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Qualitative analysis of the pest risk potential of the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), in the United States

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Executive Summary

This assessment considers scientific, expert, and empirical evidence to evaluate the risks associated with *Halyomorpha halys* (Stål) in the United States to aid in the re-evaluation of the regulatory status of this pest.

The brown marmorated stink bug (BMSB), *H. halys,* is an invasive plant pest that was introduced into the United States. This assessment examined 1) the likelihood of introduction and spread to uninfested areas of the United States, 2) the likelihood of establishment in uninfested areas of the United States, and 3) the potential consequence of BMSB in the United States. These three factors were used to arrive at a pest risk potential rating.

The assessment concluded that the pest risk potential for BMSB is HIGH for the United States. Furthermore, this assessment examined the management strategies employed to control BMSB. There are very few specific mechanisms readily available for controlling BMSB in the United States; therefore it is recommended that resources be devoted to the following:

1. Development of specific pheromone lures and more effective traps for BMSB.
2. Development of 'attract-and-kill' management strategies.
3. Development of effective chemical control strategies for growers and homeowners.
4. Development of an effective biological control program for BMSB.
5. Consideration of a coordinated area wide control program for BMSB.

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I. Introduction

This document was prepared by the Plant Epidemiology and Risk Analysis Laboratory of the Center for Plant Health Science and Technology, USDA-APHIS-PPQ in response to a request by Emergency and Domestic Programs (EDP) to evaluate the risks associated with *Halyomorpha halys* in the United States to aid in the re-evaluation of the regulatory status of this pest.

International and regional plant protection organizations, such as the International Plant Protection Convention (IPPC) of the United Nations, and the North American Plant Protection Organization (NAPPO), provide guidance for conducting pest risk analyses. The methods used to initiate, conduct, and report pest risk analyses are consistent with guidelines provided by IPPC and NAPPO, specifically ISPM No 11, Pest Risk Analysis for Quarantine Pests, Including Analysis of Environmental Risks and Living Modified Organisms (IPPC, 2004). The use of biological and phytosanitary terms conforms to the Definitions and Abbreviations (Introduction Section) in the International Standards for Phytosanitary Measures, Section 1: Import Regulations Guidelines for Pest Risk Analysis (IPPC, 2004), the Glossary of Phytosanitary Terms and the Compendium of Phytosanitary terms (IPPC, 2004, 2007), the Glossary of Phytosanitary Terms and the Compendium of Phytosanitary terms (IPPC, 2007). These guidelines describe three stages of pest risk analysis: Stage 1, Initiation, Stage 2, Risk Assessment, and Stage 3, Risk Management. This document satisfies the requirements of IPPC Stages 1, 2, and 3.

This is a qualitative risk analysis; estimates of risk are expressed in terms of High, Medium, and Low rather than numerical terms such as probabilities or frequencies. For the purposes of this assessment High, Medium, and low will be defined as:

High: Frequent events
Medium: Moderate events
Low: Rare events

Identification of appropriate sanitary and phytosanitary measures to mitigate the risk, if any, for this pest is undertaken as part of the risk management phase discussed in this document. The appropriate risk management strategy for a particular pest depends on the risk posed by that pest.

II. Risk Assessment

2.1: Initiating Event

The brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), is an invasive plant pest that was introduced into the United States from its native range in Japan, Korea, and China. BMSB was first identified in 2001 in Allentown, Pennsylvania, but is believed to have been introduced into the U.S. as early as 1996 (Hamilton, 2009; Hoebeke and Carter, 2003), possibly through the movement of bulk containers (Hamilton, 2009). Since that time, it has spread to multiple states in the continental United States and Canada (Wermelinger et al., 2008). Currently, BMSB has established populations in California, Connecticut, Delaware, Indiana, Kentucky, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Virginia, and West Virginia. BMSB has also been detected in Florida, Illinois, Maine, Mississippi, Missouri, Rhode Island, and South Carolina, but there does not appear to be an established population in these states at this time (Holtz, 2010).

The population size of BMSB has steadily grown in the United States since its introduction. In 2006, BMSB was first documented as causing economic damage in the United States (Hamilton, 2009; Nielsen et al., 2008a), although lower levels of economic damage were observed in 2002 in Pennsylvania (Bernon, 2004). During the 2009 growing season, serious economic injury to several crops including peach, apple, and Asian pear was reported due to large BMSB populations (ARS, 2010a).

In addition to the economic impacts of this pest, BMSB has also been reported as a nuisance pest for businesses and homeowners. BMSB overwinters as an adult (Watanabe et al., 1994) aggregating in high numbers when seeking shelter (Hoebeke and Carter, 2003). Adults aggregate in large numbers on the side of buildings, eventually entering attics, garages and other structures to overwinter (Hamilton, 2009).

Halyomorpha halys is currently listed as non-reportable/non-actionable for the United States because it does not meet the definition of a quarantine pest[1] as defined by relevant International Standards for Phytosanitary Measures (ISPM 5, Glossary of Phytosanitary Terms).

2.2: Pest Categorization

Stink bugs (Hemiptera: Pentatomidae) occur throughout the United States and have a broad host range, including weeds as well as economically important crops. Because of their vast host range and high mobility, stink bugs are difficult to control (Chyen et al., 1992). Stink bugs in the Atlantic states attack many crops and commodities, with different species complexes in each region of the United States. In the Mid-Atlantic area, agricultural commodities are at risk from brown, *Euschistus servus* (Say), and green stink bugs, *Acrosternum hilare* (Say) (McPherson and McPherson 2000). Further south, the southern green stink bug, *Nezara viridula* (L.), and the non-native redbanded stink bug *Piezodorus guildinii* (Westwood) cause most of the economic damage (Temple et al., 2007).

BMSB is an introduced pest from Asia. It was first identified in Pennsylvania in 2001 in Allentown, Pennsylvania, but is believed to have been introduced in 1996 (Hamilton, 2009; Hoebeke and Carter, 2003) possibly through the movement of bulk containers (Hamilton, 2009). Since that time, it has spread to multiple states in the continental United States and Canada (Wermelinger et al., 2008).

BMSB overwinters as an adult (Watanabe et al., 1994), aggregating in high numbers on man-made structures when seeking shelter (Hoebeke and Carter, 2003) making it a nuisance pest. Adult BMSB begin searching for an overwintering site at the end of September. They remain in diapause until the end of May in the United States (Hoebeke and Carter, 2003). Very little is known about the mechanisms that drive aggregative overwintering in BMSB, but preliminary

[1] Quarantine Pest = A **pest** of potential economic importance to the **area endangered** thereby and not yet present there, or present but not widely distributed and being **officially controlled** (IPPC, 2007).

research suggests that aggregation is primarily due to the function of arrestant stimuli rather than attractants (Toyama et al., 2006). Adults aggregate in large numbers on the side of buildings, eventually entering attics, garages and other structures to overwinter (Hamilton, 2009; Kobayashi and Kimura, 1969). Stink bugs native to the United States overwinter under leaf litter and debris (McPherson and McPherson, 2000). There have been undocumented reports that BMSB may also overwinter in forest areas (Short, 2010).

BMSB overwinters as a sexually immature adult (Watanabe et al., 1994). After entering diapause, BMSB remain inactive in the overwintering site until the end of May (Hoebeke and Carter, 2003). The stink bugs emerge in the spring (March to April) as reproductively immature adults. They complete sexual maturation before copulating and then ovipositing (Nielsen and Hamilton, 2009; Wermelinger et al., 2008). Mating typically begins approximately two weeks after adults emerge from overwintering sites (Hoebeke and Carter, 2003). Females may mate with multiple males, but a female only mated once is still capable of laying eggs for approximately half of her life span with fecundity decreasing with age (Hoebeke and Carter, 2003). Female BMSB average about 28 eggs per egg mass (Hoffman, 1931; Nielsen et al., 2008a; Wermelinger et al., 2008) and are capable of laying eggs throughout their lifetime (approximately 240 eggs) (Nielsen et al., 2008a). Eggs are generally deposited on the underside of host plant leaves or stems (McPherson and McPherson, 2000; Wermelinger et al., 2008), but they have also been discovered on man-made structures and non-host plants (McPherson and McPherson, 2000). In the United States BMSB has been observed laying eggs from May to late August (Hoebeke and Carter, 2003). About 4 – 7 days after deposition, the eggs hatch (Hoffman, 1931; Nielsen et al., 2008a). The stink bugs undergo five nymphal instars before becoming an adult. In Pennsylvania all five nymphal stages can be found simultaneously by July (Bernon, 2004). Photoperiod influences the nymphal instars in several ways, including pigmentation, body size, feeding frequency, developmental rate and lipid accumulation. For example, short-day-reared diapause-destined fifth instar nymphs have shorter stripes of the pronotum, smaller luminous intensity (LI) value of the pronotum, smaller body size, less feeding frequency and shorter nymphal period than long-day-reared nymphs (Niva and Takeda, 2003).

The developmental range for BMSB is between 17°C (lower) and 33°C (upper) (Nielsen et al., 2008a). The length of time in each stage varies by environment; shorter developmental time will occur in warmer weather, while cooler weather will trigger a longer developmental period. On average, the stink bugs will develop in 33-45 days (Nielsen et al., 2008a). Due to its low developmental threshold, it has also been able to expand into northern states and Canada (Bercha, 2008). However, colder winters will result in greater BMSB mortality in the overwintering population during diapause (Wermelinger et al., 2008).

BMSB does not require an overwintering period to reach sexual maturity. However, they do require time to develop into a sexually mature adult after molting from a nymph into an adult (Nielsen et al., 2008a). The developmental time for sexual maturation and growth stages causes variations in the number of generations experienced by BMSB in different latitudes. There have been conflicting accounts on the number of BMSB generations produced in the Mid-Atlantic area. Bernon (2004) and Nielsen and Hamilton (2009) reported that the insects are univoltine in the Mid-Atlantic, yet Lesky (2010b) identified two generations in West Virginia. Researchers predict that it may be multivoltine in warmer climates (Nielsen et al., 2008a), and Hoffman (1931) reported that BMSB may have up to six generations a year.

The adults and nymphs usually feed on fruiting structures, but will also feed on stems, leaves and flowers (Hoebeke and Carter, 2003; McPherson and McPherson, 2000). Stink bugs have piercing-sucking mouthparts (stylets) that are used to pierce plant tissue and suck the fluids. The insertion of the stylets can leave discolored spots on the plant and fruit. If the stylets reach the seed, the damage may result in reduced germination and dark areas on the seed (McPherson and McPherson, 2000). Early season feeding by stink bugs on fruiting structures can result in abortion of the fruit or catfacing, which id grooves or distorted brown lines on the fruit surface (Welty et al., 2008). Later season feeding will leave necrotic tissue and white spongy areas on the fruit (McPherson and McPherson, 2000). Nymphs are typically solitary feeders, but occasionally will aggregate and cluster between overlapping leaves or leaf folds (Bernon, 2004). In Pennsylvania, nymphs occasionally aggregate with other Heteropterans, including coreids and green stink bugs (*Acrosternum hilare*) (Bernon, 2004).

BMSB is also known as a vector for at least one disease. BMSB is documented as vectoring a phytoplasma that causes witches broom in *Paulownia tomentosa* (Jones and Lambdin, 2009). This is the only documented phytoplasma reported to be transmitted by BMSB although the possibility exists that it may transmit other phytoplasmas as well.

2.3: Assessment of the likelihood of introduction and spread

BMSB originated in Asia and was introduced in the United States in the late 1990s (Hamilton, 2009; Hoebeke and Carter, 2003). There has been speculation that the BMSB entered through the movement of bulk containers (Hamilton 2009), however there is no evidence to support this assertion. Between 2001 and 2010 there were fifty-four interceptions of BMSB at the United States ports-of-entry (PestID, 2010). *Halyomorpha halys* is currently listed as non-reportable/non-actionable for the United States, meaning that port inspectors are not required or directed to report interceptions or take action on containers or commodities if BMSB is detected. Therefore, the number of true interceptions of BMSB is likely much higher than the fifty-four interceptions that have been reported. From the available interception records, forty-four interceptions occurred on non-plant materials, such as machinery, furniture, and ship decks (PestID, 2010).

BMSB is considered a hitchhiker pest and is capable of dispersing over great distances seeking shelter in man-made structures, such as shipping container or cars (Hamilton, 2009; Watanabe et al., 1994). BMSB is capable of surviving for extended periods of time at low and high temperatures (Nielsen et al., 2008a), and may therefore easily survive the storage and shipment of many commodities both into the United States and between States. It took approximately 14 years from the initial introduction of BMSB for it to become widespread thought the United States. BMSB has spread from Pennsylvania, the perceived initial introduction site and now has established populations in seventeen states (Holtz, 2010), but it has also been intercepted in seven additional states, typically in the vicinity of trucks or cars (Holtz, 2010).

In nature, BMSB is a highly mobile pest and is considered a migratory insect that easily moves between hosts (Jentsch, 2008), migrating from plants with early-ripening fruit to those with late-ripening fruit (Welty et al., 2008). Nymphs and adults, like other stink bugs, are capable of dispersing to feed on susceptible hosts (Tillman et al., 2009). If disturbed, both nymphs and adults drop off of host plants or escape to sheltered areas (Bernon, 2004). Adults are also capable of long distance flight (Kamminga et al., 2009b; McPherson and McPherson, 2000) and on warm days may take flight if disturbed, but usually for only short distances (Bernon, 2004).

Summary

BMSM is a highly mobile pest capable of migrating between hosts, as well as hitchhiking on a wide array of materials. Once present in an area, BMSB is not inhibited or limited in its movement, as demonstrated by its widespread distribution throughout the United States. Therefore, there is a high likelihood that BMSB will continue to spread throughout the United States.

2.4: Likelihood of establishment

2.4.1 Availability of suitable hosts in PRA area

BMSB is highly polyphagous and has an expansive host range that includes many economically important plants (Appendix A). Primary hosts appear to be tree fruit, legumes, and deciduous hardwoods (Leskey, 2010d; Wermelinger et al., 2008), but may also feed on a variety of ornamentals and weeds (McPherson and McPherson, 2000). As BMSB is highly polyphagous, it is likely to expand its host range as it adapts to new areas in the United States. Very little information is available on the dynamics of BMSB on specific plants, and the reported data is often conflicting. For example, Funayama (2002; 2004) reported that apple may be important for BMSB to reach reproductive maturity early in the season, while Wermelinger et al. (2008) indicated that apple may only be used as a food source when the more preferred hosts are unavailable.

Like other stinkbugs (McPherson and McPherson, 2000), BMSB may feed on plants that are not true hosts, however, it is impossible to ascertain from the current literature if any of the reported hosts are actually true hosts or just plants BMSB was observed feeding on. Both adults and nymphs feed on hosts plants (Hoebeke and Carter, 2003; Kawada and Kitamura, 1983). Host plants of BMSB are readily available throughout the United States. Several risk maps were developed to describe the relative density of susceptible hosts throughout the United States (refer to Appendix A for hosts used). Based on the relative density of hosts plants of BMSB throughout the United States (Figures 1 and 2), the reported hosts of BMSB are generally concentrated in the eastern half of the U.S. Due to host plant availability, the eastern portion of the U.S. could potentially support higher populations of BMSB than the western portion of the country. The risk maps do not include ornamental or weed hosts as their distribution throughout the U.S. is not reported in a manner that could be reliably mapped; inclusion of these hosts could potentially enlarge the risk areas.

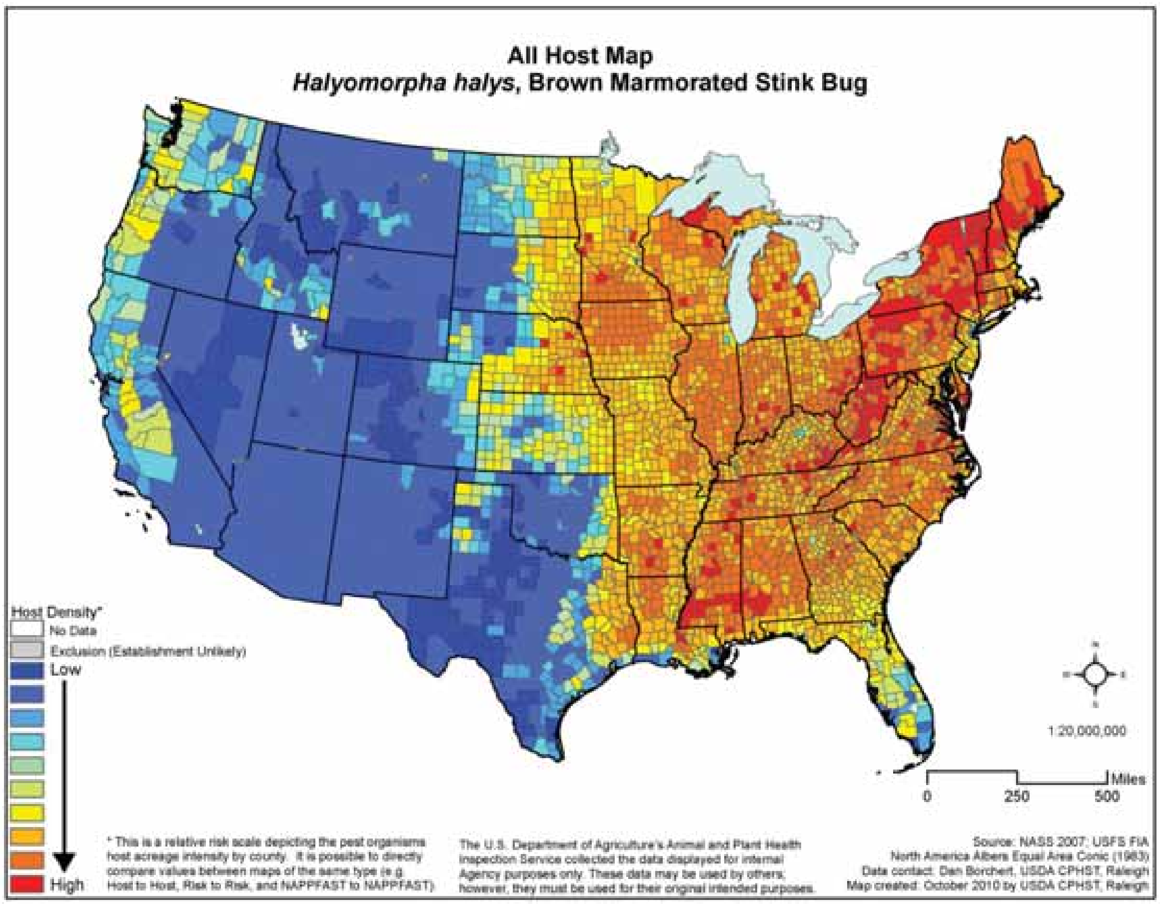
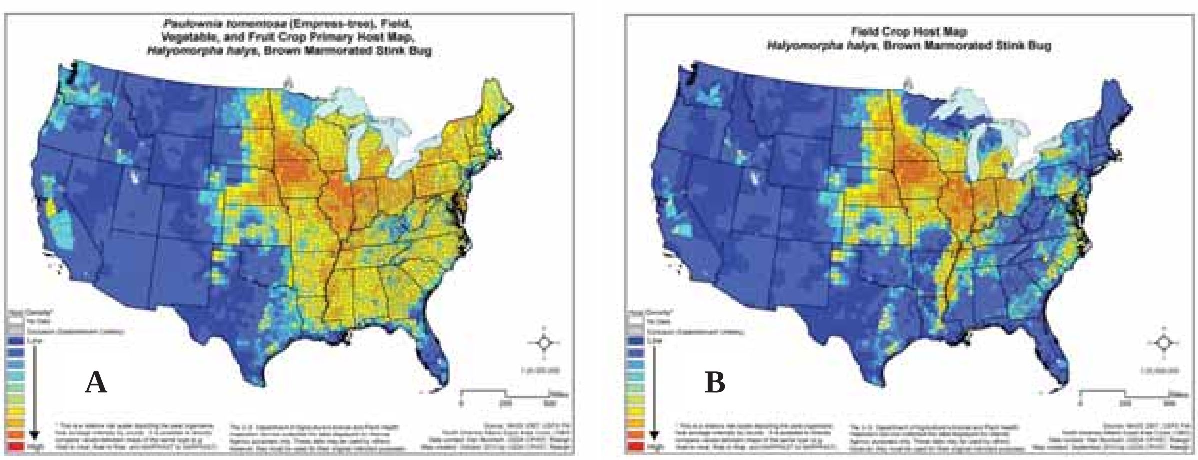


Figure 1: Risk maps displaying the relative density of field, vegetable, and fruit crop hosts plants of BMSB throughout the United States.



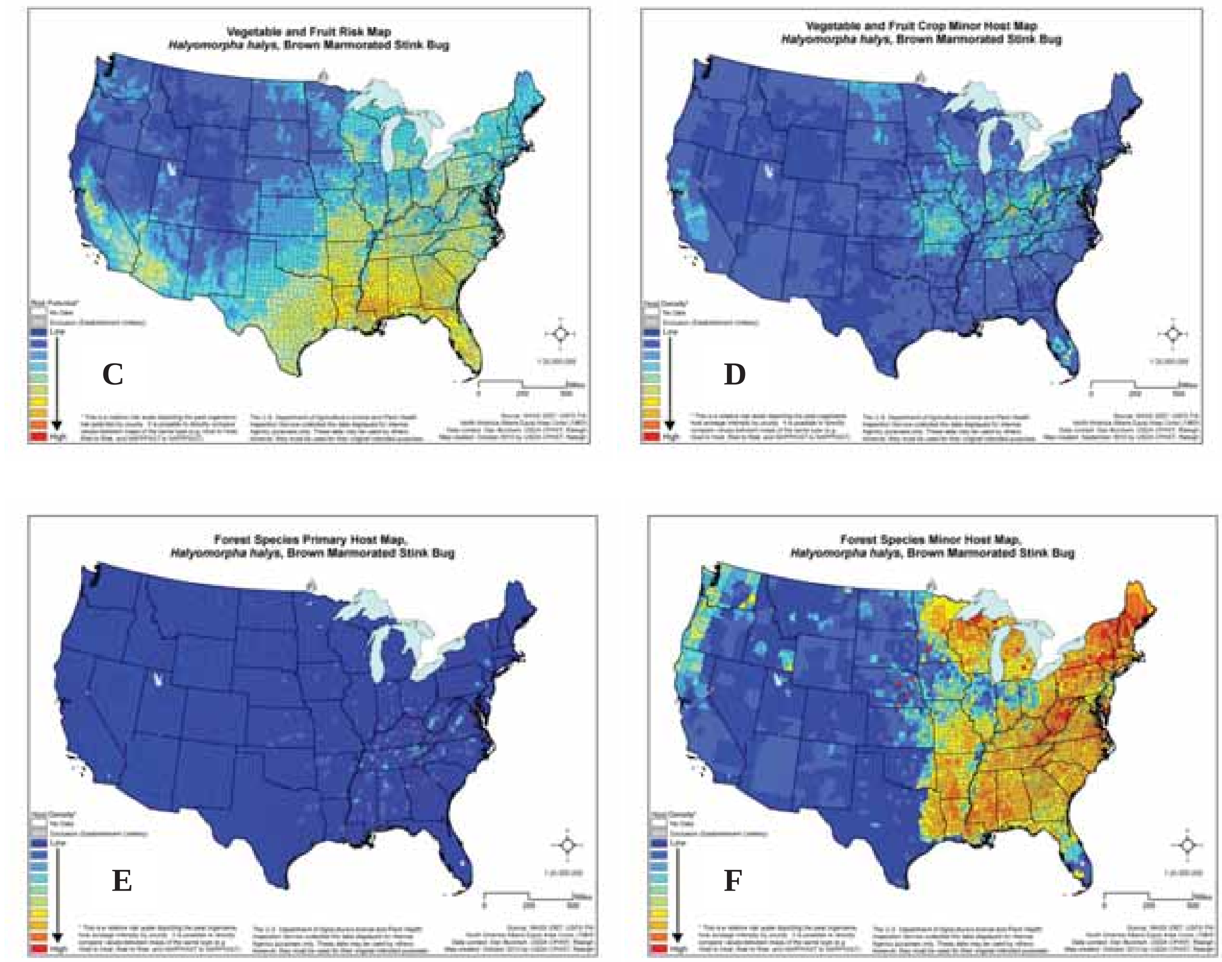


Figure 2: Risk maps displaying: A) Relative density of *Paulownia tomentosa*, field, vegetable, and fruit crop hosts; B) Relative density of field crop hosts; C) Relative density of vegetable and fruit crop major hosts; D) Relative density of vegetable and fruit crop minor hosts; E) Relative density of forest species major hosts; F) Relative density of forest species minor hosts.

Summary

BMSB has an expansive host range that includes tree fruit, legumes, deciduous hardwoods, ornamentals and weeds. Host plants are distributed throughout the United States. As BMSB is highly polyphagous, it is likely to expand its host range as it adapts to new areas in the United States. Therefore there is a high likelihood that BMSB will encounter suitable hosts throughout the United States.

2.4.2 Suitability of environment

BMSB originated in Asia and is reported from China, Japan, Korea Republic, and Taiwan (CABI, 2010). BMSB has spread from Asia to Europe (e.g., Switzerland CABI, 2010), Canada (e.g., Alberta) (Bercha, 2008)), and the U.S. (e.g., California, Connecticut, Delaware, Indiana, Kentucky, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Virginia, and West Virginia (Figure 3)) (Holtz, 2010).

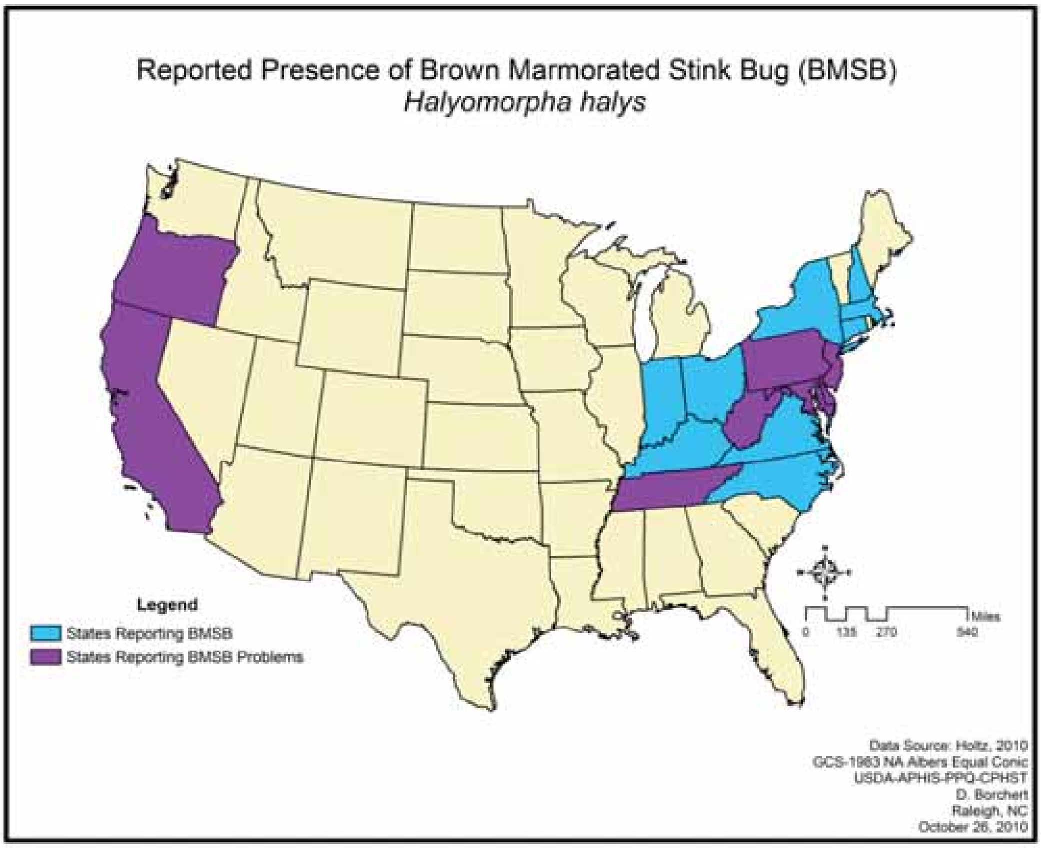


Figure 3: Distribution of BMSB in the United States, with States that have reported damage highlighted in purple.

The developmental threshold for BMSB is between17°C (lower) and 33°C (upper) (Nielsen et al., 2008a). The length of time in each stage varies by environment, shorter developmental time will occur in warmer weather, while cooler weather will trigger a longer developmental period. On average, the stink bugs will develop in 33-45 days (Nielsen et al., 2008a). A climate suitability model developed using NAPPFAST highlights the potential distribution and number of expected generations for BMSB in the United States (Figure 4). According to the risk map, BMSB can successfully complete at least one full generation in all areas of the United States. In warmer climates BMSB could complete multiple generations per year, up to 5 generations in portions of Arizona, Florida, Louisiana, and Texas. The risk map appears consistent with researchers predictions that BMSB may be multivoltine in warmer climates (Nielsen et al., 2008a), and Hoffman (1931) reported that BMSB may have up to six generations a year.

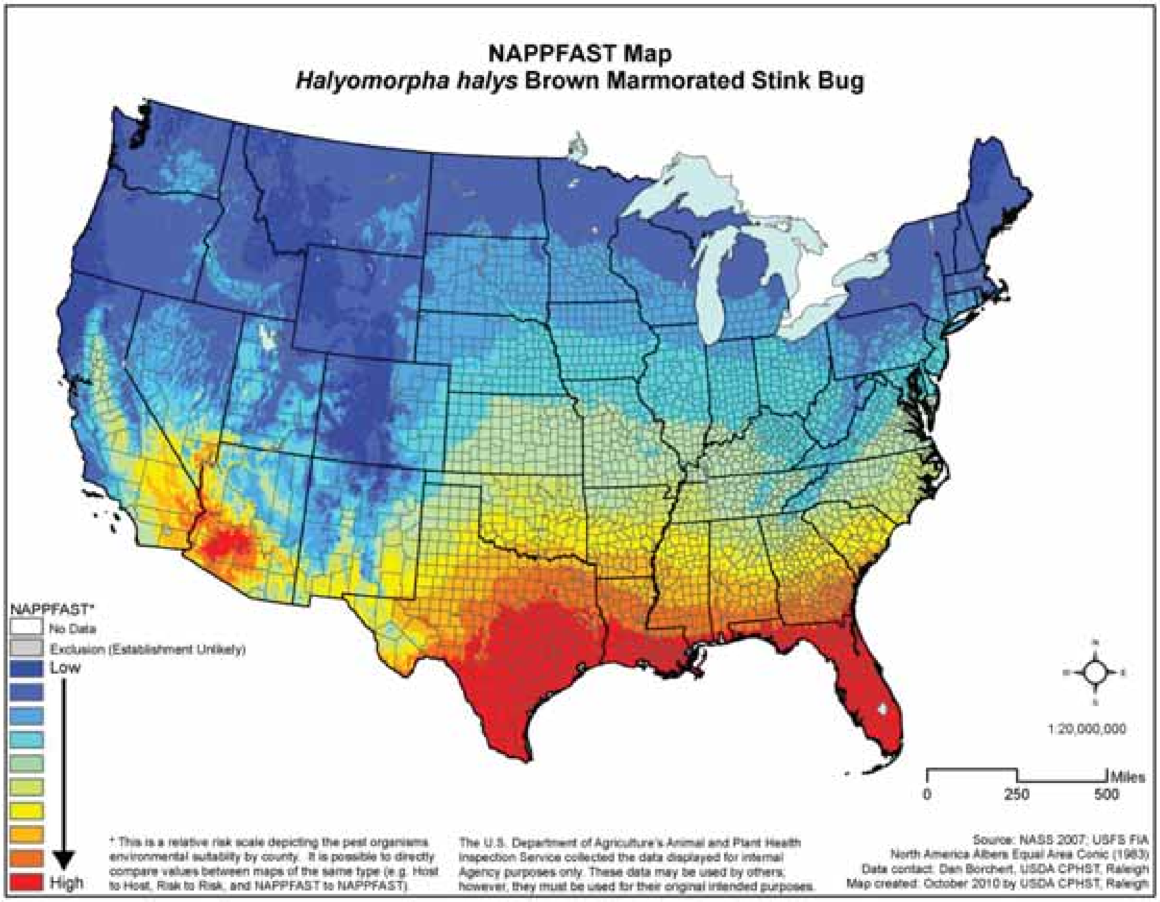


Figure 4: Predicted number of generations of BMSB per year in the continental United States, based on a generation requirement of 686DD for egg to egg development, with 148DD calculated in to capture the initial time for adult sexual maturation and emergence. The base temperature of 14.17 ^{o}C was used (DD were calculated based on data presented in Nielsen et al., 2008a). This map calculates the probability of 1-5 complete generations occurring per year, low=1, high=5 generations per year.

Stink bug population levels are often mediated by environmental factors (Kamminga et al., 2009b). During periods of optimal conditions, stink bug populations are larger than in years with less than optimal environmental conditions (Kamminga et al., 2009b). Currently, there does not appear to be any environmental limiting factors for BMSB populations (i.e. humidity, rainfall). In the United States BMSB populations increased continually. In the Mid-Atlantic States there have been no signs that the population of BMSB is on the decline, rather the population is likely still expanding (Leskey, 2010d). Between 2004 and 2008, the BMSB population in Beltsville, Maryland rose from undetectable to abundant (Aldrich et al., 2009). BMSB appears to have entered a phase of rapid expansion (Bernon 2004). Based on the size of overwintering populations in 2010, BMSB populations are predicted to be at least the same size in 2011, if not larger (Leskey, 2010d).

Summary

BMSB has a large developmental range and can successfully develop in all areas of the United States. In warmer climates BMSB could complete multiple generations per year, up to 5 generations in portions of Arizona, Florida, Louisiana, and Texas. Based on the risk map there is a high likelihood that BMSB will encounter a suitable environment in all areas of the United States.

2.4.3 Biological attributes of the pest that affect the probability of establishment

Reproductive strategy of the pest and method of pest survival

Two weeks after adults emerge from overwintering sites, mating commences (Hoebeke and Carter, 2003). Typically females mate on multiple occasions with multiple males (Hoebeke and Carter, 2003). A female only mated once is still capable of laying eggs for approximately half of her life span with fecundity decreasing with age (Hoebeke and Carter, 2003). Fecundity increases with multiple copulations as well as the egg laying time span (Nielsen et al., 2008a). Typically, BMSBs are capable of laying eggs throughout their lifetime (Nielsen et al., 2008a).

BMSB lays multiple egg masses throughout their life span (approximately 240 eggs) (Nielsen et al., 2008a). On average, BMSBs lay 28 eggs per egg mass (Hoffman, 1931; Nielsen et al., 2008a; Wermelinger et al., 2008). Female BMSBs typically deposit eggs on the underside of host plant leaves or stems (McPherson and McPherson, 2000; Wermelinger et al., 2008), but eggs may also be deposited on man-made structures and non-host plants (McPherson and McPherson, 2000). In the United States BMSB has been observed laying eggs from May to late August (Hoebeke and Carter, 2003).

BMSB overwinters as a sexually immature adult (Watanabe et al., 1994). Adults aggregate in high numbers when seeking shelter (Hoebeke and Carter, 2003). Very little is known about the mechanisms that drive the aggregative overwintering in BMSB, but preliminary research suggests that aggregation is primarily due to the function of arrestant stimuli rather than attractants (Toyama et al., 2006). BMSBs aggregate in large numbers on the side of buildings, eventually entering attics, garages and other structures to overwinter (Hamilton, 2009). Stink bugs native to the United States overwinter under leaf litter and debris (McPherson and McPherson, 2000) and there have been undocumented reports that BMSB may also overwinter in forest areas (Short, 2010).

In the United States, BMSBs begin searching for an overwintering site at the end of September (Hoebeke and Carter, 2003). After entering an over wintering site, BMSB remain inactive in the overwinter site until the end of May in the Northeast (Hoebeke and Carter, 2003). Overwintering in protected sites is a survival strategy that allows the pest to survive during unfavorable environmental conditions until more favorable conditions and host plants become available.

Adaptability

BMSB is highly polyphagous and has a large host range (Appendix A). This pest is likely to expand its host range as it adapts to new areas in the United States. Known host plants of the BMSB are readily available throughout the United States, but are concentrated in the eastern portion of the United States (Figures 1 and 2). BMSB has a large developmental range and can successfully develop in areas with temperatures as low as 17°C or as high as 33°C (Nielsen et al., 2008a). According to the risk map, BMSB can successfully complete at least one full generation in all areas of the United States. In warmer climates BMSB could complete multiple generations per year, up to 5 generations in portions of Arizona, Florida, Louisiana, and Texas (Figure 4). The length of time in each stage varies by environment, shorter developmental time will occur in warmer weather, while cooler weather will trigger a longer developmental period. Currently, it is unknown if there are other environmental factors (such as rainfall or humidity) that may limit BMSB distribution. Based on the information available in the literature it appears that BMSB will be able to adapt to the conditions in the mass majority of the United States.

Minimum population needed for establishment
There is no information currently reported in the literature that indicates the minimum population level needed for successful establishment of BMSB into a new area. Approximately 14 years after the initial introduction of BMSB it has become widespread thought the United States. There are now established populations of BMSBs in at least in seventeen states (Holtz, 2010). However, since 2003, BMSB has been intercepted or trapped in at least seven states (Florida, Illinois, Maine, Mississippi, Missouri, Rhode Island, and South Carolina) that to date have no known established BMSB populations (Holtz, 2010). Typically, interceptions occurred in the vicinity of trucks or cars (Holtz, 2010), indicating that individuals hitchhiked into the state. Suitable hosts and temperature conditions are available in all of the states listed above demonstrating that perhaps there are a minimum number of individuals that must be introduced into an area to establish new BMSB populations. It has been suggested that the introduction of BMSB into the United States and subsequent spread to Oregon was of an aggregated population and not individuals (Aldrich et al., 2009). The limitations do not appear to be significant as BMSB has established new populations in fifteen states.

Summary
BMSB has a high reproductive potential and survival is favored by the ability of the pest to overwinter in sexual diapauses in protected sites until favorable conditions and hosts become available. Suitable hosts and temperature conditions occur throughout the United States. While there may be some limitations in the number of individuals necessary to establish a new population, it does not appear to greatly mitigate the spread of BMSB in the United States. Based on the above information there is a high likelihood that the biological attributes of BMSB will increase its probability of continued establishment throughout the United States.

2.5: Assessment of potential consequences

2.5.1 Direct pest effects

BMSB, like other Pentatomidae, typically feed on the fruits of host plants, but will also feed on leaves, stems, petioles, flowers, and seeds. Damage is typically confined to the fruiting structures (McPherson and McPherson, 2000). Stink bugs are often considered fruit piercers as they obtain their food by piercing plant tissue with their stylets to extract plant fluids (McPherson and McPherson, 2000). Stink bugs undergo five nymphal instars before becoming an adult, and all stages with the exception of the 1st instar, which is a non-feeding stage, feed on plant material (McPherson and McPherson, 2000). In general, stink bug feeding can result in the loss of plant fluids, deformation of seeds and fruiting bodies, abortion of seeds and fruiting structures, delayed plant maturations, and leaves the plant vulnerable to a wide array of pathogens (McPherson and McPherson, 2000).

The damage to host plants in the United States ranges from mild, no impact on yield, to severe, complete crop loss (Wetly et al. 2008). In the United States, BMSB has been reported as causing damage to apples, Asian pears, peaches, cherries, corn, tomatoes, peppers, soybean, ornamental plants (particularly butterfly bush, *Buddleia davidii* Franch., and Princess tree, *Paulowa tomentosa* (Thunb.) Siebold & Zucc. ex Steud.) (Leskey, 2010b; Welty et al., 2008).

On fruit crops, the feeding damage is visually obvious. The most notable damage results from the saliva injected into the fruiting body by BMSB during feeding, which damages the fruit leaving brown and white spots behind (ARS, 2010a). Feeding early in the season results in grooves or distorted brown lines on the surface of the fruit (Welty et al., 2008). Late season feeding may cause the surface of the fruit to concave (i.e. pitting), or the flesh of the fruit may become soft or spongy (Hoebeke and Carter, 2003). Late season feeding sites will typically display water soaked spots on the surface or beneath the skin of the fruit (Welty et al., 2008). Severe feeding damage can lead to the complete loss of the fruit (Nault and Speese III, 2002). Damage to fruit may also be compounded by secondary infections by pathogens or visible scarring of the fruit as it matures (Welty et al., 2008). In tomatoes, stink bug feeding can induce early maturity resulting in smaller fruit size and weight and cause the fruit to have a bitter taste and pithy texture (McPherson and McPherson, 2000).

On bean crops, feeding damage is typically found within the pods on the immature seeds. BMSBs can cause significant yield loss by sucking sap from seeds (Hoebeke and Carter, 2003). A single puncture from a stink bug on a soybean seed can prevent germination if the puncture penetrates the axis of the radical-hypocotyl (McPherson and McPherson, 2000). Heavy feeding in soybeans can result in foliar retention, delayed plant maturation, and abnormal growth of the plant (McPherson and McPherson, 2000).

Feeding by both the adult and nymphal stink bugs can cause economic damage to fruits and vegetables. There are unpublished accounts that hundreds of BMSB have been observed to feed on a single fruit or ornamental plant (Hamilton, 2009). Small amounts of feeding damage on fruit and vegetables can render it unmarketable for the fresh market, while sustained injury can also result in the fruit being rejected from processing (Nault and Speese III, 2002; Zalom et al., 1997).

In 2006, BMSB was first documented as causing economic damage in the United States (Hamilton, 2009; Nielsen et al., 2008a), although lower levels of economic damage appeared in 2002 in Pennsylvania (Bernon, 2004). During the 2009 growing season, serious economic injury to several crops including peach, apple, and Asian pear was reported due to large BMSB populations (ARS, 2010a). The most severe damage was reported from Pennsylvania and West Virginia where large populations have been reported (Leskey, 2010c).

A small study conducted in 2006 examined BMSB population levels and the resulting damage in six commercial fruit orchards (peach and apple). To ascertain population levels, three pyramid traps baited with 50 mg lures of methyl (2E, 4E, 6z)- decatrienoate, a general stink bug attractant, were deployed per orchard. There are no specific pheromone lures for BMSB (Khrimian et al., 2008). Trapping began at the end of July, with a trapping average of over 400 specimens per trap for the region, and continued through to September, with a trapping average of less than 100 stink bugs per trap for the region. Population levels between orchards varied greatly independent of control programs. Trapping data was variable with some orchards trapping an average of 1093.3 nymphs in a single week while others trapped an average of 5.3 nymphs in the same week (Leskey, 2010a, 2010b).

From each orchard, 100 fruit were selected from the perimeter row and from the interior of each block to assess the level of fruit injury. The percent of fruit injured varied between orchards with some orchards reporting up to 85 percent of the fruit injured while in other orchards less than 20 percent of the fruit collected was injured. In general, approximately 50 percent of the fruit collected from the perimeter were injured and approximately 35 percent of the fruit collected from the interior were injured. In apple orchards, the percent of fruit injured also varied between orchards with some orchards reporting up to 85 percent of the fruit injured while in other orchards less than 30 percent of the fruit collected was injured. This damage resulted in approximately 60 percent of the fruit collected from the perimeter were injured and approximately 40 percent of the fruit collected from the interior were injured (Leskey, 2010a, 2010b). As expected with a migratory pest, damage caused by BMSB is more severe on the perimeter of the crop than in the interior of the crop stand.

As BSMB continues to cause economic damage in orchards farmers are expected to invest resources in controlling BMSB populations. It is unknown how much such control measures may cost, as most farmers do not routinely treat specifically for stink bugs (McPherson and McPherson, 2000). Consequently, the increased cost of production may be substantial.

BMSB will likely feed on a wide array of Threatened and Endangered plants in the United States. Currently there are no documented reports of damage to any specific Threatened or Endangered plants. However, due to the large population sizes in many areas of the United States and the observed damage to several commercial crops, it is likely that BMSB is already affecting several Threatened and Endangered plants at some level.

Based on the above information there is a high likelihood that BMSB is having and will continue to have direct negative impacts on several industries and the natural landscape in the United States.

2.5.2 Indirect pest effects

Although BMSB is not currently listed as a quarantine pest for any country (CERIS, 2010), several foreign countries may still regulate trade to prevent the entry of BMSB into their country. BMSB has a limited global distribution (only known to occur in Canada, China, Japan, Korea Republic, Switzerland, Taiwan, and the United States CABI, 2010), but could likely survive in several regions of the world, based on its host preference and suitable temperature range. BMSB has been regarded as a non-quarantine pest since 2005 for the United States, and there are no reported trade concerns that have developed due to the presence of this pest. Thus, it is not expected that the spread of BMSB in the United States will result in any additional requirements for trade than is already required for the general hitchhiker pests that may be encountered in the trade of numerous commodities. Furthermore, it is unlikely that the spread of BMSB will result in the loss of market access for any region of the United States.

Within the United States, standard practices for producing many crops may be altered. Small amounts of feeding damage on fruit and vegetables can render it unmarketable for the fresh market, while sustained injury can also result in the fruit being rejected from processing (Nault and Speese III, 2002; Zalom et al., 1997). Growing practices in many agricultural settings do not specifically mitigate for stinkbugs (McPherson and McPherson, 2000). Therefore growers will need to alter their normal practices or adopt additional mitigation measures to combat BMSB. As the production practices for the wide range of hosts likely to be impacted by BMSB vary greatly, it is impossible to quantitatively estimate what the impact of altering those practices will be both in terms of economic and biodiversity impacts.

The spread of BMSB in the United States may also impact several industries that are closely tied with the production of BMSB hosts, such as corn for cattle feed and resulting milk production, and grape production and resulting wine production. Feeding by stink bugs is documented to change the flavor in some crops (McPherson and McPherson, 2000). There is no indication if feeding by BMSB will change the quality of the final product produced from host plants, but such an effect is plausible.

Based on the above information there is a medium likelihood that BMSB will continue to have indirect negative impacts on several industries and the natural landscape in the United States.

2.5.3 Market effects

Feeding by both the adult and nymphal stink bugs can cause economic damage to fruits and vegetables. Native stink bugs currently impact a wide range of host plants. A study in Georgia in 1992 determined that stink bugs and plant bugs caused a $27,164,000 loss to the apple, cotton, field corn, grain sorghum, peach, pecan, small grain, soybean, and vegetables combined, in that State that year (McPherson and McPherson 2000). Feeding by BMSB will likely add to economic losses already attributed to stink bugs in the United States.

In 2009, BMSB was reported to cause economic damage to apples, peaches, cherries, tomatoes, corn, and soybeans (Leskey, 2010a, 2010b).These crops are generally high value economic crops for the United States (Table 1). Losses or diversion from the fresh to process market of these crops due to BMSB feeding could have significant market impacts. The total losses as a result of BMSB feeding throughout the United States are unknown. Several states have reported damage due to BMSB, including: California, Delaware, Maryland, New Jersey, Oregon, Pennsylvania, Tennessee, and West Virginia (Holtz, 2010); however, reliable reports of the specific crops and level of damage is unknown. Researchers at the USDA-ARS research lab in Kearneysville, West Virginia studying the impact of BMSB have provided the most specific reports of damage. Fifty to sixty percent of the stone and pome fruit grown commercially in Maryland and the eastern panhandle West Virginia were observed to be injured by BMSB, and some growers lost their entire crop (Leskey, 2010a, 2010b, 2010c). These losses appear similar to reports the researchers received from southeastern Pennsylvania and parts of New Jersey and Virginia (Leskey, 2010c). In these areas, the population of BMSB is reported to be extremely high (Leskey, 2010c).

The level of damage appears directly correlated with the population level of BMSB. If population levels of BMSB grow to equally high levels in other areas of the United States, similar levels of damage in other portions of the U.S. and on other crops may be expected. This would clearly have an economic impact on the United States agricultural industry. If populations remain small in other areas of the United States, then the economic impact would be expected to be much less than what is reported in the Mid-Atlantic States. Currently, there does not appear to be any environmental limiting factors for BMSB populations. The exact level of damage or monetary value of those potential damages is impossible to predict in this level of analysis.

Table 1: Market value of economically important hosts of BMSB. Values on the table represent the most recent marketing year (Garrett, 2010).

Commodity	**Value of Production in Thousands of Dollars**			**Average Price Difference from Fresh to Processed- in Dollars per Ton**
	Total Value	**Fresh market**	**Processed Utilized**	
Apples	2,246,584	2,036,532	210,052	$1,273
Peaches	593,653	407,661	185,992	$490
Sweet Cherries	505,881	466,865	39,016	$1,226
Tart Cherries	63, 231	1,352	61,879	$0.846
Tomato	2,532,853[2]	1,313,941	1,218,912	$1,313
Bell Pepper	555,643	N/A	N/A	N/A
Corn for Grain	48,588,665	N/A	N/A	N/A
Soybeans	31,760,452	N/A	N/A	N/A
Citrus	3,240,271	1,631,797	1,599,836	N/A[3]
Cotton	3,735,564	N/A	N/A	N/A

Citrus and cotton are also reported hosts of BMSB (Hoebeke and Carter, 2003; Hua, 2000). Currently, there are no reports of damage to these crops in the United States. BMSB has only recently been reported or is not known to occur in states that grow cotton and citrus commercially (Holtz, 2010), therefore these crops may be impacted in the future if BMSB population become established in those states.

BMSB feeds on numerous crops not listed in Table 1 (see Appendix A). The commodities in Table 1 were highlighted due to current reports of damage or a perceived significant impact to the crop, without implying that these are the only crops that BMSB may negatively impact. It is assumed that BMSB could cause some level of economic damage for any host plant grown for commercial purposes, although the exact impact is currently unknown.

Based on the above information, BMSB is having and will continue to have negative market effects on several industries in the United States.

2.5.4 Non-market effects

[2] Calculated from the Fresh Market Value of Production and the Processed Utilized Value of Production.
[3] No value is reported for citrus as the price differential varies greatly between varieties and States. Reporting a single average would have been misleading.

Adult BMSBs aggregate in high numbers when seeking overwintering shelters (Hoebeke and Carter, 2003) often on the side of buildings (Hamilton, 2009). In extreme cases hundreds of adults can aggregate in a single location (Wetly, 2008). Adults eventually enter attics, garages and other structures to overwinter (Hamilton, 2009). There have been several recent reports in the media about homeowners inundated with BMSB in many regions of the U.S. (i.e. Maguire, 2010; Sun, 2010). Home and business owners are expending resources to control BMSB populations on their personal property and in their home gardens, either through chemical treatments or weather-proofing (Adams, 2010; Bozick, 2010). The BMSB does not bite humans or pets, or spread any human diseases (Wetley, 2008); therefore, this pest is considered a nuisance pest.

BMSB is highly polyphagous(Appendix A) and may feed upon a variety of ornamentals and weeds (McPherson and McPherson, 2000). BMSB may expand its host range as it adapts to new areas in the United States. In addition, like other stinkbugs (McPherson and McPherson, 2000), BMSB may feed on plants that are not true hosts. There are unpublished accounts that hundreds of BMSB were observed feeding on a single fruit or ornamental plant (Hamilton, 2009). Therefore it is reasonable to expect that BMSB could displace and directly compete with native stink bugs and other pests for resources. Heavy feeding pressure by BMSB could also damage or reduce native plant species and impact biodiversity throughout the United States.

As BSMB continue to cause economic damage, farmers are expected to invest resources in controlling BMSB populations. It is unknown how much these control measures may cost; as most farmers do not routinely treat specifically for stink bugs (McPherson and McPherson, 2000). Consequently, the increased cost of production may be substantial. The chemical control programs may also negatively impact non-target pests and the environment.

Based on the above information there is a medium likelihood that BMSB is having and will continue to have negative non-market effects on homeowners and biodiversity in the United States.

2.6 Degree of Uncertainty

While there is a wealth of knowledge on stink bugs in general, there is very little specific information available on BMSB. Therefore, there is a moderate degree of uncertainty about how BMSB will behave and what the impact of BMSB will be when introduced into new areas in the United States. Based on the reports available, BMSB appears to be displaying the same general behaviors in all areas of the United States where it is currently established. As a result, it is reasonable to assume that BMSB will have a negative impact in most of the United States.

2.7 Risk Potential

The pest risk potential is a single rating which represents an overall estimate of the risk posed by BMSB. The pest risk potential is arrived at by examining the overall likelihood of introduction, the overall likelihood of establishment, and the overall potential consequences. The significant conclusions of each section are as follows:

Likelihood of introduction and spread:
BMSM is a highly mobile pest capable of migrating between hosts, as well as hitchhiking on a wide array of materials. Once present in an area, BMSB are not inhibited or limited in their movements as demonstrated by its widespread distribution throughout the United States. therefore there is a high likelihood that BMSB will continue to spread throughout the United States.

Likelihood of establishment:
BMSB has an expansive host range that includes tree fruit, legumes, deciduous hardwoods, ornamentals and weeds. Host plants are distributed throughout the United States, therefore there is a high likelihood that BMSB will encounter suitable hosts throughout the United States.

BMSB has a large developmental range and can successfully develop in all areas of the United States. In warmer climates, BMSB could complete multiple generations per year, up to 5 generations in portions of Arizona, Florida, Louisiana, and Texas. Based on the risk map there is a high likelihood that BMSB will encounter a suitable environment in all areas of the United States.

BMSB has a high reproductive potential and survival is favored by the ability of the pest to overwinter in sexual diapauses in protected sites until favorable conditions and hosts become available. Suitable hosts and temperature conditions occur throughout the United States. While there may be some limitations in the number of individuals necessary to establish a new population it does not appear to greatly mitigate the spread of BMSB in the United States. Based on the above information there is a high likelihood that the biological attributes of BMSB will increase its probability of continued establishment throughout the United States.

Potential consequences:
The assessment considered direct, indirect, market, and non-market pest effects in assessing the consequences of BMSB establishing throughout the United States. The assessment concluded that there is a high likelihood that BMSB is having and will continue to have direct negative market impacts and there is a medium likelihood that BMSB is having and will continue to have indirect and non-market negative impacts in the United States. Overall, BMSB has a high likelihood of having a negative impact in the United States.

Pest risk potential:
Based on the high likelihood of introduction and spread, the high likelihood of establishment and high likelihood of a negative impact due to BMSB in the United States, the overall risk potential is high.

III. Risk Management

Currently there are no viable strategies for the comprehensive management of BMSB in the United States (ARS, 2010a). Effective mitigation tools are currently being investigated by government and university researchers.

Population monitoring and survey

Monitoring of stink bug populations is often challenging as these pests are highly mobile and polyphagous (McPherson and McPherson, 2000). There have been multiple efforts to construct a specific pheromone lure for BMSB (Khrimian et al., 2008), but to date, these efforts have been unsuccessful. BMSB is reportedly attracted to pheromones created for other stink bugs (Aldrich et al., 2007; Khrimian et al., 2008), however a specific pheromone lure could be more effective. Lures containing (2E,4E,6Z)-decatrienoate are sufficient for attracting the stink bugs to monitoring traps, the larger the dose and release rate the more BMSBs are attracted to the lure (Leskey and Hogmire, 2005). Pheromone traps with yellow bases were successfully used for monitoring and trapping of BMSB in Maryland from 2004-2008 (Aldrich et al., 2009). Pyramid traps with yellow bases are commonly used for monitoring native stink bugs (Leskey and Hogmire, 2005). Recent research, however, indicates that BMSB is more attracted to a pheromone baited pyramid trap with a dark colored cone base (ARS, 2010b). USDA-ARS is currently researching pheromones and trapping methods to better monitor BMSB populations (ARS, 2010a).

In addition, attract-and-kill management strategies are also under development (ARS, 2010a). Researchers are beginning to explore the behaviorally active stimuli for BMSB, to attract and retain BMSB within specific settings, to allow for the implementation of more precise control strategies (ARS, 2010a). BMSB aggregate in large numbers when seeking overwintering sites. Developing stimuli that attract overwintering aggregations would allow for mass traps or sprays that could directly suppress population densities (Toyama et al., 2006).

Chemical Control

Management options for native stink bugs, *Acrosternum hilare* and *Euschistus servus,* in the Mid-Atlantic States primarily include the use of pyrethroids and organophosphates (Herbert, 2010). The efficacy of each pesticide varies between these native species (Kamminga et al., 2009a; Willrich et al. 2003; Snodgrass et al. 2005). Pyrethroids and organphosphates are recommended for control of *A. hilare*, while only organophosphates are considered to be effective on *Euschistus* spp. (Willrich et al., 2003). *Euschistus servus* has been reported as having a higher LC_{50} value than *A. hilare* for pyrethroids and organophosphates (Greene, 2001; Snodgrass et al., 2005). Combinations of pyrethroids and neonicotinoids have also been reported as being efficacious against stink bugs (Baur et al., 2010; Cullen and Zalom, 2007).

Effective chemical control for the BMSB in the United States is just beginning to be researched. Boss et al. (2002) reported that in India, BMSB is controlled though applications of etofenprox (pyrethroid) (EPA registered but not for food crops) or phenthoate (organophosphate) (Not EPA registered) in middle to late August. Glass-vial bioassays for three classes of technical grade insecticide were tested against BMSB (Nielsen et al., 2008b). Researchers reported that treatment with the pyrethroid, bifenthrin, resulted in the lowest LC_{50} of 0.03 (μg [AI]/cm^2) (mg body mass^{-1}) for males and females. The other pyrethroids tested included β-cyflutrhin, cyfluthrin, fenpropathrin and λ-cyhalothrin. Their LC_{50}s ranged from 0.06-0.49 (μg [AI]/cm^2) (mg body mass^{-1}). Of the neoniconitoids tested, thiomethoxam had the lowest LC_{50}s at 0.05 for females and 0.13 for males (μg [AI]/cm^2) (mg body mass^{-1}). Higher rates were obtained with dinotefuran and acetamiprid. The organophosphate, phosmet, had the highest LC_{50} for all insecticides tested (Nielsen et al., 2008b).

In field trials, ARS (2010b) reported adequate control of BMSB with the carbamate, oxamyl (Vydate C-LV or L, DuPont Crop Protection, Wilmington, DE), and the pyrethroid, cyfluthrin (Tombstone, Loveland Product Inc., Greeley, Colorado). Field exposure of BMSB oxamyl resulted in 96% mortality; cyfluthrin resulted in 29% mortality and 67% moribund 48 h after treatment. Many insects do not die, but rather recover after insecticide treatment, thus requiring further research on the residual activity of these insecticides (ARS, 2010b). The use of kaolin-clay and sulfur in organic apple systems more consistently and effectively reduced BMSB feeding damage on fruit than the conventional insecticides (ARS, 2010b).

In heavily infested areas, BMSB has been reported to quickly repopulate sprayed areas by migrating from untreated areas (ARS, 2010b). Therefore, a high number of insecticide applications are required for treatment in a defined area, currently registered insecticide do not appear to have a residual effect. There is growing concern over the disruption of IPM programs already in place to manage other pests with the increased use of insecticides (ARS, 2010b). There is some evidence that BMSB is developing resistance to pyrethroid insecticides (ARS, 2010b).

As BMSB is a migratory pest it may be advantageous for a variety of crops to treat the perimeter of the field before stink bugs disperse into interior crops (Tillman et al., 2009; Todd and Schumann, 1988).

To decrease house invasions, Watanabe et al. (1994) reported that application of DEET or pyrethroid treated plastic to window frames was effective. For large incursions of stink bugs, insecticide treated window treatments may not be sufficient at reducing the house invading populations (Kobayashi and Kimura, 1969). Caulking of doors and windows will also deter the insects from invading houses (Hamilton and Shearer, 2003).

Cultural Control

Trap cropping (i.e., the practice of planting pest preferred crops as a strategy to reduce feeding pressure in commercial settings) for stink bugs in soybeans through the manipulation of planting dates (Gore et al., 2006) and early maturing varieties has been documented as an effective form of cultural control in soybeans (McPherson et al., 1988). Conversely, a recent paper by Smith et al. (2009) reported that trap cropping was not an effective method of stink bug control in Arkansas soybeans. The efficacy of trap cropping for managing BMSB, and which host to use for trap cropping is unknown.

Development of stink bug resistant varieties, primarily for soybeans is ongoing for native stink bug control (McPherson and McPherson, 2000; McPherson et al., 2007). It is unknown if any of these resistant varieties would also be resistant to BMSB.

Eliminating alternative hosts (Jones and Sullivan, 1982) and overwintering habitats (McPherson and McPherson, 2000) is an effective way to control native stink bug populations. For a species such as BMSB, it would be difficult to employ these types of cultural controls due to the vast host range and preferred overwintering sites of man-made structures.

Biological Control
A stink bug egg parasitoid survey of the Mid-Atlantic States was completed in 2005 and 2006. Koppel et al. (2009) reported four species parasitizing eggs of the native stink bug population. As an introduced pest, BMSB does not have the species specific natural enemies that help control the native insects.

Kim Hoelmer, USDA-ARS, has been researching the impact of natural enemies in the United States, as well as the potential of releasing parasitoids collected from the insect's native range (China). To date his research has concluded

> "In 2005, the USDA –PPQ began monitoring the activity of indigenous natural enemies, in particular parasitoids, that attacked the invasive BMSB in the mid-Atlantic states to determine if a classical biological control program would be warranted in the event the stink bug became a significant pest. The surveys have shown that, although indigenous egg parasitoids (chalcidoid and scelionid wasps) and adult parasitoids (tachinid flies) do attack BMSB at very low levels (typically less than 5%) they do not exert significant impact on BMSB populations here. Indigenous egg parasitoids include several generalist species (*Anastatus* spp., Eupelmidae) which attack a wide range of insect orders and families without great impact, and several *Trissolcus* species (Hymenoptera: Scelionidae). *Trissolcus* species are specialists as egg parasitoids of Pentatomidae and are capable of causing substantial egg mortality, but given their low parasitism rate on BMSB the indigenous North American *Trissolcus* species (whose natural, pre-BMSB hosts are undetermined) appear poorly adapted to BMSB. The tachinid flies (species unknown) that lay eggs on adult BMSB in the Mid-Atlantic States do not appear capable of developing on BMSB, as we have never reared any adult flies from thousands of adults containing fly eggs. Levels of predation of BMSB egg masses were also recorded; although the surveys are not designed to capture and identify predators we have documented that predators include generalist predators such as ants, earwigs, lacewings, etc. In 2010 as BMSB populations have drastically increased, significant levels of egg predation by BMSB itself was observed. The monitoring surveys to date have concentrated on ornamental hosts, but together with cooperators in the newly-formed BMSB Working Group we plan next season to expand the egg parasitism surveys to include several crop types (fruits, vegetables and soybeans), as it is possible that natural enemy activity could vary by habitat and plant host .
>
> Beginning in 2005 I also initiated foreign exploration in Asia (China, Japan and South Korea) to find natural enemies adapted to BMSB in its native range. Tachinid flies are known to attack BMSB in Asia, but without much apparent impact. Egg parasitoids appear to be the most promising agents and we currently have at least three species of Asian *Trissolcus* species obtained from BMSB in Asia in culture in our quarantine facility in Newark. The *Trissolcus* species attacking BMSB in Asia typically cause very high rates of parasitism (50-80%) and are clearly adapted to BMSB. At present there is little knowledge in Asia of the full host range of these species beyond BMSB, and without field studies in

Asia we cannot be certain of their realized host range in nature. Such information would be very helpful in conducting our own host range evaluations in North America. My project resources available for BMSB have thus far been largely devoted to conducting and supporting our surveys for indigenous natural enemies and maintaining the cultures of parasitoids I obtained through foreign exploration. We have initiated host range experiments in our quarantine at Newark, however, and have begun testing several North American pentatomids. Results are still preliminary and more extensive evaluations that include a broader range of species will be required before any agents can be identified as suitable for field release (Hoelmer, 2010)."

One potential *Trissolcus* species from Japan may be worth further exploration. The egg parasitoid *Trissolcus mitsukurii* (Ashmead) (Hymenoptera: Scelionidae) has been reported as parasitizing native stink bugs, including BMSB. Research determined that the parasitoids parasitizing BMSB was more fecund than when infecting the eggs of *Nezara viridula* (L.) and *Plautia crossota stali* Scott (Arakawa et al., 2004).

Due to the wide distribution and vast host range of BMSB in the United States biological control may effective maintain population levels to controllable levels in the long-term.

Regulatory Requirements

BMSB is currently listed as non-reportable/non-actionable for the United States, as BMSB does not meet the definition of a quarantine pest[4] as defined by relevant International Standards for Phytosanitary Measures (ISPM 5, Glossary of Phytosanitary Terms). Therefore, there is currently no regulatory framework in place to federally control BMSB in the United States.

Due to the widespread distribution and broad host range of BMSB in the United States, eradication in not feasible. Quarantining areas of the United States where BMSB currently occurs, to contain the pest to those areas or slow the spread of BMSB is not possible. Due to the large host range of BMSB, regulating the movement of hosts from quarantine areas would be logistically difficult and would severely restrict domestic trade. Furthermore, BMSB is considered a hitchhiker pest and is capable of dispersing over great distances in man-made structures, such as shipping container or cars (Hamilton, 2009; Watanabe et al., 1994). There is no infrastructure in place to inspect all cars and shipping containers moving domestically between states. In addition, BMSB is a highly mobile pest that could move out of quarantine areas on its own.

A coordinated area wide control program for BMSB may be necessary to combat this pest. At this point, however, there are very few control options readily available, and it is impossible to ascertain the most effective methods for controlling BMSB. An area wide program would likely include elements of population monitoring, chemical, cultural, and biological control to effectively control BMSB populations throughout the United States.

[4] Quarantine Pest = A **pest** of potential economic importance to the **area endangered** thereby and not yet present there, or present but not widely distributed and being **officially controlled** (IPPC, 2007).

Summary
There are very few specific mechanisms readily available for controlling BMSB in the United States, but several potential options are currently under development. Eradicating or containing BMSB in the United States is not feasible at this time. A coordinated area wide control program for BMSB may be necessary to combat this pest, but would be difficult to enact with the control options presently available.

IV. Conclusion

This document was prepared in response to a request by Emergency and Domestic Programs (EDP) to evaluate the risks associated with BMSB in the United States to aid in the agency in the re-evaluation of the regulatory status of BMSB (*Halyomorpha halys*).

This assessment used scientific, government and other documents to examine the likelihood of introduction and spread, the likelihood of establishment, and the potential consequence of BMSB in the United States to arrive at a pest risk potential rating.

The pest risk potential for is high for the United States. Furthermore this assessment examined the management strategies employed to control BMSB. There are very few specific mechanisms readily available for controlling BMSB in the United States; therefore it is recommended that resources be devoted to the following:

1. Development of specific pheromone lures and more effective traps for BMSB.
2. Development of 'attract-and-kill' management strategies.
3. Development of effective chemical control strategies for growers and homeowners.
4. Development of an effective biological control program for BMSB.
5. Consideration of a coordinated area wide control program for BMSB.

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Appendix A: BMSB Host List

Table 2: Reported host list for BMSB. This pest's host range is likely larger than what has been reported in the literature and likely includes a wide variety of ornamentals and weeds that have not been specifically documented in the literature. (* indicates hosts used to develop the risk maps in Figure 1 and 2).

Host	**Common name**	**Reference**
Abeliea x *grandiflora* (André) Rehd	Glossy abelia	Bernon, 2004
Acer campestre L.	Hedge maple	Bernon, 2004
Acer palmatum Thunb.	Japanese maple	Bernon, 2004
Acer platanoides L.	Norway maple	Bernon, 2004; Hamilton and Shearer, 2003
Acer pseudoplatanus L.		Wermelinger et al., 2008
Acer rubrum L.	Red maple	Bernon, 2004
Acer spp.*	Maple	Hoebeke and Carter, 2003; Wermelinger et al., 2008
Amelanchier spp.	Shadbush	Bernon, 2004; Hoebeke and Carter, 2003
Arctium minus Bernh.	Burdock	Bernon, 2004
Arctium spp.		Wermelinger et al., 2008
Asparagus officinalis L.*	Asparagus	Hamilton and Shearer, 2003
Asparagus spp.		Bernon, 2004; Wermelinger et al., 2008
Basella rubra Linn.	T'ang ts'oi or Climbing spinach	Hoffman, 1931
Beta vulgaris L.	Beat Root	Hua, 2000
Betula spp.	Birch	Bernon, 2004
Buddleja davidii Franch.	Butterfly bush	Bernon, 2004; Wermelinger et al., 2008
Buddleia spp.	Butterfly bush	Hamilton and Shearer, 2003
Camellia oleifera C. Abel	Tea-oil camellia	Hua, 2000
Capsicum annuum L*	Bell pepper	Bernon, 2004; Leskey, 2010a, 2010b
Caragana arborescens Lam.	Siberian pea shrub	Bernon, 2004; Nielsen and Hamilton, 2009
Carya spp.	Pecan	Bernon, 2004
Catalpa spp.*	Catalpa	Bernon, 2004; Hoebeke and Carter, 2003
Celastrus spp.	Bittersweet	Bernon, 2004
Celosia argentea L.	Princess feather or Cock's comb	Hoffman, 1931
Celtis occidentalis L.	Hackberry	Bernon, 2004
Cercis canadensis L.	Redbud	Bernon, 2004
Cleome spp.	Cleome	Bernon, 2004
Citrus spp.*	Citrus	Wermelinger et al., 2008; Hoebeke and Carter, 2003
Cornus racemosa Lam.	Gray dogwood	Bernon, 2004
Cornus sericea L.	Redosier dogwood	Bernon, 2004

Host	Common name	Reference
Corylus colurna L.	Turkish filbert	Bernon, 2004
Crataegus spp.	Hawthorn	Bernon, 2004
Cryptomeria spp.	Japanese cedar	Wermelinger et al., 2008
Cucumis sativus L.	Cucumber	Bernon, 2004
Cupressus spp.	Cypress	Wermelinger et al., 2008
Decaisnea fargesii Franch.		Wermelinger et al., 2008
Diospyros kaki L.	Persimmon	Hoebeke and Carter, 2003
Diospyros kaki Thunb.	Japanese persimmon	Kawada and Kitamura, 1983
Diospyros spp.*	Persimmon	Bernon, 2004; Hoebeke and Carter, 2003; Wermelinger et al., 2008
Elaeagnus angustifolia L.	Russian olive	Nielsen and Hamilton, 2009
Euonymus alatus (Thunb.) Siebold	Winged Euonymus	Bernon, 2004
Euonymus spp.	Euonymus	Bernon, 2004
Ficus spp.	Fig	Hoebeke and Carter, 2003
Fraxinus americana L.	White ash	Nielsen and Hamilton, 2009
Franxinus spp.	Ash	Bernon, 2004
Glycine max Merrill	Soybean	Bernon, 2004; Hoebeke and Carter, 2003; Wermelinger et al., 2008 Hua, 2000; Son et al., 2000
Gossypium spp.	Cotton	Hua, 2000
Helianthus spp.	Sunflower	Bernon, 2004
Hibiscus rosa-sinensis L	Chinese hibiscus	Hoffman, 1931
Hibiscus spp.		Wermelinger et al., 2008
Ilex opaca Ait.	American holly	Bernon, 2004; Hamilton and Shearer, 2003
Ilex spp.*	Holly	Bernon, 2004
Ilex verticillata (L.) A. Gray	Winterberry holly	Bernon, 2004
Juglans nigra L.*	Walnut	Bernon, 2004
Koelreuteria spp.	Goldenrain Tree	Bernon, 2004
Ligustrum spp.	Privet	Bernon, 2004
Lonicera spp.	Honeysuckle	Bernon, 2004; Hoebeke and Carter, 2003; Wermelinger et al., 2008
Lycopersicon spp.	Tomato	Bernon, 2004
Magnolia stellata (Siebold & Zucc.) Maxim.	Star magnolia	Bernon, 2004
Malus domestica L. (or Brokh)*	Apple	Hua, 2000; Hoebeke and Carter, 2003
Malus spp.	Crabapple	Bernon, 2004; Hamilton and Shearer, 2003; Wermelinger et al., 2008
Morus spp.	Mulberry	Wermelinger et al., 2008; Bernon, 2004; Hoebeke and Carter, 2003
Paulownia spp.	Paulownia	Hoebeke and Carter, 2003
Paulownia tomentosa (Thunb.) Siebold & Zucc. ex Steud.*	Princess Tree or Paulownia	Bernon, 2004; Hoebeke and Carter, 2003; Wermelinger et al., 2008
Phaseolus lunaius Linn.	Lima beans	Hoffman, 1931

Host	Common name	Reference
Phaseolus spp.*	Pole bean, Bush bean	Bernon, 2004
Phaseolus vulgaris L.	String beans	Hamilton and Shearer, 2003; Wermelinger et al., 2008
Pisum sativum L.	Peas	Wermelinger et al., 2008
Platanus occidentalis L.	Sycamore	Bernon, 2004
Prunus armenica L.	Apricot	Bernon, 2004; Wermelinger et al., 2008
Prunus avium L.	Cherry	Wermelinger et al., 2008; Hoebeke and Carter, 2003
Prunus domestica L.	Plum	Bernon, 2004; Wermelinger et al., 2008
Prunus grayana Maxim.	Japanese bird cherry	Funayama, 2007
Prunus mume Sieb. et Zucc	Japanese apricot	Hoebeke and Carter, 2003
Prunus persica Batsch	Japanese peach	Hoebeke and Carter, 2003; Wermelinger et al., 2008; Hua, 2000
Prunus spp.*	Peach,	Bernon, 2004; Leskey, 2010a, 2010b; Wermelinger et al., 2008
Prunus spp.	Ornamental plum, Sour cherry, Black cherry	Bernon, 2004
Pyracantha coccinea M. Roem	Firethorn	Wermelinger et al., 2008
Pyracantha spp.	Firethorn	Bernon, 2004; Hamilton and Shearer, 2003
Pyrus prifolia Nakai	Japanese pear	Hoebeke and Carter, 2003
Pyrus pyrifolia (Burm. f.) Naki	Asian pear	Nielsen and Hamilton, 2009
Pyrus spp.*	Pear	Bernon, 2004; Nielsen and Hamilton, 2009; Hua, 2000;
Rhamnus spp.	Buckthorn	Bernon, 2004
Rhodotypos scandens (Thunb.) Makino	Jetbead	Bernon, 2004
Rhus spp.	Sumac	Bernon, 2004
Rosa rugosa Thunb.	Rugosa rosea	Bernon, 2004; Nielsen and Hamilton, 2009;
Rosa spp.	Rose	Hamilton, 2009
Rubus spp.*	Raspberry	Bernon, 2004; Hamilton and Shearer, 2003; Wermelinger et al., 2008
Salix spp.	Willow	Bernon, 2004; Wermelinger et al., 2008
Sambucus spp.	Elder	Bernon, 2004
Sicyos angulatus L.	Burcucumber	Bernon, 2004
Solanum nigrum L.	Black nightshade	Hoffman, 1931
Solanum spp.	Nightshade	Bernon, 2004
Solanum spp.*	Tomato	Hamilton, 2009; Leskey, 2010a, 2010b
Sorbus spp.	Mountainash	Bernon, 2004
Spiraea spp.	Spirea	Bernon, 2004
Stewartia pseudocamellia Maxim.		Wermelinger et al., 2008
Symphytum spp.	Comfrey	Bernon, 2004
Syringa spp.	Lilac	Bernon, 2004; Wermelinger et al., 2008

Host	**Common name**	**Reference**
Tilia americana L.	Linden	Bernon, 2004
Tilia spp.*	Basswood	Hoebeke and Carter, 2003
Triticum aestivum L.	Wheat	Hua, 2000
Tropaeolum majus L.		Wermelinger et al., 2008
Ulmus spp.	Elm	Hua, 2000
Uncultivated hedge		Nielsen and Hamilton, 2009
Viburnum opulus var. *americanum* Ait.	Highbush cranberry	Nielsen and Hamilton, 2009
Viburnum prunifolium L.	Blackhaw viburnum	Bernon, 2004; Nielsen and Hamilton, 2009
Viburnum setigerum Hance	Tea Viburnum	Bernon, 2004
Vibernum spp.	Cranberry bush	Bernon, 2004
Vigna sesquipedalis L.	Chinese long bean	Hoffman, 1931
Vitis spp.*	Grape	Bernon, 2004; Hamilton, 2009
Vitis vinifera L.	Grapevine	Wermelinger et al., 2008
Zea mays L.*	Corn	Leskey, 2010a, 2010b