PEST STATUS OF THE BROWN MARMORATED STINK BUG, *HALYOMORPHA HALYS* IN THE USA

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Abstract

Since its initial discovery in Allentown, PA, USA, the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Heteroptera: Pentatomidae) has now officially has been detected in 38 states and the District of Columbia in the USA. Isolated populations also exist in Switzerland and Canada. This Asian species quickly became a major nuisance pest in the mid-Atlantic USA region due to its overwintering behavior of entering structures. BMSB has an extremely wide host range in both its native home and invaded countries where it feeds on numerous tree fruits, vegetables, field crops, ornamental plants, and native vegetation. In 2010, populations exploded causing severe crop losses to apples, peaches, sweet corn, peppers, tomatoes and row crops such as field corn and soybeans in several mid-Atlantic states. Damaging populations were detected in vineyards, small fruit and ornamentals. Researchers are collaborating to develop management solutions that will complement current integrated pest management programs. This article summarizes the current pest status and strategies being developed to manage BMSB in the USA.

Introduction

Native Geographic Distribution, Introduction and Spread. The brown marmorated stink bug (BMSB), *Halyomorpha halys*, is native to China, Japan, Korea and Taiwan (Hoebeke & Carter 2003). Early Asian literature refers to BMSB as the yellow-brown stink bug and as *H. picus* or *H. mista*. The first USA populations were discovered in the mid-1990s in or near Allentown, PA. In 2001, Karen Bernhardt with Penn State Cooperative Extension recognized that the insect invading homes was probably not native and sent a specimen to Richard Hoebeke at Cornell University who identified it as BMSB (Hoebeke & Carter 2003). Today BMSB has been detected in 38 states and the District of Columbia (Figure 1) with isolated populations in Switzerland (Wermelinger *et al.* 2008) and Canada (Fogain & Graff 2011).

General Biology. Adults are distinguished from other brown stink bugs in the USA by their larger size, light colored banding on the antennae and legs and alternating light and dark bands around the abdomen (Figure 2). The term 'marmorated' means having a marbled or streaked appearance. Females emerge with undeveloped ovaries and must feed before mating. Once mated, females lay light green egg masses of ~28 eggs on the undersides of leaves. Depending

Figure 1. Distribution and impact of BMSB in the USA based on State records and BMSB Working Group assessments as reported by May 2012. In addition, at least one unofficial detection has been made in CO.

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Figure 2. BMSB life stages.

on temperature, eggs hatch in 3–4 days. Nymphs go through 5 instars. First instar nymphs are reddish and black in color and stay with the egg mass until they molt to the second instar at which time they seek food sources. Nymphs darken and express pronounced light and dark banding on their legs and antennae (Hoebeke & Carter 2003).

In temperate Asia, BMSB completes one generation per year, but is reported to have a partial second generation in sub-tropical regions (Fujiie 1985) and up to 5–6 generations in southern China (Hoffmann 1931). In Allentown, PA, BMSB completes one generation per year (Nielsen *et al.* 2008, Nielsen & Hamilton 2009a). Further south in WV, two complete generations were documented (Leskey *et al.* 2012a). In the mid-Atlantic region, summer adults appear from early July to early September. Development occurs on a variety of host plants with leaves, stems, fruit, pods, or seeds used as resources. Adults readily move between hosts coinciding with the presence of fruit, but can complete development on a single species such as *Paulownia* (Chung *et al.* 1995, Funayama 2004). Beginning in late August, decreasing day length and temperature trigger adults to congregate in large numbers on hosts prior to entering overwintering sites including human-made structures (Hamilton 2009, Inkley 2012), dead, standing trees, and rocky outcroppings in wooded areas (Lee, *unpubl. data*). In spring when temperatures and day length increase, adults emerge from overwintering sites to locate host plants.

Pest status

Orchard Crops. In Asia, BMSB is an outbreak pest of tree fruit (Funayama 2002). Damage to tree fruit in the USA was first detected in Allentown, PA and Pittstown, NJ (Nielsen & Hamilton 2009b). In orchards where BMSB is established, it quickly becomes the predominant stink bug species and, unlike native stink bugs, is a season-long pest (Nielsen & Hamilton 2009b, Leskey *et al.* 2012b). In 2008–2009, increasing BMSB populations in WV and MD caused late-season problems to fruit crops (Leskey & Hamilton 2010a). In southern PA and VA, BMSB was not a recognized pest until the 2010 season. However, injury to apple (Figure 3) was probably mistaken for physiological disorders such as cork spot and bitter pit. Severe pest pressure in 2010 resulted in $37 million in losses to mid-Atlantic apples alone (American/Western Fruit Grower 2011) with some stone fruit growers losing > 90% of their crop (Figure 4, Leskey & Hamilton 2010b). In 2011, damage, though not as severe, was observed

Figure 3. Internal injury to 'Pink Lady' apple as a result of BMSB feeding.

throughout the mid-Atlantic states. Damage may have been mitigated by ~4-fold increase in insecticide applications against BMSB in some MD and WV orchards (Leskey *et al.* 2012b). Intervention depended heavily on broad spectrum-insecticides, especially pyrethroids. This practice disrupted IPM programs, causing outbreaks of secondary pests such as European red mites, wooly apple aphids and San Jose scale, that are normally controlled by natural enemies. In 2010 and 2011, BMSB was detected in areas close to major fruit growing districts in OR, WA, NY, and MI (2011 only). Cherries and hazelnuts, important crops in MI and OR, respectively, are also at risk.

Grapes. Although the degree of impact is unclear, more insight into the importance of BMSB in vineyards is emerging (Pfeiffer *et al.* in press). Issues include impact on grape cluster yield and quality, the effect of malodorous insects on crushed clusters and potential contamination of juice and wine, resulting in "stink bug taint", analogous to previously reported "ladybug taint" resulting from crushed Asian ladybird beetles. BMSB feeding on ripening berries causes a progressive necrosis with fruit collapse. Though unconfirmed, BMSB feeding on the rachis may also cause abscission. Studies in NJ showed possible differential susceptibility of grape cultivars to BMSB infestation. Infestation levels of BMSB on Cabernet Sauvignon and Traminette were 2–3 times greater compared with those on Chambourcin. Future studies will focus on resistance of

Figure 4. 'Red Haven' peaches stripped from trees by a MD grower and left to rot because of ~100% BMSB injury in July, 2010.

Figure 5. BMSB nymphs crawling from a container of machine-harvested blueberries highlighting the problem of contamination at harvest.

a wider range of grape cultivars and possible mechanisms of resistance. Management programs in grapes that do not rely on pyrethroids are needed to avoid secondary outbreaks of grape mealybug, the vector of grapevine leafroll virus. As for potential taint of wine, controlled inoculation (as many as 25 BMSB/11.3 kg fruit) of juice/mush has not resulted in perceptible taint/aroma following fermentation; chemical analysis is in progress (J. Fiola, unpubl. data). Effective means to remove BMSB from clusters just before harvest were established in VA, lessening the risk of tainted wine. Additionally, large numbers of BMSB adults seeking overwintering sites damage the ambiance of commercial wine tasting rooms.

Small Fruit. Little is known about the impact of BMSB in small fruit crops. Research is underway to establish the impact of BMSB feeding, determine BMSB phenology, and to identify landscape and temporal risk factors associated with BMSB on small fruit crops. In blueberries, BMSB was first observed during the late-season in 2010, and many NJ blueberry growers have since reported it in and around structures and houses. Contamination risks are a great concern to blueberry growers who mechanically harvest and then sell to processors or ship to other countries and regions within the USA (Figure 5). During 2011, BMSB populations in NJ blueberry farms remained low and did not require control measures. In caneberries, stink bug species cause two types of injury. Although not thoroughly investigated, it appears that early season feeding can cause death of buds. Late in the season, BMSB attack mature berries, inserting their stylets between the drupelets, and possibly feeding on the receptacle. This feeding causes discoloration and collapse of individual drupelets (Maxey 2011). In VA caneberries, BMSB accounted for 25% of the entire pentatomid community by the end of 2011.

Vegetables. The extent of BMSB damage and risk to vegetables has not been fully determined. Based on observations and initial research from the mid-Atlantic USA region, this pest will feed on and cause severe damage to a number of vegetables when densities are high (Kuhar *et al*. 2012). Sweet corn (*Zea mays*) appears to be a strongly preferred host crop, on which numerous nymphs and adults have been observed on a single ear and nearly 100% damage has been recorded in fields (Figure 6). The feeding stylets of BMSB are inserted through the husk and pierce the tender kernels, which may cause them to collapse and/or discolor. This damage is especially apparent after the ear is cooked. Bean crops such as *Phaseolus* species are also attractive hosts and feeding may result in scarred, flattened, and deformed pods. Vegetables such as pepper, tomato, eggplant, and okra also suffer heavy feeding damage, typically averaging more than 20% in research plots. Relatively less damage has been observed on other vegetable groups such as crucifers or cucurbits. However, because more than 200 species of plants are considered vegetables, more research is needed on this topic. Additionally, the risk of damage to a particular commodity may be heavily influenced by the presence of neighboring host plants.

Row Crops. BMSB has been found damaging soybean, wheat, and field corn. BMSB was first surveyed in soybean fields in 2006 near Allentown, PA (Nielsen *et al*. 2011). By 2010, the majority of soybean fields in western and central MD showed delayed maturity at field edges because of earlier feeding by BMSB, especially next to woodlots, with growers reporting > 50% yield loss. In 2011, BMSB surveys conducted in DE, MD, and VA revealed that highest populations were present on field edges. Treating just 12 meters into the field prevented further invasion and resulted in an 85–95% reduction in insecticide used compared with whole-field treatments. Follow-up studies will focus on defining specific protocols for

Figure 6. BMSB adult and nymphal feeding damage to sweet corn kernels.

Figure 7. BMSB feeding injury to the periphery of a soybean field illustrating the "stay green" effect and contrasting with the unaffected, normally senescing plants at the center of the plot.

perimeter treatments and identifying BMSB densities needed to cause delayed plant maturity, the "stay green effect" (Figure 7). Results from insecticide trials conducted in VA and MD indicate that most labeled products provide control though further information including residual activity is needed. Several wheat fields in MD were reported to contain very high BMSB adults and one field yielded egg masses. Most adults were near the field edge, adjacent to wooded borders. Research on native stink bugs indicates that the most susceptible stages of wheat development are the milk and soft dough stages (Viator *et al*. 1983). This coincides with the stage of the wheat fields containing large numbers of BMSB adults. Adults from those fields laid many eggs over a very short time in the laboratory. In the absence of a more highly preferred host, wheat may be susceptible to BMSB, though more studies are needed to determine if BMSB poses a significant risk. High populations (> 3 per ear) were found on corn plants after the ear had started to form especially within the first 12 meters of field margins in DE. Unlike soybeans, perimeter treatments are generally impractical for treatment of late-stage corn. A pilot investigation in MD to determine how the surrounding landscape influences densities in field corn suggests that corn fields bordered by woodlots, other crops, and buildings have higher populations compared with fields bordered by roads.

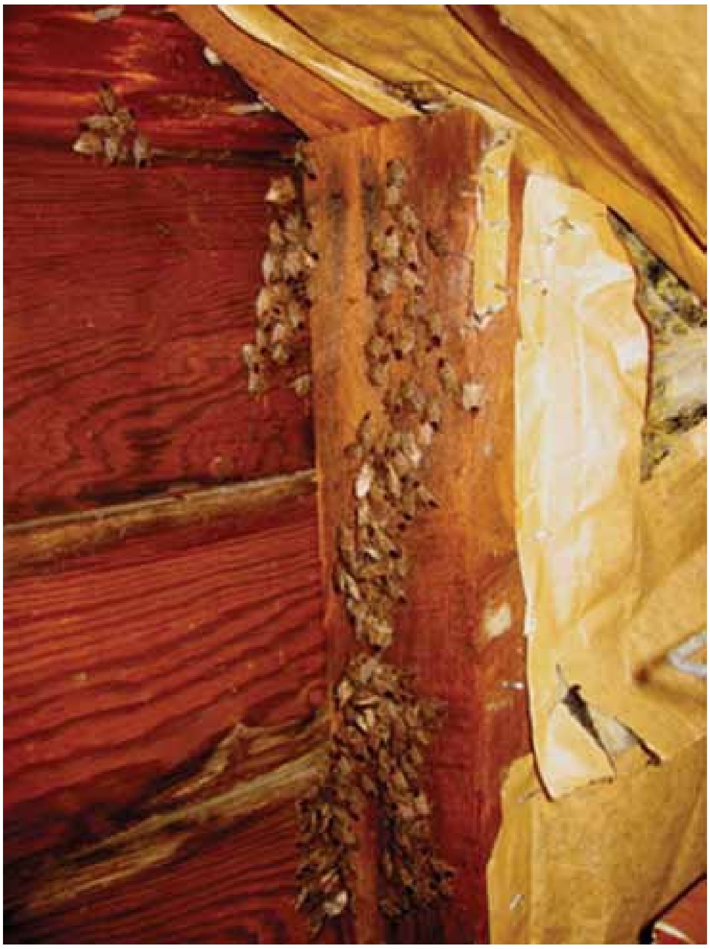
Ornamentals. In its native range, BMSB feeds on numerous ornamental plants (Hoebeke & Carter 2003). Ornamental crops in the USA are at risk because of the highly polyphagous nature, high mobility, and the observed direct and potential indirect damage by BMSB. Known ornamental hosts include woody and herbaceous plants in nurseries, urban landscapes, natural areas, and house plants (Raupp *et al. unpubl. data*). Currently, the host list of BMSB includes > 100 plants many of which are ornamentals (USDA APHIS 2010 and references therein). BMSB became an important pest and economic threat in commercial nurseries and landscapes with the large populations of 2010. By mid-summer in MD, BMSB was feeding on fruits of crabapples, hawthorns, and serviceberries, disfiguring fruits and wilting plants. By autumn, BMSB became very abundant feeding on the trunks of several trees and shrubs (Figure 8). The resultant injury included copious sap flow, fluxes, and discolored bark at feeding sites. Death of herbaceous perennials has been reported. A 2011 field survey of trees and shrubs at a commercial nursery in MD showed 150 of 178 cultivars were used by BMSB. Top hosts included cultivars or species of *Syringa* (lilac), *Acer* (maple), *Cercis* (redbud), *Platanus* (London planetree), and *Prunus* (ornamental cherry). Certain host plants are used solely for feeding, whereas other hosts are used for feeding and oviposition (USDA APHIS 2010, Raupp *et al. unpubl. data*). There is concern that BMSB could vector pathogens to ornamental plants in the USA because in Asia it vectors the phytoplasma responsible for *Paulownia* witch's broom (Bak *et al*. 1993, Yu & Zhang 2009). Ornamental hosts may contribute to damage in other ways. In natural and semi-natural areas, ornamental plants and other wild host trees may provide overwintering habitat allowing BMSB to populate crops easily, and they may support large BMSB populations that invade homes to overwinter.

Nuisance Problems. BMSB is a significant nuisance to homeowners and businesses because they will utilize attics, garages, offices, and other buildings to overwinter (Watanabe *et al*. 1994, Hoebeke & Carter 2003, Hamilton *et al*. 2008, Hamilton 2009, Inkley 2012). This problem is exacerbated in rural areas where forests and agricultural fields provide suitable habitat for BMSB to reproduce during the growing season. Surprisingly large numbers of BMSB overwinter in walls, insulation, attics and other suitable crevices that provide cool, dry refugia (Figure 9). One homeowner in rural Maryland collected 26,205 adult BMSB from January–June in 2011, of which 10,584 (40.4%) were found in first and second floor living space, with the remainder found in the attic (Inkley 2012). Throughout the winter and spring, especially on warmer days, BMSB become active indoors, often finding their way into living areas.

BMSB do not bite or sting humans and are not known to transmit human pathogens. Nonetheless, they are a nuisance because of the unpleasant odor they emit when disturbed, sheer numbers and daily presence, staining of walls and

Figure 8. Adult BMSB feeding on the trunk of a London plane tree, *Platanus × acerifolia*.

(A)



(B)

Figure 9. BMSB adults aggregating (A) beneath a mattress and (B) in the attic of a home in rural MD in 2010-2011. Over 26,000 overwintering adults were removed from the interior of this home in 2011 (Inkley 2012).

floors with their frass, and activity due to their attraction to light and moisture especially as temperatures warm (Inkley 2012). Their nuisance impact is well-documented by an enormous volume of requests for information on the biology and management of this pest at web sites and telephone hot lines maintained by state government agencies and institutions. Since 2004, a Rutgers University web-reporting site has received 10,000 BMSB reports and Pennsylvania State University's BMSB online fact sheet has been viewed more than 600,000 times since 2008 (Jacobs, *personal communication*). In 2010 and 2011, University of Maryland's BMSB web page received more than 80,000 visits, while email and phone contacts addressed approximately 900 inquiries (Traunfeld, *personal communication*) and a self-help YouTube for consumers generated about 1,300 hits per month since posting in 2011. Distinct autumnal peaks of reports/visits clearly defined the annual activity pattern of BMSB as they begin to enter homes in mid-September. Additional web activity occurs in January-April.

Long-term solutions

The Response. Most major media networks including ABC, CBS, NBC, Fox, CNN, BBC, and NPR and major print outlets including The Wall Street Journal, Washington Post, New York Times, Los Angeles Times, Chicago Tribune, and Philadelphia Inquirer have run stories on the agricultural and nuisance pest problems caused by BMSB raising national attention. Researchers have formed a "Brown Marmorated Stink Bug IPM Working Group" through the Northeastern IPM Center (Leskey & Hamilton, 2010a,b, 2011a) which has established itself as the primary platform for facilitating and coordinating research efforts, priority development, and offering outreach across the USA. Content generated by

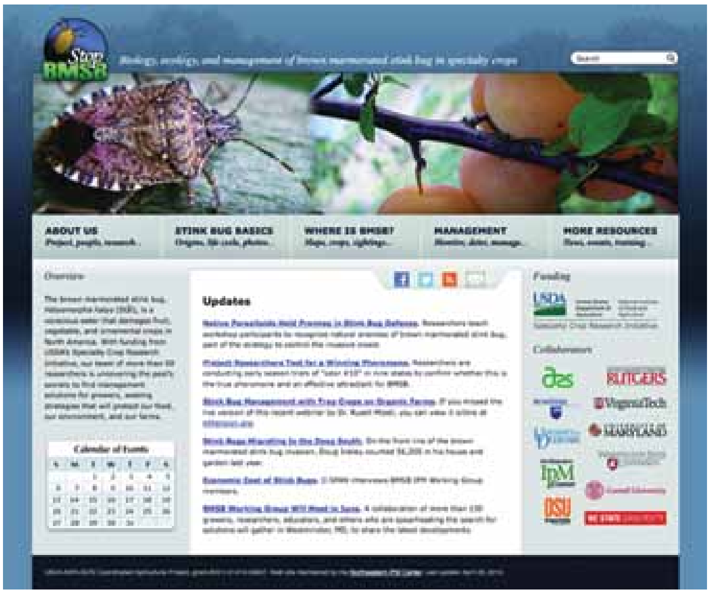


Figure 10. StopBMSB.org, the web site for the USDA-NIFA SCRI coordinated agricultural project.

Figure 11. Adult *Trissolcus* female attacking eggs of BMSB.

the Working Group and available on the Northeastern IPM website has resulted in > 16,000 visits since 2010. Successful grant initiatives that have cited priorities defined by the Working Group include the USDA-NIFA Critical Issues and Northeastern and Southern Regional IPM grants. In addition, a national coordinated agricultural project funded by USDA-NIFA Specialty Crop Research Initiative is studying the biology, ecology, and management of BMSB in specialty crops. This project includes over 50 researchers from 10 states and includes a national outreach program that specifically targets growers. The Northeastern IPM Center leads this national outreach effort. A website, StopBMSB.org, (Figure 10) serves as a hub for delivering BMSB management information and providing knowledge emanating from the project's research program, links to key BMSB resources, and provides "the best of" current information with an eye toward adding value for growers. The United Soybean Board has funded a multi-state research project to develop information on impact by and management of BMSB in soybeans.

Conclusions. Without immediate intervention, BMSB could put many farmers out of business, and dismantle IPM and organic programs. The goal of the SCRI and other funded projects is to generate information and technology building a framework for management of BMSB in areas where it is established and preventing future problems in new regions and crops. Immediate efforts have focused on developing management programs with chemical tactics (Leskey *et al.* 2012b), and then integrating these chemicals into comprehensive management programs. Researchers are focusing on identification of the BMSB pheromone to improve monitoring tools to detect activity and need for intervention. Efforts to develop behaviorally based management strategies such as attract-and-kill and biological control programs to reduce insecticide inputs are underway.

Asian natural enemies of BMSB are thought to be an important mortality factor and high levels of egg parasitism are reported in China (Yang *et al.* 2009). In Asia, several species of parasitoid wasps in the genus *Trissolcus* and tachinid flies parasitize BMSB eggs and adults, respectively. Surveys to determine the occurrence and impact of resident natural enemies on BMSB in mid-Atlantic states revealed that in non-crop landscape habitats, parasitoids attack BMSB eggs and adults at very low levels that are typically less than 5% (Hoelmer, *unpubl. data*) much lower than in Asia. However, parasitoid activity may be significantly higher in agroecosystems. BMSB egg parasitism was found at rates of 23, 26, and 55% in eggplant, pepper and field corn plots, respectively (Hooks *et al*, *unpubl. data*). These varying results suggest that the local composition of host plant species and landscape structure influence natural enemy activity. Several indigenous *Trissolcus* spp., *Telenomus podisi*, generalist chalcidoid wasps, tachinid flies, and various invertebrate and vertebrate predators have been observed attacking BMSB. Predation of BMSB egg masses by spiders and big eyed bugs (*Geocoris* spp.) reached ~47% in MD soybean plots.

An entomopathogenic fungus, *Ophiocordyceps nutans*, was reported infecting BMSB in Japan (Sasaki *et al.* 2012) and several other fungus species have shown efficacy against BMSB in the laboratory (Gouli *et al.* 2011). Exploration in China, Japan, and South Korea resulted in the importation of Asian *Trissolcus* species for host range studies to determine their specificity to BMSB and suitability for field release in the USA (Figure 11). Ultimately, classical biological control utilizing Asian natural enemies and conservation biological control to enhance the activity of introduced and indigenous natural enemies may provide the most promising long-term solutions for landscape-level reduction of BMSB populations.

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