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

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USDA-NIFA SCRI #2011-51181-30937
Brown Marmorated Stink Bug IPM Working Group

Funded in 2010 and 2011, this working group has established itself as the primary platform for facilitating and coordinating research and outreach efforts for Brown Marmorated Stink Bug (BMSB) across the United States. The group hosts formal meetings on BMSB at which members share the latest research results and field observations and established research and extension priorities. Participants include researchers, extension personnel, growers, pest control operators, and a hotel manager. Learn about this working group’s plans for 2011-12.
Grower And Consultant Experiences

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

- Relying on mid- and late-season pyrethroids, creating a treadmill effect.

- Need a monitoring tools and control options that do not disrupt beneficials.

- 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

Invasive Tree-of-Heaven

Native Woody Hosts

Corn

Apple

Photo Courtesy of Chris Bergh
• 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

- Orchard Crops
- Vegetables
- Small Fruit
- Grapes
- Ornamentals
- IPM
- Field Ecology
- Biological Control
- Insect Behavior
- Economics
- Horticulture
- Taxonomy
- Chemical Ecology
- Plant Pathology
- Molecular Genetics
- Sociology
- Host Plant Resistance
- Extension/Outreach
BMSB SCRI CAP Team

USDA

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Jayson Harper
Steve Jacobs

Rutgers

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Mark Abney
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Carrie Koplinka-Loehr
Steve Young

IPM Center

VT

Tom Kuha
Chris Bergh
Doug Pfeiffer
Eric Day

Cornell

Arthur Agnello
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.
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.

<table>
<thead>
<tr>
<th>Recommended for Funding:</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Outstanding %</td>
<td>18</td>
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<tr>
<td>High Priority %</td>
<td>26</td>
</tr>
<tr>
<td>Medium Priority %</td>
<td>18</td>
</tr>
<tr>
<td>Low Priority %</td>
<td>22</td>
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<table>
<thead>
<tr>
<th>Not Recommended for Funding:</th>
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<tr>
<td>Some Merit %</td>
<td>14</td>
</tr>
<tr>
<td>Do Not Fund %</td>
<td>4</td>
</tr>
</tbody>
</table>

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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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

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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.
Specialty Crops at Risk to BMSB Damage

**HIGH RISK**
- apple, Asian pear, beans (green, pole, snap), beets, 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\(^1\), broccoli, cauliflower, cherry\(^2\), collard, cucumber, flowering dogwood, horseradish, lima bean, littleleaf linden, serviceberry, tomatillo

**LOW RISK**
- black gum, 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

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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.

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1—Potential risk of taint/contamination. 2—Additional risk potential due to bark feeding. 3—Considered moderate-high risk.
Host Plants of BMSB Includes >170 Records
made by collaborating researchers

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

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.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Genus</th>
<th>Species</th>
<th>Common Name</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Om.</td>
<td>Abelia</td>
<td><em>A. grandiflora</em></td>
<td>glossy abelia</td>
<td></td>
</tr>
<tr>
<td>Agric.</td>
<td>Abelmoschus</td>
<td><em>A. esculentus</em></td>
<td>okra</td>
<td></td>
</tr>
<tr>
<td>Om.</td>
<td>Acer</td>
<td><em>A. buergerianum</em></td>
<td>trident maple</td>
<td></td>
</tr>
<tr>
<td>Om.</td>
<td>Acer</td>
<td><em>A. pseudoplatanus</em></td>
<td>vine maple</td>
<td></td>
</tr>
<tr>
<td>Om.</td>
<td>Acer</td>
<td><em>A. japonicum</em></td>
<td>Amur (Japanese Downy) maple</td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Rank</th>
<th>Insecticide</th>
<th>Class</th>
<th>Lethality index</th>
<th>Initial efficacy $E_0$</th>
<th>Efficacy change $E_f$ - $E_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dimethoate</td>
<td>O</td>
<td>93.3</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>2</td>
<td>Malathion</td>
<td>O</td>
<td>92.3</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>3</td>
<td>Bifenthrin</td>
<td>P</td>
<td>91.3</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>4</td>
<td>Methidathion</td>
<td>O</td>
<td>90.4</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>5</td>
<td>Endosulfan</td>
<td>—</td>
<td>90.4</td>
<td>Moderate</td>
<td>Increasing</td>
</tr>
<tr>
<td>6</td>
<td>Methomyl</td>
<td>C</td>
<td>90.1</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>7</td>
<td>Chlorpyrifos</td>
<td>O</td>
<td>89.0</td>
<td>Moderate</td>
<td>Increasing</td>
</tr>
<tr>
<td>8</td>
<td>Acephate</td>
<td>O</td>
<td>87.5</td>
<td>Moderate</td>
<td>Increasing</td>
</tr>
<tr>
<td>9</td>
<td>Fenpropathrin</td>
<td>P</td>
<td>79.3</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>10</td>
<td>Permethrin</td>
<td>P</td>
<td>77.1</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>11</td>
<td>Dinofuran</td>
<td>N</td>
<td>67.3</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>12</td>
<td>Kaolin clay + Thiamethoxam</td>
<td>—</td>
<td>66.7</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>13</td>
<td>Gamma-cyhalothrin</td>
<td>P</td>
<td>64.2</td>
<td>High</td>
<td>Decreasing</td>
</tr>
<tr>
<td>14</td>
<td>Formetanate HCl</td>
<td>C</td>
<td>63.5</td>
<td>Moderate</td>
<td>Stable</td>
</tr>
<tr>
<td>15</td>
<td>Thiamethoxam</td>
<td>N</td>
<td>56.3</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>16</td>
<td>Clothianidin</td>
<td>N</td>
<td>55.6</td>
<td>High</td>
<td>Stable</td>
</tr>
<tr>
<td>17</td>
<td>Beta-cyfluthrin</td>
<td>P</td>
<td>54.8</td>
<td>High</td>
<td>Decreasing</td>
</tr>
<tr>
<td>18</td>
<td>Lambda-cyfluthrin</td>
<td>P</td>
<td>52.9</td>
<td>High</td>
<td>Decreasing</td>
</tr>
<tr>
<td>19</td>
<td>Zeta-cypermethrin</td>
<td>P</td>
<td>52.1</td>
<td>High</td>
<td>Decreasing</td>
</tr>
<tr>
<td>20</td>
<td>Cyfluthrin</td>
<td>P</td>
<td>49</td>
<td>High</td>
<td>Decreasing</td>
</tr>
<tr>
<td>21</td>
<td>Oxamyl</td>
<td>C</td>
<td>46.8</td>
<td>Moderate</td>
<td>Stable</td>
</tr>
<tr>
<td>22</td>
<td>Esfenvalerate</td>
<td>P</td>
<td>43.3</td>
<td>Moderate</td>
<td>Decreasing</td>
</tr>
<tr>
<td>23</td>
<td>Imidacloprid</td>
<td>N</td>
<td>39.2</td>
<td>Moderate</td>
<td>Increasing</td>
</tr>
<tr>
<td>24</td>
<td>Tolfenpyrad (SC)</td>
<td>—</td>
<td>36.5</td>
<td>Moderate</td>
<td>Increasing</td>
</tr>
<tr>
<td>25</td>
<td>Tolfenpyrad (EC)</td>
<td>—</td>
<td>33.3</td>
<td>Moderate</td>
<td>Decreasing</td>
</tr>
<tr>
<td>26</td>
<td>Pyridfluimazin</td>
<td>P</td>
<td>28.3</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>27</td>
<td>Kaolin clay</td>
<td>—</td>
<td>23.1</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>28</td>
<td>Diazinon</td>
<td>O</td>
<td>20.4</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>29</td>
<td>Phosmet</td>
<td>O</td>
<td>20.0</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>30</td>
<td>Acetamiprid</td>
<td>N</td>
<td>18.8</td>
<td>High</td>
<td>Decreasing</td>
</tr>
<tr>
<td>31</td>
<td>Thiaceprold</td>
<td>N</td>
<td>18.3</td>
<td>Moderate</td>
<td>Stable</td>
</tr>
<tr>
<td>32</td>
<td>Abamectin</td>
<td>—</td>
<td>16.3</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>33</td>
<td>Indoxacarb</td>
<td>—</td>
<td>11.3</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>34</td>
<td>Spirotetramat</td>
<td>—</td>
<td>9.8</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>35</td>
<td>Carbaryl</td>
<td>C</td>
<td>9.0</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>36</td>
<td>Flonicamid</td>
<td>—</td>
<td>7.7</td>
<td>Low</td>
<td>Increasing</td>
</tr>
<tr>
<td>37</td>
<td>Cyangranilprole</td>
<td>—</td>
<td>1.7</td>
<td>Low</td>
<td>Stable</td>
</tr>
</tbody>
</table>

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

Doo-Hyung Lee, John P. Cullum, Jennifer L. Anderson, Jodi L. Daugherty, Lisa M. Beckett, Tracy C. Leskey

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
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
Nymphs can walk >25 m/day

Adults can fly >2 km/day
Identifying Risk Factors For Spread and Establishment


Adam M. Wallner¹, George C. Hamilton², Anne L. Nielsen², Noel Hahn², Edwin J. Green³, Cesar R. Rodriguez-Saona²

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. KDEs 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.0095169.g002
BMSB can be monitored successfully throughout the U.S. season-long using pheromone-baited traps.
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.
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.
BMSB can now be monitored successfully season-long throughout the U.S. using pheromone-baited traps.

**Key Personnel Trained**

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

- Studies of BMSB Biology, Behavior and Ecology
- Identification of Aggregation Pheromone
- Identification of Effective Insecticides
- Identification of Effective Biological Control Agents
- 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.


- 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 management? 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.
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.
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• Collaborating Commercial Companies