-H., S.E. Wright, and T.C. Leskey. 2013. Impact of insecticide residue exposure on the invasive pest, Halyomorpha halys (Stål) (Hemiptera: Pentatomidae): analysis of adult mobility. Journal of Economic Entomology. 106(1): 150-158. Supports Original Obj. 2.2.1
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Chemical Ecology

JOURNAL OF NATURAL PRODUCTS

Article

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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[∇]

[†]U.S. Department of Agriculture, Agricultural Research Service, Beltsville Area, IIBBL, Maryland 20705, United States

[‡]The Institute of Cellular and Organismic Biology, Academia Sinica, Taipei, Taiwan 115

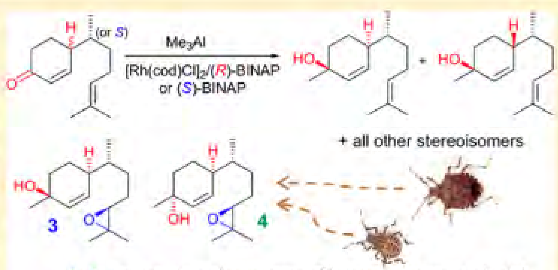
[⊥]U.S. Department of Agriculture, Agricultural Research Service, NCAUR, Peoria, Illinois 61604, United States

[∥]Department of Chemistry, Johns Hopkins University, Baltimore, Maryland 21218, United States

[∇]U.S. Department of Agriculture, Agricultural Research Service, AFRL, Kearneysville, West Virginia 25430, United States

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, (3*S*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol (**3**) and (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol (**4**), were identified as the main components of a male-produced aggregation pheromone of the brown marmorated stink bug, *Halyomorpha halys*, using GC analyses on enantioselective columns. Both compounds attracted female, male, and nymphal *H. halys* in field trials. Moreover, mixtures of stereoisomers containing epoxides **3** and **4** were also attractive to *H. halys*, signifying that the presence of additional stereoisomers did not hinder attraction of *H. halys* and relatively inexpensive mixtures can be used in monitoring, as well as control strategies. *H. halys* is a polyphagous invasive species in the U.S. and Europe that causes severe injury to fruit, vegetables, and field crops and is also a serious nuisance pest.



3+**4**: aggregation pheromone of brown marmorated stink bug, *Halyomorpha halys*

Insecticide Efficacy and Management Programs

EFFICACIES OF COMMON READY TO USE INSECTICIDES AGAINST *HALYOMORPHA HALYS* (HEMIPTERA: PENTATOMIDAE)

ERIK J. BERGMANN AND MICHAEL J. RAUPP*
University of Maryland, Department of Entomology, College Park, MD 20742, USA

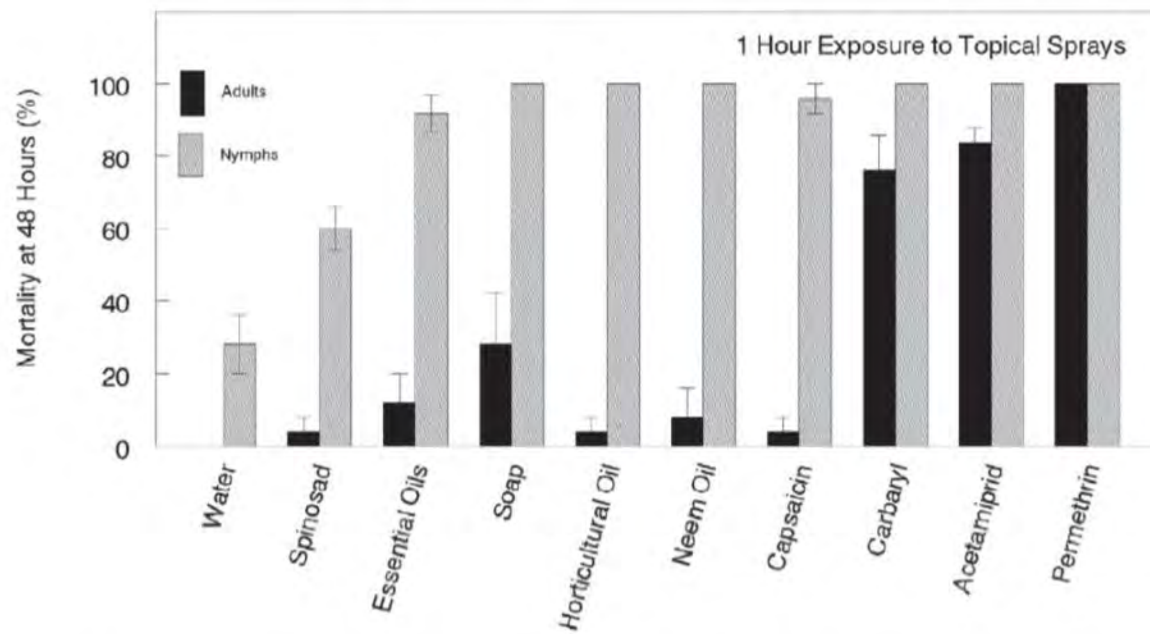


Fig. 1. Percentage mortality at 48 h post exposure of *H. halys* adults (black bars) and nymphs (gray bars) exposed to topical sprays of insecticides for 1 hour. Bars represent means and vertical lines are standard errors. Treatments differed significantly within each life stage (Kruskal - Wallis Analyses, $P < 0.0001$). Comparisons were not made between life stages.

Biological Control

Contents lists available at ScienceDirect

Biological Control

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

Sentinel eggs underestimate rates of parasitism of the exotic brown marmorated stink bug, *Halyomorpha halys*

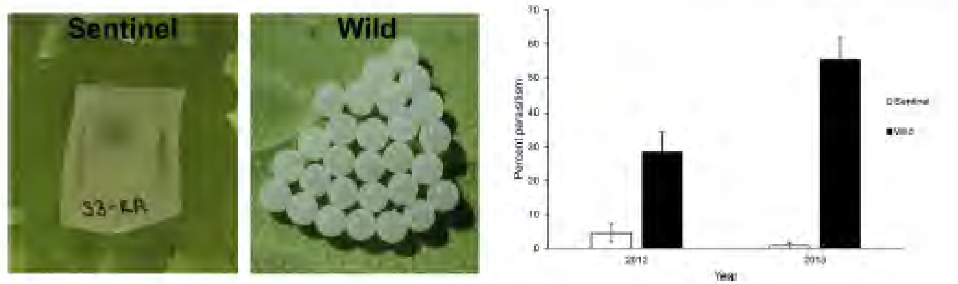
Ashley L. Jones, David E. Jennings, Cerruti R.R. Hooks, Paula M. Shrewsbury *

Department of Entomology, University of Maryland, 4112 Plant Sciences Building, College Park, MD 20742, USA

HIGHLIGHTS

- We compared parasitism of wild (field-laid) and sentinel (laboratory-laid) eggs.
- Wild egg masses had higher parasitism, parasitoid abundance and species richness.
- *Anastatus reduvii* was the most common parasitoid species overall.
- Sentinel egg masses underestimate parasitoid communities and impact.
- Wild egg masses should be used for estimating biological control impacts.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 May 2014
Accepted 28 July 2014
Available online 7 August 2014

Keywords:
Biological control
Native parasitoids
Invasive species
Pentatomidae
Ornamental nursery crops

ABSTRACT

Native to eastern Asia, the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), has become a serious invasive pest in North America. Consequently, accurate assessment of parasitism rates under field conditions is critical for determining baseline parasitism rates of native egg parasitoids on BMSB, and for future evaluations of native or exotic parasitoid biological control release strategies and impacts. BMSB sentinel (laboratory-laid) egg masses have typically been used for this purpose, even though they could be providing misleading estimates of parasitoid activity. Accordingly, we compared the use of BMSB sentinel (laboratory-laid) and wild (naturally field-laid) egg masses in 2012 and 2013 to examine rates of parasitism and the parasitoid community composition of indigenous egg parasitoids in outdoor ornamental nurseries. Wild egg masses consistently had higher rates of parasitism than sentinel egg masses. In 2012, wild egg masses had a mean percent parasitism of 28.4% compared to 4.6% in sentinel egg

Pending Questions

- 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?*

Objective 3

- ORIGINAL Establish effective management programs for BMSB in specialty crops

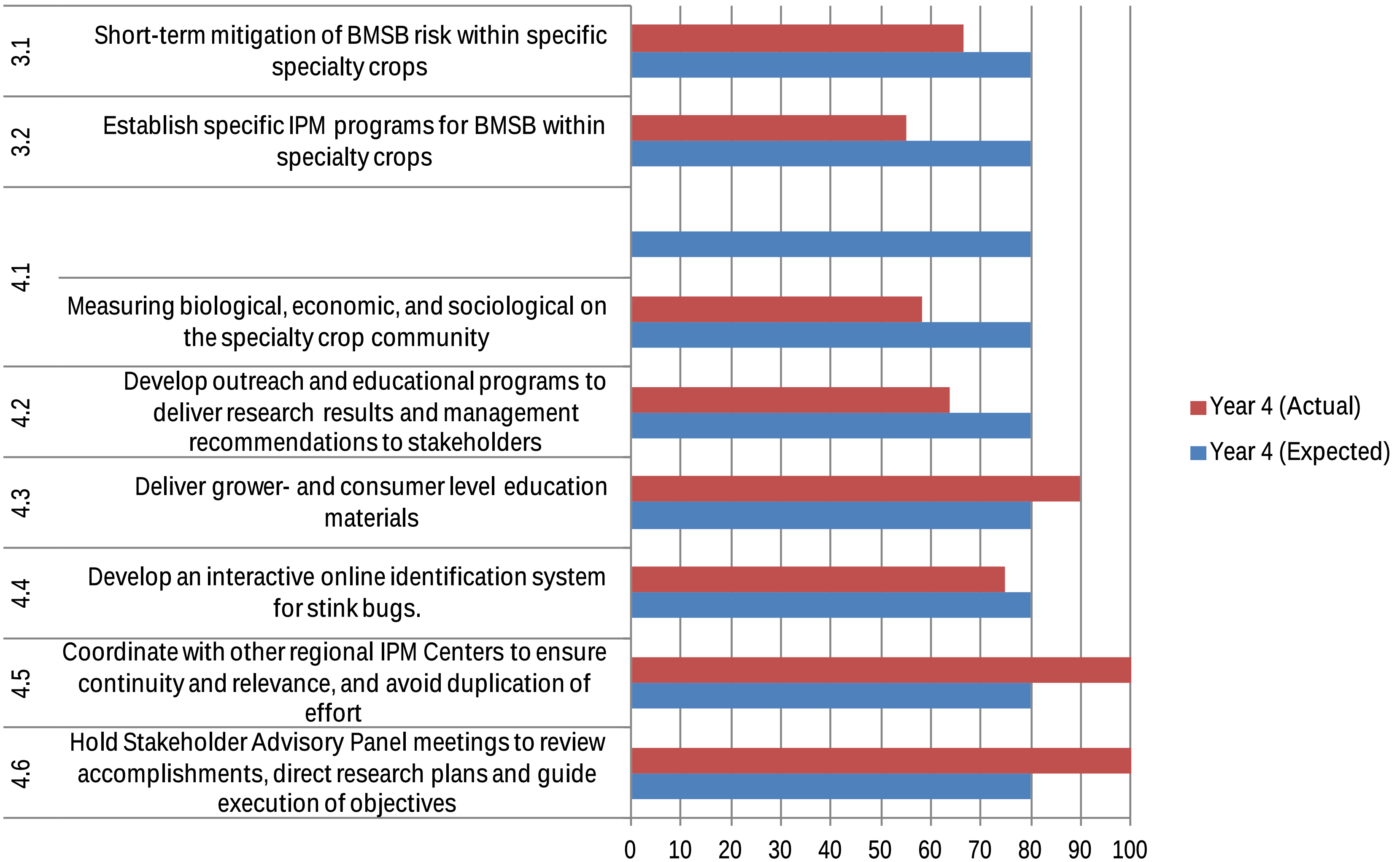
- RENEWAL Improve existing BMSB management programs and transfer information to other at-risk specialty crops

Objective 4

- ORIGINAL Integrate stakeholder input to form and deliver practical outcomes.

- RENEWAL Integrate stakeholder input to form and deliver practical outcomes.

Objective 3. Establish effective management programs for BMSB in specialty crops *and* Objective 4. Integrate stakeholder input and research findings to form and deliver practical outcomes



Objective 3 - Progress

CURRENT STATE We are on the cusp of integrating tactics.

- **Defining Risk Factors** Use monitoring traps (pheromone and/or light-based) in conjunction with geospatial analyses to define risk factors based on proximity to sources of BMSB infestation. (adjacent wild or cultivated plants, overwintering sites) and to better develop spatially precise management plans.
- **Phenology and Degree-Day Models** Use Monte Carlo-based phenology and degree-day models to predict emergence and BMSB phenology within specific regions, specialty crops, and general agroecosystems.
- **Trap-Based Monitoring** Use optimized trap designs and attractants to detect presence, abundance, and monitor seasonal activity
- **Treatment Thresholds** Correlate levels of BMSB abundance with subsequent damage to provide information critical to making informed pest management decisions for BMSB
- **Chemical Control** Utilize insecticides found to be effective, economical and compatible with other IPM tactics. If necessary, utilize fungicides to diminish secondary rot problems associated with BMSB feeding sites. Minimize use of non-selective materials to reduce the risk of exacerbating secondary pest problems (Jones et al. 2009) or risks to pollinators and natural enemies.
- **Border Sprays** Treating only borders of specialty can reduce insecticide use by up to 75%, causing a direct decrease in grower production costs and increase the sustainability of agroecosystems by providing refugia for natural enemies and reducing likelihood of secondary pest outbreaks.
- **Biological Control** Utilize practices that encourage presence and increased abundance of effective biological control agents (based on conservation or classical biological control program if foreign agents are approved for release) of BMSB in specialty crops. Practices may include presence of companion plantings and refugia, minimizing non-selective, broad-spectrum insecticides, and/or augmentative or inundative releases.
- **Behavioral Control** Encourage behaviorally based management strategies within specialty crops to decrease localized BMSB populations and reduce insecticide input and encourage biological control. Approaches include several “attract-and-kill” management systems designed to work within or outside the specialty crop.
- **Cultural Control** Removal of wild host plants that serve as BMSB reproductive hosts and population reservoirs within the vicinity of vulnerable specialty crops if economically feasible. If these hosts also serve as resources for biocontrol agents, the impact of removal will be quantified relative to the benefit of the biocontrol agent. Encourage ground cover management to increase natural enemy abundance and reduce BMSB density. Promote optimized planting density (for annual crops) and canopy density (for perennial crops) to maximize penetration and residual effectiveness of chemical controls. Utilize selective harvesting and mechanical techniques that reduce the likelihood of contamination or taint.
- **Trap Cropping** Based on results from the BMSB OREI project, cultivate alternate host plants found to be more attractive to BMSB to serve as a trap crop alone or in combination with aggregation pheromone or other kairomones to attract and aggregate BMSB away from the managed specialty crop. Potentially include an insecticide treatment on the trap crop to control infesting BMSB populations.
- **Alternative Controls** Integrate the use of repellents and tactile deterrents for border-row treatments or in combination with an insecticide to provide a behavioral bridge between insecticide applications to deter BMSB dispersal into specialty crops and/or enhance efficacy of insecticides. Integrate RNAi technology and entomopathogenic fungi as potential treatments for reducing BMSB population levels.
- **Resistant Cultivars** Promote planting of BMSB resistant or tolerant specialty crops to reduce damage and/or populations in managed landscapes and agroecosystems.

Pending Questions

- 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, 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 mananagement? *Establish baseline levels and monitor potential development in different area of US.*

Stop BMSB

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

Search

Video Series

TRACKING THE BROWN MARMORATED STINK BUG

"Tracking the Brown Marmorated Stink Bug" shows growers and others how to identify BMSB, why this pest is important in agriculture, and what's at stake if we don't stop it. A team of 50 scientists is working toward sustainable solutions, and our outreach team is producing this video series to showcase the group's work.

Part 1: History and Identification
Duration: 4:34

Part 2: Overwintering and Spread
Duration: 5:38

Part 3: Monitoring and Mapping
Duration: 6:32

Part 4: Host Plants and Damage in Orchard Crops
Duration: 6:24

Part 5: Host Plants and Damage in Small Fruit
Duration: 3:05

Part 6: Host Plants and Damage in Vegetables
Duration: 4:52

Part 7: Host Plants and Damage in Ornamentals
Duration: 4:17

Part 8: Host Plants and Damage in the Pacific Northwest
Duration: 3:35

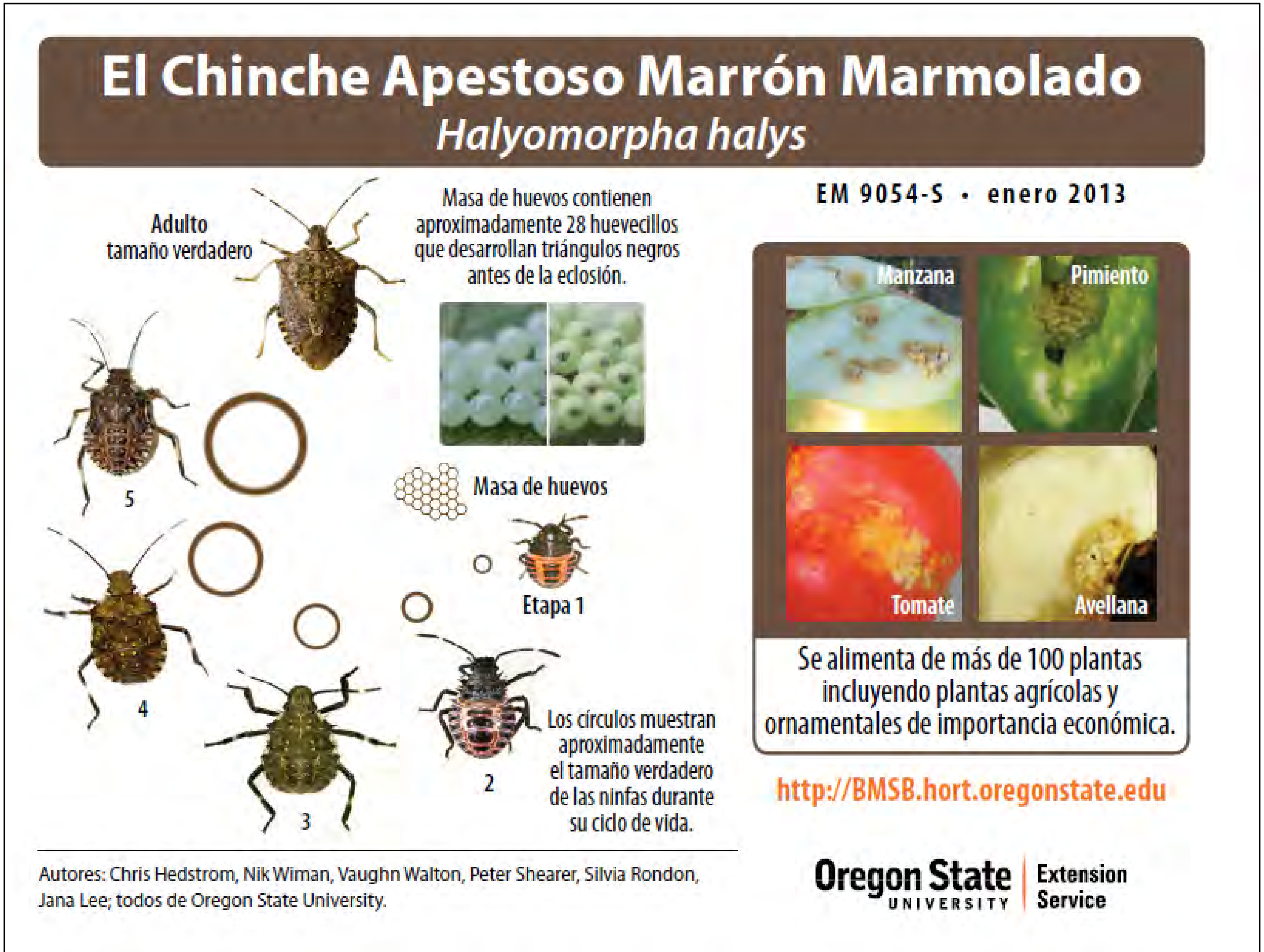
RELATED VIDEOS

Brown marmorated stink bug control: Keeping stink bugs out of your house
Source: Mike Raupp, Univ. of Maryland Extension

To Fight Stink Bugs, Take a Closer Look at Their Spit Scientists have developed a way to extract saliva from stink bugs and identify the proteins in it, paving the way

https://www.youtube.com/watch?v=BzM7IkdtOLs

State-Level Extension / Outreach



Identification Kits

Pending Questions

- Economics of BMSB? *Programs with integrated tools? Production of pheromone depending on synthetic pathway, loading, ratios, etc. Cost of and potential ROI for 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.*

Key Personnel Trained

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

Feedback from 2014 SAP Meeting

- Current ‘state of knowledge’ / guidance document. Deliverables.

- The need for an improved IPM practices continued to be a major message.

- Various opinions on RNAi technology.

BMSB SCRI SAP Schedule

- Morning Session One
  - Overall project progress, Objective 1 – Voltinism, dispersal, landscape and dispersal, Objective 1 – Nutritional ecology, Objective 1 – Commodity Report
  - Discussion
- Morning Session Two
  - Objective 2 – Short-term mitigation, Objective 2 – Monitoring tactics
  - Discussion
- Lunch
  - Mini-presentations and posters by graduate students and post-docs
- Afternoon Session One
  - Objective 2 – Biological Control, Objective 2 – Other control tactics,
  - Objective 3 – IPM Principles
  - Objective 4 – Extension/Outreach, Objective 4 - Economics
- Afternoon Session Two
  - Other Projects (OREI, SARE, United Soybean, IPM-CPR)
- Open Discussion and Evaluations

Thank you!