Nursery levy at work: **Building Resilience & Biosecurity Capacity**

Threat specific contingency plan for Brown Marmorated Stink Bug

Queensland Department of Agriculture and Fisheries

Nursery & Garden Industry Australia

November 2016

Nursery & Garden Industry Australia

Queensland Government

Acknowledgements

This contingency plan was prepared by Lindy Coates and Andrew Manners (Queensland Department of Agriculture and Fisheries). Thanks go to John McDonald (NGIA) for providing helpful comments that improved this contingency plan significantly. This plan refers extensively to PHA's "Response strategy for exotic stink bugs, with specific focus on Brown marmorated stink bugs (*Halyomorpha halys*)" (2016). Modifications have been made to the plan to make the information relevant to an incursion of BMSB in the nursery industry as per recommendations. As such, this document is designed as an amendment to PHA's response strategy dealing with the nursery industry specifically and should be used together in the event of an incursion.

Table of Contents

1 Purpose and background of this contingency plan

This contingency plan provides background information on pest biology and available control measures to assist production nurseries with preparedness for an incursion into Australia of Brown marmorated stink bug (*Halyomorpha halys*). It provides guidelines and options for steps to be undertaken and considered when developing a Response Plan to this pest. Any Response Plan developed using information in whole or in part from this Contingency Plan must follow procedures as set out in PLANTPLAN and be endorsed by the National Management Group prior to implementation. This contingency plan was developed for the Nursery & Garden Industry Australia (NGIA) and is focused on production nurseries. In the event of an incursion, operations not covered by the NGIA (e.g. retail outlets) will not be eligible for Owner Reimbursement Costs, as defined in the Emergency Plant Pest Response Deed, if affected by actions carried out under an approved Response Plan.

This plan refers extensively to PHA's "Response strategy for exotic stink bugs, with specific focus on Brown marmorated stink bugs (*Halyomorpha halys*)" (2016). Modifications have been made to the plan to make the information relevant to an incursion of BMSB in the nursery industry as per recommendations. As such, this document is designed as an amendment to PHA's response strategy dealing with the nursery industry specifically and should be used together in the event of an incursion.

2 Impact of brown marmorated stink bug

BMSB is native to China, Japan, Korea and Taiwan (Hoebeke and Carter, 2003; Lee *et al*., 2013). It was first introduced into the USA during the mid-1990s, although was not officially reported until 2001. It is now present in many U.S. states, as well as Canada and several European countries.

BMSB has a very wide host range, feeding on over 170 different host plants from a large number of different plant families (Bergmann *et al*., 2016a), including many commercially important fruit, vegetable and ornamental species. Preferred hosts include many woody ornamental plants (e.g. amaranth, catalapa, Eastern redbud, English holly, Southern magnolia, crab apple, moth orchid, yellowwood, London planetree, dogwood, Chinese pistachio and sweet cherry), and economically important food crops (e.g. capsicum, eggplant, tomato, sweet corn, apple, stone fruit, grape, walnut, soybean and sunflower) (Bergmann et al., 2016a; Bakken et al., 2015; Shrewsbury et al., 2016; Lee et al., 2013).

BMSB can cause feeding damage to fruit, kernels, buds, pods, stems and bark (Haye *et al.* 2015). Adults usually feed on fruit, whereas nymphs feed on leaves, stems and fruit. Crop losses can result from direct production losses (e.g. fruit drop, reduced fruit set and yield) as well as from reduced fruit quality (due to feeding damage and contamination) (Rice *et al*., 2014).

BMSB is also a major nuisance pest, as adults aggregate in large numbers in various human-made structures (such as buildings, vehicles, shipping containers/packing crates) during their overwintering phase, producing an unpleasant odour when disturbed (Inkley, 2012).

Pathogenic bacteria and fungi can be introduced as a result of BMSB feeding, leading to the development of fruit rots (Rice *et al*., 2014). BMSB is also considered a vector of Paulownia witches' broom phytoplasma (PaWB) in Asia, which causes a severe decline in the genus *Paulownia* (Hiruki, 1999).

Control of BMSB has added significantly to the cost of production in the United States. BMSB infestations have resulted in up to four-fold increases in pesticide use for tree fruits such as apple and stone fruit, leading to an abandonment of IPM programs and subsequent increase in secondary pests (Rice *et al.* 2014; Joseph *et al.* 2015; Leskey *et al.* 2015). In apple alone, a 2010 outbreak in the mid-Atlantic region of the U.S. resulted in losses totaling over $US 37 million (CABI, 2016).

Some impacts on a wide range of agricultural hosts are given in Appendix 3.

3 Critical tasks

There are a number of areas which will require careful planning or implementation following the detection of BMSB that are not covered in this contingency plan. These tasks include (but are not limited to):

- Determine if BMSB is notifiable as per the state/s legislation.
- Identify diagnostic laboratories capable of promptly identifying BMSB.
- Prepare fact sheets and posters as part of the communication/education strategy.
- Define a program for surveillance for early detection.
- Contact APVMA to activate emergency pesticide permits

4 Australian nursery industry

The Australian nursery industry is a significant horticultural sector with a combined supply chain (production to retail/grower) valued at more than $6 billion dollars annually. The industry employs approximately 45,000 people spread over more than 20,000 small to medium sized businesses, including production nurseries and retail outlets. The industry is located predominantly along the Australian coastline, and in major inland regions servicing urban and production horticulture.

Nursery production adds significant value to Australia's primary industry's sector annually, contributing more than $2 billion to the national economy. Nursery production is a highly diverse industry, providing a critical service to the broader horticultural sector, valued at $14 billion within Australia (Table 1).

Table 1. Nursery production supply sectors within Australian horticulture

Production nursery	Horticultural market	Economic value
Container stock [1]	Ornamental/urban horticulture	$2 billion retail value
Foliage plants [1]	Interior-scapes	$87 million industry
Seedling stock [2]	Vegetable growers	$3.3 billion industry
Forestry stock [3]	Plantation timber	$1.7 billion industry
Fruit and nut tree stock [2]	Orchardists	$5.2 billion industry
Landscape stock [1]	Domestic & commercial projects	$2 billion industry
Plug and tube stock [4]	Cut flower	$319 million industry
Revegetation stock	Farmers, government, landcare groups	$109 million industry
Mine revegetation	Mine site rehabilitation	Value unknown

5 Pest information/status – BMSB

5.1 Pest details

Table 2. *Halyomorpha halys*

Common names	Brown marmorated stink bug
Scientific name	*Halyomorpha halys* (Stal) (Hemiptera: Pentatomidae)
Synonyms	*Pentatoma halys*

5.2 Biology

For detailed aspects of the biology of BMSB, refer to the Pest Risk Assessment (2016)[5]. Information deemed to be of most significance to the immediate response are outlined below:

- Like many stink/shield bugs, BMSB is dormant in cooler winter temperatures and emerges when temperatures increase in spring. In the United States, BMSB begins mating about two weeks after emerging from its overwintering dormancy. In this two week period, adults need to feed and do not appear to respond to aggregation or sex pheromones.

- Diapause appears most strongly controlled by day length, with a threshold of 14.8 - 15.5 hours day length required to break diapause (Rice *et al.* 2014). While records

1 Data sourced from Market Monitor
2 Data sourced from Horticultural Handbook 2004
3 Data sourced from ABARE 2005
4 Data sourced from industry

5 Full citation for the Pest Risk Assessment will be provided once this document is released

have indicated four to possibly six generations per year in parts of sub-tropical China, evidence from Korea and the United States indicates 1-2 generations are more likely (Penn State Entomological Notes, 2013; Ingels *et al.* 2015; Lee 2015). In the Northern United States (e.g. New Jersey), one generation per year is more common, while in West Virginia, it appears to undergo two generations per year (Leskey *et al.* 2015). Where two generations occur in the United States, overwintering adults emerge in May and lay eggs. These develop into first summer generation adults, which mature around mid-late July, then lay eggs which develop into adults early September (Leskey *et al.* 2015). The minimum temperature for development is 14.1°C (Nielsen *et al.* 2008; Basnet *et al.* 2015).

- In the eastern United States, decreasing day length and temperature in late August triggers adults to congregate on plant hosts prior to seeking refuge sites for their overwintering phase (Leskey *et al.* 2012a).

- BMSB has a relatively high survival rate over winter down to temperatures of about 4°C. Increasing the mean winter temperature increases winter survival rates of BMSB significantly (Kiritani 2006; 2007).

- Eggs are laid on the underside of leaves and egg hatch is strongly influenced by temperature. At 30°C egg hatch can occur in as little as 3-4 days, while at cooler temperatures (15°C) egg hatching takes 22-26 days. Eggs do not hatch at temperatures >35°C (Lee 2015).

- BMSB has 5 nymphal stages. Early stage nymphs are more brightly coloured than adults.

5.2.1 Host range

BMSB feeds on a wide range of fruit, vegetables, ornamentals, forestry and legume crops, with over 170 host plants reported from many different families (Bergmann *et al*., 2016).

Preferred ornamental host plants include amaranth, catalapa, Eastern redbud, English holly, Southern magnolia, various *Malus* spp. (e.g. crab apple), moth orchid, yellowwood, London planetree, dogwood, Chinese pistachio and various *Prunus* spp. (e.g. sweet cherry) (Bergmann *et al*., 2016a; Bakken *et al*., 2015; Shrewsbury *et al*., 2016; Lee *et al*., 2013), but many other ornamental species (over 80) can be affected (Wainwright-Evans and Palmer, 2011; Shrewsbury *et al*., 2011). Many ornamental plant hosts of BMSB are woody species, but some are herbaceous plants such as dahlia, chrysanthemum, spider flower, impatiens, tiger lily, sunflower and zinnia (Shrewsbury *et al*., 2011). In visual surveys of 220 plant taxa in commercial nurseries in Maryland (USA), Martinson *et al*. (2016) reported that BMSB was more abundant on non-Asian plants and selected these over Asian plants.

Preferred agricultural crops in the U.S. include capsicum, eggplant, tomato, sweet corn, apple, stone fruit, grape, walnut, soybean and sunflower (Bergmann *et al*., 2016a; Bakken *et al*., 2015).

There are also a number of wild hosts of BMSB reported in the U.S., including preferred hosts such as Tree of Heaven (*Ailanthus altissima*), sensitive plant (*Mimosa* sp.), Princess tree (*Paulownia tomentose)* and white mulberry (*Morus alba*) (Bergmann *et al*., 2016a).

Current host lists (not exhaustive) can be found at:

http://www.cabi.org/isc/datasheet/27377

http://www.stopbmsb.org/where-is-bmsb/host-plants/

http://www.northeastipm.org/neipm/assets/File/BMSB%20Resources/ESA-Eastern-Branch-2011/05-Brown-Marmorated-Stink-Bug-Activities-in-Ornamental-Systems-and-Research-Plans-for-2011.pdf

Recent research suggests that BMSB preferentially targets plants bearing mature fruits. Martinson *et al*. (2015) surveyed 223 cultivars of woody plants in production nurseries in Maryland (USA), and found that fruit maturity was a strong predictor of the seasonal abundance and within-tree distribution of BMSB. The conclusion drawn was that in landscapes with a high diversity of plant species, BMSB preferentially targets plants bearing mature fruits, despite being widely regarded as a broad-feeding generalist pest species. A separate 3 year survey of production nurseries in Maryland (Bergmann *et al*., 2016b) evaluated the host status of 254 species/cultivated varieties of woody ornamental trees and shrubs. A total of 88 taxa were identified as BMSB hosts (some new hosts not previously reported), 43 taxa identified as non-hosts (not supporting any life stage of BMSB), and 123 identified as partial hosts (i.e. supporting some but not all life stages). In some cases, non-host status was related to the timing or absence of fruiting resources. Of the non-hosts, some were congeners of plants identified as hosts (e.g. *Acer palmatum* identified as a non-host, and *Acer rubrum* identified as a host), indicating the high intrageneric variation in the use of plants by this pest species. The authors noted that while some gymnosperms were found to be partial hosts, none were identified as full hosts, suggesting a role for these species in reducing BMSB populations in diverse landscapes.

5.2.2 Damage and symptoms

BMSB nymphs and adults cause direct damage by piercing fruit (or other plant parts such as leaves and stems) and sucking out juices in a straw-like fashion (Gyeltshen *et al*., 2013). Small necrotic spots often appear around feeding sites, from which secondary infections may develop during fruit maturation. Feeding damage often causes depressed or sunken areas on fruit that become ‘cat-faced’ (a characteristic deformity) as the fruit develops (CABI 2016). Corking inside fruit may also occur. Symptoms do however vary according to host species, with apple for example typically showing pitting and discolouration symptoms, and peach often showing cat-facing.

On woody ornamental plants, damage can occur from large numbers of BMSB feeding on the phloem sap of trunks and branches, causing wounding, wet spots, scarring and tree stress (Shrewsbury *et al*., 2011, 2016; Wiman, 2015). Ants and stinging Hymenoptera may be attracted to feeding wounds on trunks, and disease transmission/secondary infections can occur. Leaves and fruit can become discoloured and develop spots, and fruit can become deformed as previously described. Recent research from the U.S. (University of Maryland) indicates that deciduous trees which produce seeds or fruits are the plants most likely to host BMSB (Wiman, 2015).

BMSB will also feed on a select number of herbaceous perennial plants, particularly when high populations of the pest are present (Kunkel, 2014). Feeding sites in these hosts are usually flowers, seed pods or fruiting parts. In some herbaceous ornamental host plants, plant death has been reported as a result of BMSB infestation (Shrewsbury *et. al.*, 2011).

Images of BMSB damage in a range of hosts can be found at: http://www.stopbmsb.org/where-is-bmsb/host-plants/ and http://www.stopbmsb.org/where-is-bmsb/bmsb-damage-gallery/.

5.2.3 Geographical distribution

The current worldwide geographical distribution of *Halyomorpha halys*, based on all hosts, is given below (more details in CABI, 2016 and Bergmann *et al*., 2016b):

Asia: China, Japan, Korea, Taiwan

North America: Canada (restricted distribution), USA (widespread, 42 states)

Europe: France, Germany (restricted distribution), Switzerland, Greece, Italy, Liechtenstein, Romania and Hungary.

Oceania: Guam

Increased numbers of BMSB border interceptions have also been reported in Australia and New Zealand (Bergmann *et al*., 2016b; MacLellan, 2013).

5.2.4 Diagnostic information

An identification guide for Brown marmorated stink bug (*Halymorpha halys* and other similar bugs) has been developed by the Department of Agriculture and Water Resources and PaDIL.

There are a number of stink bug species similar to BMSB in Australia, as well as several species that are exotic to Australia. Each species has characteristic features that can be identified by experienced personnel. A nationally endorsed diagnostic protocol has not been developed.

A summary description of BMSB (adapted from the University of Florida Featured Creatures website) is as follows:

- Adult BMSB has a shield-shaped body (Figure 1) and emits a pungent odour when disturbed. Adult females are 14.4 mm mean body length and adult males are 12 mm mean body length. Average length is given as a range of 12-17 mm long (Lee 2015).

- Adults and late stage nymphs are mottled brown. Both males and females have characteristic alternating dark and light bands across the last two antennal segments that appear as a single white band. The exposed lateral margins of the abdomen have alternate bands of brown and white in both nymphs and adults.

- Nymphs lack fully developed wings and have been described as tick-like in appearance, ranging in size from 2.4 mm (1st instar) to 12 mm (5th instar). First instars are orange or red (Figure 2).

Figure 1 Adult Brown Marmorated Stink Bug (image courtesy Bugwood.org: D.R. Lance, USDA APHIS

Figure 2 Brown marmorated stink bug egg mass and newly hatched nymphs (image courtesy Bugwood.org: G. Bernon, USDA, APHIS)

5.2.5 Dispersal

- Adult BMSB are strong fliers when temperatures increase over 20^{o}C (adults do not fly when temperatures are <16^{o}C). While they can fly distances of up to 117 km in 22 hours, they more commonly fly distances of <5 km (Wiman *et al.* 2014; Lee, 2015). In spring and summer, adults will fly in search of a food source and will preferentially seek mature fruit crops (Martinson *et al.* 2015).

- As day length decreases in autumn and winter and temperatures cool, adults will seek sheltered sites to overwinter.

- Long distance dispersal of stink bugs occurs by human-assisted means, particularly as they seek refuge as part of their overwintering strategy in autumn and winter. They are capable of hitchhiking in cargo, packing crates, aircraft, machinery, vehicles and personal luggage (Haye *et al.* 2015).

- In summer, adults may be active at night and will fly if temperatures are over 20^{o}C.

- Dispersal in summer occurs as adults fly to seek new mates or food sources and although they will feed on many plant species, they are strongly attracted to ripened fruit and vegetables and will move readily in search of these food sources. In summer, BMSB may seek shade within trees but also in vehicles and equipment and could be dispersed to new areas by human-assisted means.

- Nymphs do not fly but are active walkers, especially when temperatures are >25ºC. Nymphs will move readily between gardens, paddocks and orchards in search of a food source. Under laboratory conditions, nymphs have been shown to disperse at 3 m per hour (Lee *et al.* 2014b).

- Both adults and nymphs are described as very defensive and will drop or move quickly when disturbed (Leskey *et al.* 2015).

5.2.6 Availability of control measures

BMSB is difficult to control, and the insecticides that do provide control are generally toxic to beneficials (Wainwright-Evans and Palmer, 2011). Insecticides reported to have efficacy against BMSB in the U.S. include acephate, acetamiprid, bifenthrin, chlorpyrifos, cypermethrin, dimethoate, dinotefuron, endosulfan, malathion, methidation, methomyl, permethrin and combinations of pyrethroids and neonicotinoids (Wainwright-Evans and Palmer, 2011; Dudek, 2013). More information on insecticides potentially available for use in Australia in the event of an incursion of BMSB is provided in Section 7.3.4.

Trapping and baiting BMSB is another management strategy under evaluation in the U.S., with the aggregation pheromone of the Asian brown-winged green bug being one example of a potential treatment (Wainwright-Evans and Palmer, 2001).

A combination of mechanical exclusion and insecticide application are recommended for the control of overwintering populations of BMSB in buildings and other human-made structures (Gyeltshen *et al*., 2013). This would be highly relevant to the various structures associated with production nurseries.

Venugopal *et al.* (2015) found that the edges (0-5 m) of production areas generally support higher numbers of BMSB than the core (15-20 m) of production areas, thus it has been suggested that BMSB management and crop monitoring strategies should preferentially target these areas. In production nursery situations where there are a diversity of species grown, there may also be opportunity to reduce BMSB populations by growing non-preferred host species or varieties where possible, particularly around the edges of production areas. A number of conifer species are known to be non- or only partial hosts in the U.S., and as such may play a role in BMSB management as edge plants (Shrewsbury, 2016). As the production of reproductive structures such as fruit, pods and seeds is a factor in the relative risk for BMSB attack (Martinson *et al*., 2015), persistence of these food sources may be another consideration in production nurseries.

Biological control perhaps provides the best hope for control of BSMB where it has become established, but is currently not available as an eradication strategy during an incursion. So far native beneficials in the U.S. have failed to control BMSB populations, but Asian parasitoids in the genus *Trissolcus* attack BMSB eggs and may have future potential. *Trissolcus halymorphae* has been identified as the primary biocontrol agent responsible for the control of BSMB in China (Yang *et al*., 2009). Recently Wiman (2015) reported that one of the Asian parasitoid species being evaluated in U.S. quarantine has been found outside quarantine as a result of an unrelated introduction into the country. This species is expected to eventually spread across the U.S., ultimately reducing BMSB populations.

Traps using entomopathogenic fungi to kill BMSB are also under evaluation in the U.S. (Shrewsbury *et al*., 2011). McClellan (2015) noted that a naturally occurring fungus, *Ophiocordyceps nutans*, attacks BMSB in Japan. Other fungi have also been shown in laboratory studies to target BMSB.

Ultimately it is likely that management of BMSB will incorporate biological control with crop monitoring and strategic insecticide application in a more sustainable IPM program.

6 Surveillance and collection of samples

6.1 Surveillance

6.1.1 Technical information for planning surveys

Detection and delimiting surveys are required to determine the extent of the outbreak, ensuring areas free of the pest retain market access and appropriate quarantine zones are established.

Initial surveillance priorities for BMSB should include the following:

- In spring, summer and potentially into autumn, stink bugs will be feeding. Particular focus should be on plants and crops with ripe/ripening fruit such as apples, pears, berry crops and summerfruit, vegetables such as tomatoes, capsicums, sweetcorn and eggplant, or ornamental plants bearing reproductive structures.

- BMSB appears to move from edges of crops and orchards and therefore it is suggested crop edges should be targeted in surveillance activities. BMSB nymphs and adults were found to be more abundant at the edges of production areas/fields (0-5m from edges) than in the core of production areas/fields (15-20m from edges) (Venugopal *et al.* 2015)

- Ornamental trees such as the weed species Tree of Heaven (*Ailanthus altissima*) and Princess tree (*Paulownia tomentose)* as well as English holly (*Ilex aquifolium)*, Magnolia (*Magnolia grandiflora)* and Chinese pistachio (*Pistacia chinensis*) have been observed as preferential hosts for BMSB (Lee *et al.* 2013) (Refer to Bergmann *et al*. (2016a) for a more comprehensive list of preferred ornamental and wild hosts).

- Red sorghum and sunflower have been used as trap crops in the United States possibly as they are tall, brightly coloured and have seeds that are good protein sources (Zinati 2015). In broadacre situations in the northern cropping areas, these crops may therefore be useful ones to monitor or undertake surveillance.

- In cooler conditions (<16^{o}C), stink bugs will be in an overwintering state and focus for BMSB surveillance should be on:

    - Large (>60 cm diameter), dead trees with porous dead tissue and peeling bark (Lee *et al.* 2014a).

- Refuges such as buildings or structures. In the United States, BMSB appear to aggregate in darker locations for their overwintering sites (Lee *et al.* 2013).

- If undertaking visual surveillance in plant crops, BMSB may be difficult to observe as a result of defensive behaviour which causes them to drop to the ground when disturbed.

- There is some evidence that BMSB prefers to aggregate (and feed) at tree tops, although little information is available on whether this refers to all tree species or whether there is a time of year or temperature component to this preference (Leskey *et al.* 2012b). It has been suggested that this tendency for aggregation at tree tops will make ground-based surveillance difficult in established orchards or within larger trees in backyards (Leskey *et al.* 2012b).

6.1.1.1 Surveillance tools

- The most effective traps trialed in the eastern United States were 1.5 m tall black pyramid traps placed on the ground (Leskey *et al.* 2012c; Leskey *et al.* 2015). It is believed that darker colour traps are effective as they mimic trunks of trees and BMSB have a natural tendency to climb upwards (Leskey *et al.* 2012c).

- Lures have been investigated for both traps and sticky strips with a two component aggregating pheromone (100 mg) and the synergist pheromone methyl (2*E*,4*E*,6*Z*)-decatrienoate (MDT) (66 mg) proving to be effective (Ingels *et al.* 2015; Leskey *et al.* 2015). Commercial lures are available from the United States (see Appendix 4 for examples of sources of monitoring tools).

- Research undertaken in the eastern states of the U.S. has focussed on management of BMSB using traps and attractants i,e, not for eradication or delimiting surveillance purposes. There is evidence that there is a linear relationship between attractant dosage and efficacy i.e. higher concentrations of attractants (up to 500 mg of methyl (2*E*,4*E*,6*Z*)-decatrienoate (MDT)) attract more BMSB (Leskey *et al.* 2012c; Leskey *et al.* 2015).

- Research is required on the optimum lure dosage, trap placement and trap type for early detection, eradication or delimiting surveillance.

- Trapping grids of 20-25 m apart have been used within management programs in the United States (Quarles, http://www.stopbmsb.org/managing-bmsb/management-overview) however a wider trapping array may be possible with higher dose lures. No information is available on the use of traps within eradication programs as no country or region has attempted to eradicate BMSB.

- Lures with incorporation of kill strip in traps, resulted in increased collection of BMSB (Ingels *et al.* 2015). Lures should be replaced every 4-6 weeks and fresh kill strips are more likely to be effective than 3 week old strips (Joseph *et al.* 2013).

- There is some evidence that sticky strips embedded with pheromone lures may also be effective (Ingels *et al.* 2015) for placement within trees. Insects caught in sticky traps can suffer predation from birds and may therefore be less effective in a delimiting surveillance program.

- Foliage should be inspected within 1 - 2 m of lures traps as BMSB may be attracted to the lure but not enter the trap (Ingels *et al.* 2015).

- BMSB is attracted to light sources and light traps can be used for detection (Nielsen *et al.* 2013). Night time temperatures below 15ºC will limit the usefulness of light traps however, as insect movement is reduced in cooler conditions. At night, adults will only fly when temperatures are >20ºC. A simple light trap can be made by shining a light into an aluminium tray filled with soapy water.

- Beat sheets placed under trees (then tap or hit tree limbs to cause BMSB to drop) have been used as a surveillance tool however stink bugs can be difficult to detect due to hiding behaviour, nocturnal activity or presence higher in the tree (Nielsen and Hamilton, 2009).

- In the United States, detector dogs have been used to assist detection of overwintering populations of BMSB. Use of detector dogs, coupled with visual identification of key tree characteristics by surveillance personnel, increased detection efficiency to 84% in woodland situations (Lee, 2014a).

6.1.2 Monitoring by nursery producers

Systematic, regular and careful inspection of nursery plants and propagated material for signs of pests and disease should be the basis of all monitoring processes. A range of detection methods should be implemented and performed by production nursery managers or consultants on behalf of the grower/owner.

If it is not feasible to monitor all plants at the one time (because the number of plants and area involved are too great), a representative sample of all host plant species should be visually inspected on a weekly basis. Different plants should be monitored each week such that all plants are inspected at least once per month, preferably at least twice. It should be noted that BMSB nymphs and adults are typically more abundant at the edges of production areas (0-5 m from edges) than in the core of production areas (15-20 m from edges) (Venugopal *et al*., 2015), so monitoring efforts should be intensified in these locations. While BMSB attacks a wide range of plant species, it does have preferred hosts, and preferred host phenological stages (i.e. presence of reproductive structures such as fruit, seeds, pods, etc.), which should also be the focus of nursery monitoring.

Suspected detections of BMSB should be reported to the Emergency Plant Pest Hotline (1800 084 881).

The NGIA Nursery Production Farm Management System provides greater detail on crop monitoring, site surveillance and consignment inspections under the Biosecure HACCP program.

6.1.3 Delimiting surveys in the event of an incursion

BMSB has a very wide host range, and in spring and summer will disperse by walking and flying in search of food or mates. In winter BMSB will disperse to refuges (e.g. buildings and trees) in search of shelter.

Following BMSB detection, the following points are recommended for delimiting surveillance:

- Surveillance should occur within a 5 km zone[6] around the initial detection.
- Surveillance should be a combination of the following:
  - Visual inspection of high risk areas (e.g. trees with mature fruit and vegetable crops)
  - Sticky traps or pyramid traps with pheromone lures for BMSB
  - If night time temperatures are > 20ºC, light traps should be deployed
  - Beat sheets for fruit trees may be an option
- Surveillance will need to be accompanied with public awareness material, personal visits to households and businesses within the surveillance zone and buffer zones, signage and targeted awareness material for businesses.

6.1.4 General surveillance

6.1.4.1 Activities for general surveillance immediately following a detection

Given the comparatively large size of adult BMSB (12-17 mm long), its impact as a nuisance pest in urban environments, and its damage to many commercial crops, BMSB will be a suitable target for general surveillance programs that request submission of images and/or samples. To establish a general surveillance program, the following will be required:

- As there are native stink bugs that appear similar to BMSB, diagnostic laboratory(ies) will be needed to triage and diagnose images and samples submitted as part of a general surveillance program.
- On-line or app reporting tools such as MyPestGuide should be established and promoted to allow submission of reports of suspected BMSB detections.
- Factsheets to provide information on the pest, symptoms, impacts and reporting mechanisms
- Media releases to describe the impact of the pest, surveillance programs and activities within the response program.
- Information for industry communication channels including articles for industry newsletters, magazines and websites, information for Twitter feeds and Facebook and presentations for industry talks.

[6] A 5 km zone has been proposed following discussion with experts and also in consultation with government agencies to provide an indication of a proposed management zone that may be feasible in an incursion response. 5 km is the average distance adult BMSB fly in search of a food source (Section 5.2.5).

- A website to provide information for the public and for commercial businesses and links to other relevant sites such as www.StopBMSB.org

- Release and promotion of information on details for physical sample collection and submission, as well as information on how to take and send images of stink bugs.

- An example of engagement with affected urban communities in the United States to assist with monitoring/trapping can be found at http://njaes.rutgers.edu/stinkbug/.

- Broader awareness campaigns should consider literature (brochures and factsheets) in several languages.

6.1.5 Stakeholder engagement

Issues to be considered in engagement with stakeholders on BMSB includes:

- BMSB's wide host range and its high ability to move between crops.

- The expected impact on crop production and potentially on trade. In the United States, Integrated Pest Management within crops has been affected as a result of increased sprays which have reduced numbers of beneficial insects or arachnids controlling secondary pests (Joseph *et al.* 2015).

- Nuisance potential in homes and gardens (smell, invasive potential and difficulty of keeping out of structures, damage to fruit, vegetables and ornamentals).

- Given BMSB appear to congregate higher in trees (Leskey *et al.* 2012b), aerial sprays could be considered to achieve best coverage of host vegetation. Stakeholder engagement associated with aerial spray programs would need to be considered and may not be feasible for urban environments.

- Access to private properties for surveillance or treatment.

Groups that should be engaged following a detection include:

- Nursery and Garden Industry Australia (NGIA), state NGI's; production nurseries and retail outlets

- Host industry group associations/peak industry bodies

- Parks and garden organisations, e.g. botanic gardens, national/state parks

- Local councils/main road authorities that may have roadside host plants

- Relevant community groups, e.g. groups that maintain community gardens

- The general public

6.2 Collection and treatment of samples

- Follow the PLANTPLAN procedure for hard bodied pests.

- For stink bugs, United States protocols recommend that no ventilation holes are required for live insects (See **https://njaes.rutgers.edu/stinkbug/faq.asp** for an example of sample submission protocols from New Jersey Agricultural Experimental Station).

For submission of samples for DNA analysis, stink bugs can be placed in 95% ethanol.

7 Course of action – immediate response to a detection

For a range of specifically designed procedures for the emergency response to a pest incursion and a general communication strategy refer to PLANTPLAN (Plant Health Australia 2014).

7.1 Tracing

Detection and delimiting surveys are required to delimit the extent of the outbreak, ensuring areas free of the pest retain market access and appropriate quarantine zones are established.

Extensive forward tracing may not be feasible or useful as BMSB adults can readily disperse by flying however if trace forwards are conducted, focus should be on high risk linkages such as:

- Premises linked directly with the initial detection, particularly where movements of vehicles or freight may have moved BMSB long distances.

- In spring/summer, linkages to commercial production, particularly areas where plant hosts are available.

- In autumn/winter, focus should be on premises that have received equipment, vehicles, machinery from the Infected Premise that may have received stink bugs as hitchhikers.

For trace-backs, focus should include:

- Any material (products, equipment, machinery) received from overseas within a 12 month period.

- Note that BMSB is a hitchhiker and has been shown to be transported in personal effects.

7.2 Quarantine and movement controls

7.2.1 Movement controls

- If Restricted or Quarantine Areas are practical, movement of equipment or machinery should occur by permit. Movement controls should include visual inspection and potentially treatment for stink bugs. Disinfestation using heat treatment and/or fumigation has been used on larger complex machinery and equipment. If seeking refuge, BMSB can be difficult to locate using visual inspection.

- The size of the Restricted Area will be dependent on the type and scale of the incursion however a 5 km zone is recommended as the area in which surveillance should be undertaken to begin initial delimitation (Section 6.1.3).

- Voluntary movement control should be considered for urban/residential detections. Voluntary controls would involve negotiation with residents to undertaken inspection and treatment of goods prior to movement from Infested Premises. Residents should be advised on measures to minimise the inadvertent transport of the pest from the infested area to unaffected areas. Voluntary compliance is likely to be implemented for urban areas using awareness campaigns to highlight high risk goods/situations and appropriate treatments.

7.3 Destruction strategy

7.3.1 Physical exclusion and control of stink bugs

Physical methods for exclusion have been useful for management of BMSB in the United States. It should be noted these methods have only been implemented with respect to managing high numbers of BMSB and would need to be assessed for effectiveness and practicality within an eradication program e.g. used in conjunction with chemical sprays or in limiting spread from an initial detection as a component of eradication.

In organic vegetable production in the United States, exclusion netting has been used however maintaining netting is difficult and costly (Lee *et al.* 2013). Netting has also been used in combination with chemical sprays at the edges of orchards to stop stink bugs entering crops. For households in the U.S., the following physical methods of exclusion have been reports (Anon, 2010):

- Physical sealing of structures to limit entry (or exit in the case of an eradication program) of stink bugs.

- Netting of 0.1 cm or mosquito netting treated with pyrethroids has been found to be useful for exclusion of stink bugs.

7.3.2 Physical removal of BMSB

As noted in Section 7.3.1, physical methods for control have been useful for management of high numbers of BMSB, however it would need to be assessed for effectiveness and practicality within an eradication program e.g. used in conjunction with chemical sprays or in limiting spread from an initial detection as a component of eradication. Sargent *et al.* (2011) reports the following physical methods for removal of BMSB:

- Vacuuming up bugs and killing in soapy water.

- Using natural dropping behaviour to collect BMSB – place container under bugs and broom over the top of them. BMSB will tend to drop into the container and can be killed in soapy water.

- Collect and kill BMSB by creating a light trap – shine a light into an aluminium tray filled with soapy water. Note that BMSM will only fly at night if temperatures are >20^{o}C.

- Use of lure and kill traps. Sticky traps impregnated with lure pheromones have been used in the U.S. in management programs. No eradication has been attempted in the U.S. using lure and kill, and research would be required on trap distribution and pheromone concentration if considered for eradication purposes.

7.3.3 Removal of hosts

While not a common method of control in the U.S., removal of specific hosts such as Tree of Heaven (*Ailanthus altissima*) has been listed as a cultural control method to limit numbers of BMSB and remove key hosts that provide a food source (http://www.berriesnw.com/DisordersDetail.asp?id=151).

Removal of hosts could be considered as part of an eradication program if it is suspected that egg masses may be present or if this will assist in limiting refuges. This may be more impactful if its distribution is limited. In contained situations such as glasshouses, removal of hosts could be considered to limit the availability of refuges for nymphs and adults however, as nymphs and adults are easily disturbed, unless coupled with insecticide control, movement of host material could cause insects to rapidly disperse.

Alternatively, maintenance of a small number of key hosts could be considered as sentinels within an ongoing surveillance program to declare area freedom.

7.3.4 Chemical control

Considerable work has been undertaken in the United States to identify control (but not eradication) methods for BMSB. Active ingredients that have been most effective include pyrethroids (bifenthrin, permethrin, fenpropathrin, beta-cyfluthrin), neonicotinoids (dinotefuran, clothianidin and thiamethoxam), carbamates (methomyl, oxamyl) and organophosphates (acephate, dimethoate, methidathion, chlorpyrifos) (Lee *at al*. 2012d, 2013; Rice *et al.* 2014).

Overwintered adults appeared more susceptible to insecticides than F1 adults that emerge later in the season (Lee *et al.* 2014a).

In the U.S., the focus of control is on management and reduction of stink bug levels to levels that minimise commercial damage in crops rather than eradication. Three key challenges are noted with control of BMSB:

- The sheer number of individuals that are present in crops.

- Poor efficacy of many chemicals. Some chemicals e.g. neonicotinoids and pyrethroids can cause knockdown only and up to 33% of BMSB can recover from chemical application. Residual activity of some chemicals is poor (there is greater residual effect on nymphs compared with adults).

- Disruption of Integrated Pest Management (IPM) systems is a major issue in the United States as more aggressive chemicals must be used more frequently. More frequent use of chemicals and disruption to IPM has resulted in secondary pests becoming more damaging or developing increased levels of chemical resistance (for example Green peach aphid) (Leskey *et al.* 2015; Joseph *et al.* 2015).

Emergency permit applications which have been submitted to APVMA for control of BMSB in the event of an incursion into Australia are listed in the PHA response strategy for BMSB (refer to Table 1 in PHA response plan). In addition, a number of products have general registrations against bugs that would allow for their application against BMSB.

Table 3. Active ingredients with current registrations that could be used against BMSB in home and garden or production nurseries.

Mode of action group	Active ingredient	Example product	Home Garden or Commercial	Registration details
1B	Diazinon	Diazinon	C	Registered against plant bugs on nursery plants
1B	Methidathion	Suprathion	C	Registered against plant bugs on ornamentals, trees, shrubs in nurseries, parks, gardens and forestry situations.
3A	Beta-cyfluthrin	Tempo	C	Registered against bugs generally but only on azaleas, hibiscus, pelargoniums and roses
3A	Beta-cyfluthrin	Bayer advanced lawn and garden	H	Registered against bugs generally but only on azaleas, hibiscus, pelargoniums, roses, broccoli, brussels sprouts, cabbages, cauliflowers, and tomatoes
3A	Bifenthrin	Bug-B-Gon	H	Regsitered against all plant bugs on indoor and outdoor trees, shrubs and flowering ornamental plants.
3A	Esfenvalerate	Sumi-Alpha	H	Registered against bugs on home and garden including indoor and outdoor ornamental plants
3A	Myclobutanil & Bifenthrin	Rosepride	H	Registered against plant bugs on roses and other ornamental plants [shrubs, perennials and annuals]
4A&3A	Imidacloprid & Tau-fluvalinate	Rose Shield advanced	H	Registered against sap sucking bugs on ornamental plants [shrubs, flowering annuals and perennials]
4A&3A	Imidacloprid & Betacyfluthrin	Temprid	C	Registered against bugs on all ornamental plants
4A	Imidacloprid	Rose spray	H	Registered against sap sucking bugs on ornamental plants.

7.3.5 Control of stink bugs on buildings, goods, machinery or equipment

In the United States, commercial pesticide applicators have used deltamethrin, cyfluthrin, lambdacyhalothrin, cypermethrin, sumithrin and tralomethrin on building exteriors (Sargent *et al.* 2010). Most synthetic pyrethroids and organophosphates tested are very effective in causing high mortality immediately after application and even after 7 days, though some exceptions exist (Lee et al 2012d). See below points for efficacy of pesticides from this study:

- Highly effective (greater than 90% mortality immediately after application and at 7 days): dimethoate, malathion methidathion, methomyl, bifenthrin, permethrin and thiamethoxam.
- Moderately effective (80-100% mortality immediately after application or at 7 days, but not both): Beta-cyfluthrin, clothianidin, lambda-cyhalthrin
- Acetamiprid and Cyfluthrin both were very effective at application but had relatively low efficacy at 7 days after application.
- Chlorpyrifos and acephate had high efficacy 7 days after application, but not immediately after application.
- Other products had moderate efficacy: Esfenvalerate, imidacloprid, oxamyl, diazinon.
- Spirotetramat, carbaryl, cyantraniliprole and abamectin had relatively low efficacy.

Treatment conditions for control of stink bugs approved by the Australian Department of Agriculture and Water Resources for treatment of interception at the border in goods, machinery and equipment are:

- **Sulfuryl fluoride** – at least 48g/m^3 for 6 hours or longer or at least 16g/m^3 for 12 hours or longer both with an end point reading of 50% or more of the initial concentration and conducted at a temperature of 10°C or higher.

- **Methyl bromide** – at least 16g/m^3 for 12 hours or longer with an end point reading of 50% or more of the initial concentration and conducted at a temperature of 15°C or higher.

- **Heat** – at 50°C or greater for at least 20 minutes.

In addition, use of hot soapy water has been used for control of BMSB in the United States. Use of steam could be considered although it may disperse bugs if they cannot be contained.

7.3.6 Decontamination protocols

- If decontamination procedures are required, machinery, equipment and vehicles infested with stink bugs or present within the Quarantine Area, should be treated as described in Section 7.3.5.

- BMSB will use defensive behaviour and if aggregating, will drop from plants or structures or rapidly disperse if disturbed.

- Footbaths will not be useful for limiting the spread of stink bugs between premises/sites but should be considered if limiting the spread of soil borne pests and pathogens.

7.4 Decision support for eradication

- A summary of key activities associated with differing scenarios associated with a detection of BMSB is provided in Table 4. Differing physical detection scenarios have been chosen to highlight operational differences in urban compared with agricultural and horticultural environments.

- Differing seasonal scenarios were also selected as the activity of BMSB changes between seasons. In spring and summer BMSB will be actively seeking mates and food sources, while in autumn and winter BMSB will be seeking refuge and overwintering.

- A summary of factors to be considered for eradication or alternative action is provided in Tables 4-5.

- The decision to eradicate will be based on the potential economic impact of host damage, the cost of eradication and its technical feasibility. At each decision point information will be reviewed by the Consultative Committee on Emergency Plant Pests (CCEPP) and recommendations will be provided to the National Management Group (NMG) on proceeding to eradication.

Table 4: Recommended responses and considerations for differing scenarios of detection of Brown Marmorated Stink Bug[7]

Scenario	Recommended eradication/ control treatments – see Section 7.3	Recommended Movement Controls – See Section 7.2.1	Recommended surveillance options – See Section 6.1

Present only within commercial glasshouse or QAP (i.e. not present outside the facility)	- See Section 7.3 for eradication treatments for insects and equipment.
	- Destroy all plant material present within facility
	- Decontaminate all benches, walls and equipment present in the facility
		- Total movement control	- Minimum 5 km surveillance zone around the IP. Focus on known hosts or areas that provide refuge.
			- Surveillance at linked properties.
			- See Section 6 for points to consider when establishing surveillance program. Key points for glasshouses are:
			  - Undertake surveillance on all plants but target ripening fruit where available.
			  - Consider using traps and lures in larger glasshouses

Present in a production nursery (within or outside of protected cropping environments)	- Chemical sprays (or fumigation of feasible) to eradicate nymphs and adults. - Surveillance within 5 km radius (visual and traps). - Bait (lure and kill) traps - Physical removal of insects, where feasible - Removal of fruit from crop plants, motherstock and garden plants	- No movement of equipment or produce without permit. - Permits to include information on inspection, decontamination or destruction.	- Minimum 5 km surveillance zone around each IP although note that zone will require assessment depending on the property size and proximity to food sources for BMSB. - Pheromone traps/strips should be deployed in the 5 km zone. -Use light traps if night time temperatures are higher than 20ºC. - General surveillance awareness campaigns - Surveillance at linked properties
Building/urban detection in autumn/winter – insects entering or in overwintering phase.	- Chemical sprays (or fumigation if feasible) to eradicate the pest. - Bait (lure and kill) traps - Physical removal of insects may be required in conjunction with chemical sprays or treatments. - Treatments within urban/ residential situations to focus on negotiation with residents to achieve voluntary compliance pending a confirmed validation of the pest.	- Inspection/decontamination of equipment moving from IP - Where feasible, destruction of packaging material - Movement controls undertaken by permit or as voluntary compliance (coupled with awareness campaign for urban areas).	- Minimum 5 km surveillance zone around the IP. In the autumn/winter period, focus on areas that provide refuge. BMSB appear to prefer darker locations when seeking refuge during overwintering. - Visual inspections of any remaining plant material/ facilities for insects during overwintering period.
Urban backyard in summer – insects	- As per overwintering stage, except also work with residents to remove all fruit on trees. -	- Movement controls could be undertaken by permit or as voluntary movement controls (coupled with awareness campaign for urban areas).	- Surveillance on food sources (e.g. fruit and vegetable hosts) in 5 km zone around IP (noting adults likely to be more active and seeking food sources or mates in

[7] Modified from PHA (2016) 'Response Strategy for Brown Marmorated Stink Bug (Halyomorpha halys)

feeding on fruit and vegetables			spring and summer. - Consider using sentinel plants with mature fruit present. Ensure such plants are labeled to avoid well-meaning people removing fruit. - Surveillance to be done in conjunction with awareness campaigns for households providing information on the pest and symptoms. - Pheromone traps/strips should be deployed in the 5 km zone. - Use of light traps should be deployed if night time temperatures are higher than 20ºC in collaboration with community members (.
Port vicinity in spring/summer – insects emerging from diapause seeking food sources	- Chemical sprays (or fumigation of feasible) to eradicate nymphs and adults. - Surveillance within 5 km radius (visual and traps). - Bait (lure and kill) traps	- Decontamination of equipment moving from IP - Visual inspection of plant material and equipment - Where feasible, fumigation of packaging &/or plant material. - Destruction using high temperature incineration (care taken in moving any potentially infested material off-site)	- Surveillance on food sources (e.g. fruit and vegetable hosts) in 5 km zone around IP noting adults likely to be more active and seeking food sources or mates. - Use of sentinel plants with mature fruit present - Include awareness campaign for households within 5 km of the port area. - Pheromone traps/strips should be deployed in the 5 km zone. -Use light traps if night time temperatures are higher than 20ºC. - Surveillance at linked properties
Open agricultural/ horticultural setting – insects feeding on crops	- Chemical sprays over areas where detections have been made pending outcomes of delimiting surveillance - Bait (lure and kill) traps	- No movement of equipment or produce without permit. - Permits to include information on inspection, decontamination or destruction.	- Minimum 5 km surveillance zone around each IP although note that zone will require assessment depending on the property size and proximity to food sources for BMSB. - Pheromone traps/strips should be deployed in the 5 km zone. -Use light traps if night time temperatures are higher than 20ºC. - General surveillance awareness campaigns - Surveillance at linked properties
Open natural environment E.g. Detection on roadsides or national park in summer	- Chemical sprays over areas where detections have been made pending outcomes of delimiting surveillance - Bait (lure and kill) traps	- Movement restrictions at state/ territory borders pending outcomes of delimiting surveillance	- Minimum 5 km surveillance zone around the IP. - General surveillance awareness campaigns

Table 5. Summary of factors to be considered in determining whether eradication or alternative action will be taken for an incursion of an exotic stink bug[8]

Factors to consider regarding the technical feasibility of eradication
• **The population size and population structure associated with the initial detection** - Detections of large numbers of stink bugs (>1,000 individuals)[9] seeking refuge in structures as part of their over-wintering phase may indicate an established population in gardens or commercial production in the vicinity. - Large populations (>1,000 individuals)[10] in commercial production areas may indicate a population that has been established for a period of time. • **The cost effectiveness of recommended control technique options** - Multiple chemical applications may be required to eradicate stink bug populations. - Treatments other than chemical control may be an effective strategy but could be cost prohibitive or not feasible on larger scales. • **The ability to remove or destroy all stink bug individuals by the recommended control techniques** - Permission to enter private premises for surveillance and treatment must be considered. - Determination of whether treatments can effectively eradicate stink bug populations within premises or environments. • **The ability to remove stink bugs at a faster rate than they can increase until proof of freedom can be achieved** - Treatments are available for control of BMSB. Population size, time of season the detection occurs, area to be covered and ability for treatments to reach all individuals must be considered. • **The recommended control techniques are publically acceptable** - Chemical treatments (fumigation, sprays, bait trapping) in residences or backyards may not be acceptable or will require negotiation with residents. • **Whether Emergency Containment measures can effectively be put in place** • **Whether there are control methods, commonly employed for endemic pests that may prevent the establishment of the exotic stink bug species or be impacted by treatment for stink bugs** - In the US, treatment for BMSB has resulted in significantly higher numbers of chemical sprays per season. 'Softer' chemicals such as pyrethroids have limited effectiveness, and application of a range of other chemicals has had an adverse effect on Integrated Pest Management programs, resulting in an increase of other secondary pest species that were previously well managed. • **Legislative impediments to undertaking an eradication response** - If not a prescribed pest, confirmatory diagnosis will be required under legislation in some jurisdictions before powers to enter premises and undertake treatments can be enacted. - Delimiting surveillance in urban environments may be restricted to backyards and environs rather than entry into premises (unless permission from the resident can be negotiated). - Emergency permits will be required for chemical treatments. Amendments to chemical labels will be required for longer term management of stink bugs. • **The ability to delimit the known area of infestation** - Determination of linked properties in an urban detection may be infeasible given the ability of stink bugs to disperse. High risk linkages such as travel to commercial production areas or facilities should be investigated. • **The ability to identify and close the pathway for entry of the pest into Australia**

[8] From PHA (2016) 'Response Strategy for Brown Marmorated Stink Bug (Halyomorpha halys)

[9] Number estimated as representing a high level based on expert opinion of a recent incursion into Australia.

[10] Number estimated as representing a high level based on expert opinion of a recent incursion into Australia.

- Pathways into Australia have been identified (and closed) as a result BMSB of hitchhiking on imported products.

- **The dispersal ability of the pest**
  - It is considered unlikely stink bugs will travel with harvested produce (unless as an accidental hitchhiker) as the process of harvesting or moving produce is likely to cause them to disperse.
  - In spring and summer, adult stink bugs may disperse widely in search of a food source or mate. Adults are strong fliers when temperatures are >20ºC. Nymphs are strong walkers when temperatures are >25ºC.
  - BMSB is a good hitchhiker that seeks refuge as part of overwintering behaviour triggered by shorter day lengths. Long distance spread (between and within countries) has resulted from human-assisted dispersal following aggregation in buildings, packaging, equipment and vehicles. Human assisted dispersal may occur between sites if insects have taken refuge from heat in summer in packing material or vehicles or if they seek refuge as part of over-wintering behaviour in colder temperatures
- **The capability to detect exotic stink bugs at very low densities for the purpose of declaring freedom, and that all sites affected by the pest have or can be found**
  - For BMSB, lures are available that combine a synergist and an aggregation pheromone. Insects take two weeks (providing they can access a food source) to become sexually mature following emergence from their over-wintering state, and in this period are not responsive to lures.
- **The ability to put into place surveillance to confirm proof of freedom**
  - Surveillance options are available for BMSB and include visual surveillance and lures (in insect traps and sticky strips). Detector dogs have also been used successfully in the US.
- **Whether community consultation activities have or will be undertaken**
  - In an urban environment, community consultation critical to assist secure public support for delimiting surveillance and an eradication program.
  - Given the nuisance potential of this pest in urban environments, general surveillance activities should be implemented comprising awareness, media releases, web-based reporting tools and the exotic plant pest hotline.

8 References

Anon (2010) Brown Marmorated Stink Bug. University of Maryland Entomology Bulletin 2010.

Bakken AJ, Schoof SC, Bickerton M, Kamminga KL, Jenrette JC, Malone S, Abney MA, Herbert DA, Reisig D, Kuhar TP, Walgenbach JF (2015) Occurrence of brown marmorated stink bug (Hemiptera: Pentatomidae) on wild hosts in nonmanaged woodlands and soybean fields in North Carolina and Virginia. *Environmental Entomolology* 44(4): 1011–1021; DOI: 10.1093/ee/nvv092

Basnet S, Maxey LM, Laub CA, Kuhar TP, Pfeiffer DG (2014) Stink bugs (Hemiptera: Pentatomidae) in Primocane-bearing raspberries in southwestern Virginia. *Journal of Entomological Science* 49: 304-312.

Basnet S, Kuhar TP, Laub CA, Pfeiffer DG (2015) Seasonality and distribution pattern of Brown marmorated stink bug (Hemiptera: Pentomidae) in Virginia vineyards. *Journal of Economic Entomology* DOI: 10.1093/jee/tov124.

Bergmann E, Bernhard KM, Bernon G, Bickerton M, Gill S, Gonzales C, Hamilton GC, Hedstrom C, Kamminga K, Koplinka-Loehr C, Krawczyk G, Kuhar TP, Kunkel B, Lee J, Leskey TC, Martinson H, Nielsen AL, Raupp M, Shearer P, Shrewsbury P, Walgenbach J, Whalen J, and Wiman N (2016a) Host Plants of the Brown Marmorated Stink Bug in the U.S. A publication of the Brown Marmorated Stink Bug IPM Working Group in conjunction with the Northeastern IPM Center. Available from: http://www.stopbmsb.org/where-is-bmsb/host-plants/

Bergmann EJ, Venugopal PD, Martinson HM, Raupp MJ, Shrewsbury M (2016b) Host plant use by the invasive *Halyomorpha halys* (Stål) on woody ornamental trees and shrubs. *PLOS One* DOI:10.1371/journal.pone.0149975.

CABI (2016) *Halyomorpha halys (*brown marmorated stink bug). *Invasive Species Compendium*. Available from: http://www.cabi.org/isc/datasheet/27377

Cissel WJ, Mason CE, Whalen J, Hough-Goldstein J, Hooks CRR (2015) Effects of Brown marmorated stink bug (Hemiptera: Pentatomidae) feeding injury on sweet corn yield and quality. *Journal of Economic Entomology* DOI: 10.1093/jee/tv059.

Dudek T (2013) Brown marmorated stink bug: a new nursery pest in Michigan. Michigan State University Extension. Available from: http://msue.anr.msu.edu/news/brown_marmorated_stink_bug_a_new_nursery_pest_in_michigan

Gyeltshen J, Bernon G, Hodges A, Stocks S, Brambila (2013) Brown marmorated stink bug – *Halomorpha halys*, University of Florida. Available from: http://entnemdept.ufl.edu/creatures/veg/bean/brown_marmorated_stink_bug.htm

Haye T, Gariepy T, Hoelmer K, Rossi JP, Streito JC, Tassus X, Desneux N (2015) Range expansion of the invasive Brown marmorated stink bug, *Halyomorpha halys*: an increasing threat to field, fruit and vegetable crops worldwide. *Journal of Pest Science* COI 10.1007/s10340-015-0670- 2.

Hedstrom C, Walton V, Winman NG, Shearer PW, Miller J, Brewer L (2014) How to recognize Brown marmorated stink bug damage in commercial hazelnuts. Oregon State University. Publication EM9102. Available from: https://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/54471/em9102.pdf.

Hiruki C (1999) Paulownia witches-broom disease important in East Asia. *Acta Horticulturae* 496: 63-68.

Hoebeke ER and Carter ME (2003) *Halyomorpha halys* (Stal) (Heteroptera: Pentatomidae): A polyphagous plant pest form Asia newly detected in North America. *Proceedings of the Entomological Society of Washington* 105(1):225-237.

Ingels C, Varela L, Elkins R, Hurley C (2015) Phenology and distribution of brown marmorated stink bug in and near California pear orchards. 2015 Report of the Sacramento County Cooperative Extension http://cesacramento.ucanr.edu/files/227657.pdf

Inkley DB (2012) Characteristics of home invasion by the brown marmorated stink bug (Hemiptera: Pentatomidae). *Journal of Entomological Science* 47(2):125-130.

Joseph SV, Bergh C, Wright SE, and Leskey TC (2013) Factors affecting capture of Brown Marmorated Stink Bug, *Halymorpha halys* (Hemiptera: Pentatomidae), in baited pyramid traps. *Journal of Entomological Science* 48(1): 43-51.

Joseph SV, Nita M, Leskey, TC and Bergh, JC (2015) Temporal effects in the incidence and severity of brown marmorated stink bug (Hemiptera: Pentatomidae) feeding injury to peaches and apples during the fruiting period in Virginia. *Journal of Economic Entomological*. Advance Access. DOI: 10.1093/jee/tou059: 1-8.

Kamminga K, Herbert DA, Toews MD, Malone S, Kuhar T (2014) *Halyomorpha halys* (Hemiptera: Pentatomidae) feeding injury on cotton bolls. *Journal of Cotton Science* 18: 68-74.

Kim J and Park CG (2015) Effects of persimmon tannin on survival and reproduction of *Halyomorpha halys* (Hemiptera: Pentatomidae). *Entomological Research* DOI: 10.1111/1748-5967.12095.

Kiritani, K (2006) Predicting impacts of global warming on population dynamics and distribution of arthropods in Japan. *Population Ecology* 48:5–12.

Kiritani, K (2007) The impact of global warming and land use change on the pest status of rice and fruit bugs in Japan. *Global Change Biology.* 13:1586–1595.

Kuhar TP, Kamminga KL, Whalen J, Dively GP, Brust G, Hooks CRR, Hamilton G, Herbert DA (2012) The pest potential of Brown marmorated stink bug on vegetable crops*. Plant Health Progress* DOI:10.1094/PHP-2012-0523-01-BR.

Kunkel B, (2014) How destructive is stink bug? *American Nurseryman*, November 1, 2014. Available from: http://www.amerinursery.com/growing/how-destructive-is-stink-bug/

Lee D-H (2015) Current status of research progress on the biology and management of *Halyomorpha halys* (Hemiptera: Pentatomidae) as an invasive species. *Applied Entomology and Zoology* 50:277-290. DOI 10.1007/s13355-015-0350-y.

Lee D-H, Short BD, Joseph SV, Bergh JC, Leskey TC (2013) Review of the biology, ecology, and management of *Halyomorpha halys* (Hemiptera: Pentatomidae) in China, Japan and the Republic of Korea. *Environmental Entomology* 42: 627-641.

Lee D-H, Cullum JP, Anderson JL, Daugherty JL, Beckett LM and Leskey TC (2014a) Characterization of overwintering sites of the invasive brown marmorated stink bug in natural landscapes using human surveyors and detector canines. PLoS ONE 9(4): e91575. Doi:10.1371/journal.pone.0091575.

Lee D-H, Nielsen AL, Leskey TC (2014b) Dispersal capacity and behavior of nymphal stages of *Halyomorpha halys* (Hemiptera: Pentatomidae) evaluated under laboratory and field conditions *Journal of Insect Behaviour* 27:639-651.

Leskey TC, Hamilton GC, Nielsen AL, Polk DF, Rodriguez-Saona C, Bergh JC, Herbert DA, Kuhar TP, Pfeiffer D, Dively GP, Hooks CRR, Raupp MJ, Shrewsbury PM, Krawczyk G, Shearer PW, Whalen J, Koplinka-Loehr C, Myers E, Inkley D, Hoelmer KA, Lee DH, Wright SE (2012a) Pest status of the Brown marmorated stink but, *Halyomorpha haly*s in the USA. *Outlooks on Pest Management* DOI: 10.1564/23oct07

Leskey TC, Short BD, Butler BR, Wright SE (2012b) Impact of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), in mid-Atlantic tree fruit orchards in the United States: case studies of commercial management. *Psyche: A Journal of Entomology*, doi: 10.1155/2012/535062.

Leskey TC, Wright SE, Short BD, and Khrimian A (2012c) Development of behaviorally-based monitoring tools for the brown marmorated stink bug (Heteroptera: Pentatomidae) in commercial tree fruit orchards. *Journal of Entomological Science* 47:76-85.

Leskey TC, Lee DH, Short BD, Wright SE (2012d) Impact of insecticides on the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae): analysis of insecticide lethality. *Horticultural Entomology* 105:1726-1735.

Leskey TC, Agnello A, Bergh, JC, Dively, GP, Hamilton GC, Jentsch P, Khrimian A, Krawcyzk G, Kuhar TP, Lee D-H, Morrison WR, Polk DF, Rodriguez-Saona C, Shearer PW, Short BD, Shrewsbury PM, Walgenbach JF, Weber DC, Welty C, Whalen J, Wiman N and Zamen F (2015) Attraction of the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) to traps baited with semiochemical stimuli across the United States. *Environmental Entomology. Advance Access* DOI: 10.1093/ee/nvv049: 1-11.

MacLellan R (2013) Brown marmorated stink bug: a potential risk to New Zealand. *Surveillance* 40: 34-36.

McClellan M (2015) Brown marmorated stink bug: *Halyomorpha halys*. *Nursery Management* November 18, 2015. Available from: http://www.nurserymag.com/article/nm1115-brown-marmorated-stink-bug-pest-control/

Martinson HM, Bergmann EJ, Venugopal PD, (…), Shrewsbury PM, Raupp, MJ (2016) Invasive stink bug favours naïve plants:Testing the role of plant geographic origin in diverse managed environments. *Scientific Reports* 6, Article No. 32646 DOI: 10.1038/Srep32646.

Martinson H, Venugopal DP, Bergmann E, Shrewsbury P, Raupp M (2015) Fruit availability influences the seasonal abundance of invasive stink bugs in ornamental tree nurseries. *Journal of Pest Science.* DOI http://dx.doi.org/10.1007/s10340-015-0677-8

Medal J, Smith T, Santa Cruz A (2013) Biology of the Brown Marmorated Stink bug *Halyomorpha halys* (Hemiptera: Pentatomidae) in the laboratory. *Florida Entomologist* 96(3): 1209-1212.

Nielsen AL, Hamilton GC, and Matadha D (2008) Development rate estimation and life table analysis for *Halyomorpha halys* (Hemiptera: Pentatomidae). *Environmental Entomology* 37: 348-355.

Nielsen AL and Hamilton GC (2009) Seasonal occurrence and impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) in tree fruit. *Journal of Economic Entomology* 102: 1133-1140.

Nielsen AL, Holmstrom K, Hamilton GC, Cambridge J and Ingerson-Mahar J (2013) Use of black light traps to monitor the abundance, spread and flight behaviour of *Halyomorpha halys* (Hemiptera: Pentatomidae) *Journal of Economic Entomology* 106(3): 1495-1502.

Pennsylvania State University (2012) Brown marmorated stink bug as a pest of corn and soybeans. *Entomological notes*, Pennsylvania State University.

Pennsylvania State University (2013) Brown marmorated stink bug*. Entomological notes*, Pennsylvania State University.

Plant Health Australia (2016) Response strategy for exotic stink bugs, with specific focus on Brown marmorated stink bugs (*Halyomorpha halys*). Plant Health Australia.

Quaries W (2014) IPM for the Brown marmorated stink bug. *IPM Practitioner* 84: 1-5.

Rice KB, Bergh CJ, Bergmann EJ, Biddinger DJ, Dieckhoff C, Dively G, Fraser H, Gariepy T, Hamilton G, Haye T, Herbert A, Hoelmer K, Hooks CR, Jones A, Krawczyk G, Kuhar T, Martinson H, Mitchell W, Nielsen AL, Pfeiffer DG, Raupp MJ, Rodriguez-Saona C, Shearer P, Shrewsbury P, Venugopal PD, Whalen J, Winman NG, Leskey TC, Tooker JF (2014) Biology, ecology, and management of brown marmorated stink bug (Hemiptera: Pentatomidae). *Journal of Integrated Pest Management* 5: 1-13.

Shrewsbury P (2016) Video series. Tracking the brown marmorated stink bug, Part 7 – Host plants and damage in ornamentals. StopBMSB website, Northeastern IPM Center. Available from: http://www.stopbmsb.org/more-resources/video-series/

Shrewsbury P, Raupp M, Martinson H (2011) Brown marmorated stink bug activities in ornamental systems and research plans for 2011. Department of Entomology, University of Maryland. Available from: http://www.northeastipm.org/neipm/assets/File/BMSB%20Resources/ESA-Eastern-Branch-2011/05-Brown-Marmorated-Stink-Bug-Activities-in-Ornamental-Systems-and-Research-Plans-for-2011.pdf

Smith JR, Hesler SP, Loeb GM (2015) Potential Impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) on Grape Production in the Finger Lakes Region of New York. Journal of Entomological Science 49(30): 1-14.

Soergel DC, Ostiguy N, Fleischer SJ, Troyer RR, Rajotte EG. Krawczyk G (2015). Sunflower as a Potential Trap Crop of Halyomorpha halys (Hemiptera: Pentatomidae) in Pepper Fields. *Environmental entomology*, nvv136.

USDA APIS (2010) Qualitative analysis of the pest risk potential of the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), in the United States. Available from: https://www.michigan.gov/documents/mda/BMSB_Pest_Risk_Potential_-_USDA_APHIS_Nov_2011_344862_7.pdf

Venugopal PD, Martinson HM, Bergmann EJ, Shrewsbury PM, Raupp MJ. (2015) Edge effects influence the abundance of the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) in woody plant nurseries. *Environmental Entomology* 44(3):474-9. doi: 10.1093/ee/nvv061.

Wainwright-Evans S and Palmer C (2011) Controlling the brown marmorated stink bug. *Greenhouse Management*, August 2011.

Watanabe K (1996) Specific characteristics of damage to cherry caused by *Lycogoris (Apolygus) lucorum* (Meyer-Dur) (Hepteroptera: Miridae) and *Halyomorpha halys* (Stal) (Hepteroptera: Pentatomidae). Annual report of the Plant Protection Society of North Japan 143-144.

Wermelinger B, Wyniger D, Forester B (2008) First records of an invasive bug in Europe: *Halyomorpha halys* Stal (Heteroptera: Pentatomidae), a new pest on woody ornamentals and fruit trees? *Bulletin de la Societe Entomologique Suisse* 81: 1-8.

Wiman N, (2015) Managing for brown marmorated stink bug. *Digger Magazine*, November 2015. Available from: http://www.diggermagazine.com/managing-for-brown-marmorated-stink-bug/

Wiman NG, Walton VM, Shearer PW, Rondon SI and Lee JC (2014) Factors affecting flight capacity of brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae). *Journal of Pest Science* 88(1):37-47.

Wiman NG, Parker JE, Rodriguez-Saona C, Walton VM (2015) Characterizing damage of Brown marmorated stink bug (Hemiptera: Pentatomidae) in blueberries. *Journal of Economic Entomology* DOI: 10.1093/jee/tov036.

Wiman N, Dalton D, Brewer L, Shearer P, and Walton V (2016) How to monitor for Brown Marmorated Stink Bug in Specialty Crops. Oregon State University Extension Service EM9138 March 2016.

Yang Z, Yao Y, Oiu L, Li Z (2009) A new species of *Trissolcus* [Hymenoptera: Scelionidae] parasitizing eggs of *Halyomorpha halys* (Heteroptera: Pentatomidae) in China with comments on its biology. *Annals of the Entomological Society of America* 102: 39-47.

Yuan TL (1984) Some studies on witches' broom disease of Paulownia in China. *International Journal of Tropical Plant Diseases* 2: 181-190.

Zinati GM (2015) Organic management of Brown Marmorated Stink Bug (BMSB). Rodale Institute website http://rodaleinstitute.org/organic-management-of-brown-marmorated-stink-bug-bmsb/

Appendix 1: Important nursery industry contacts

It is important to note that the Industry Development Officers (IDOs) change from time to time. Therefore, the current list may become out of date relatively quickly. For this reason, one can always refer to the NGIA website for the latest details for the NGI for each state and territory. In addition, some states may have more than one IDO, the below list are important contacts who may then direct you to the most appropriate person.

Northern Territory Website: http://www.ngia.com.au/Category;jsessionid=57FAB91F4A656937462E3F34A910B531?Action=View&Category_id=266 Michele Shugg Public Officer/NT Farmers Representative Nursery & Garden Industry Northern Territory PO Box 348 Palmerston NT 0831 Ph: 08 8983 3233 Fax: 08 8983 3244 Email: ngint@ntha.com.au	Western Australia Website: http://www.ngia.com.au/Category?Action=View&Category_id=308 Chief Executive Officer Nursery & Garden Industry of WA PO Box 135 Mount Helena WA 6082 Email: reception@ngiwa.com.au
South Australia Website: www.ngisa.com.au Grant Dalwood Development Officer Mob: 0412 692 600 Fax: 08 8372 6833 Ph: 08 8271 1012 Email: gdalwood@ngisa.com.au 505 Fullarton Rd (Gate A) Netherby SA 5062	NSW and ACT Web: www.ngina.com.au Michael Danelon Nursery Industry Development Officer (NIDO) 344-348 Annangrove Road (PO Box 3013) Rouse Hill NSW 2155 Ph: 02 9679 1472 Fax: 02 9679 1655 Mob: 0400 010 049 Email: michael@ngina.com.au
Queensland Website: www.ngiq.asn.au Kerry Battersby Executive Officer PO Box 345 SALISBURY QLD 4107 Ph: 07 3277 7900 Mob: 0419 683 457 Fax: +61 07 3277 7109 Email: nido@ngiq.asn.au	Victoria Website: www.ngiv.com.au David Reid Nursery Industry Development Officer PO Box 2280 Wattletree Road LPO East Malvern Victoria 3145 Ph.: 03 9576 0599 Fax: 03 9576 0431 Email: david@ngiv.com.au
Tasmania Website: http://www.ngia.com.au/Category?Action=View&Category_id=307 Mark Van Der Staay PO Box 3009 Rosny Park Tasmania 7018 Email: president@ngitas.com.au	Australia Website: http://www.ngia.com.au Peter Vaughan Chief Executive Officer, Nursery and Garden Industry Australia Ph: 02 8861 5107 Fax: 02 9659 3449 Mob: 0400739802 Email: peter.vaughan@ngia.com.au

Appendix 2: Resources and facilities – diagnostic service facilities in Australia

The diagnostic facilities below should be contacted prior to sending any samples to ensure the availability of all necessary equipment and reagents to complete the tests required.

.

Facility	State	Details
Crop Health Services	VIC	AgriBio Specimen Reception Main Loading Dock, 5 Ring Road La Trobe University, Bundoora VIC 3083 Ph: 03 9032 7515; Fax: 03 9032 7064
DPI New South Wales – Elizabeth Macarthur Agricultural Institute	NSW	Woodbridge Road Menangle NSW 2568 PMB 8 Camden NSW 2570 Ph: 02 4640 6327; Fax: 02 4640 6428
SARDI Plant Research Centre – Waite Main Building, Waite Research Precinct	SA	Hartley Grove Urrbrae SA 5064 Ph: 08 8303 9400; Fax: 08 8303 9403
Biosecurity Queensland	QLD	DAF Ecosciences Precinct Dutton Park Q 4102 Ph: 07 3255 4378; Fax: 07 3844 4529
Department of Agriculture and Food, Western Australia (AGWEST) Plant Laboratories	WA	3 Baron-Hay Court South Perth WA 6151 Ph: 08 9368 3721; Fax: 08 9474 2658
Department of Primary Industry and Fisheries	NT	Department of Primary Industry and Fisheries Plant Industries Division BAL building, Berrimah Farm, Makagon Road, Berrimah NT 0828 Ph: 08 8999 2261; Fax: 08 8999 2312

Appendix 3: Impact on agricultural hosts[11]

Symptoms caused by BMSB differs between hosts. On the leaves and fruit of many plants, small necrotic lesions develop. The table below describes the types of symptoms and damage seen on different hosts and also outlines whether the main impacts are on quality and/or production losses.

Host	Affected plant part	Impact description	Quality or production losses
Acacia[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Adzuki bean[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Almonds[3]		Reported to feed on almonds, no details about significance of this crop as a host plant (Haye *et al.* 2015).	
Apple[1]	Fruit	Feeding during petal fall can cause an increase in fruit abortion, feeding mid-season causes dimples to appear on the fruit, while feeding later in the season during fruit swell caused white or brown corking (puckering), dimpling or pitting near the skin surface, or water soaked lesions. Some orchards in the United States have reported >25% of fruit being damaged by BMSB and in some areas this was significantly higher (Nielsen and Hamilton 2009). Damage in the US caused growers to increase their insecticide sprays to manage BMSB but this disrupted IPM programs and caused secondary pest problems (Leskey *et al.* 2012a).	Quality
Apricot[1]		Affected by BMSB (Haye *et al.* 2015)	
Asparagus[3]	Leaves and stems	Reported to be affected and damaged by BMSB (Lee *et al.* 2013). This was the first host that BMSB was reported on in Switzerland (Wermelinger *et al.* 2008)	Quality
Beet[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Blackberries[1]	Fruit and flowers	Feeding early in the season can cause death of buds. Late season feeding causes collapse of individual drupelets and the insects droppings can also cause fruit to taste (Rice *et al.* 2014).	Quality
Blueberries[1]	Fruit	Feeding caused discolouration, necrosis of the internal tissue of the fruit and also resulted in reduced fruit	Quality

[11] From PHA (2016) 'Response Strategy for Brown Marmorated Stink Bug (Halyomorpha halys)

Host	**Affected plant part**	**Impact description**	**Quality or production losses**
		weights. Some cultivars were more susceptible to damage than others (Wiman *et al.* 2015).	
Capsicum[1]	Fruit	Feeding causes blemishes (discoloured spongy areas) on the skin as well as internal damage (Kuhar *et al.*, 2012).	Quality
Carrot[3]		Listed as a food source for rearing stinkbugs (Medal *et al.* 2013). No information available its status as a field host.	
Cherry[1]	Fruit	Cherry are affected by BMSB (Watanabe 1996; Haye *et al.* 2015). On cherry the adults feed on the young and ripening fruit. After feeding a significant areas of the fruit (20-60%) becomes brown and the fruit begins to collapse. Damaged fruit mostly abscise prior to harvest (Watanabe 1996).	Quality and production losses
Citrus[3]		Reported to feed on citrus, no details about significance of this crop as a host plant (Haye *et al.* 2015; Lee *et al.* 2013).	
Cotton[1]	Bolls	BMSB feeds on bolls, including large (>32mm) bolls that are usually not attacked by stinkbugs. Feeding can cause reduction in lint quality and yield (Kamminga *et al.* 2014)	Quality and production losses
Cucumber[1]	Fruit	Feeding causes damage to fruit (Lee *et al.* 2013)	Quality
Cucumber[3]	Fruit	Damage to up to 90% of cucumbers have been reported overseas (Lee *et al.* 2013).	Quality
Egg plant[1]	Fruit	Feeding causes blemishes (discoloured spongy areas) on the skin as well as internal damage (Kuhar *et al.* 2012)	Quality
Grapes – Table grapes/ Viticulture/ Dried Fruits[2]	Fruit	All life stages have been found in vineyards in the United States (Smith *et al.* 2015). BMSB feed on the grapes and causes abscission of the clusters and they can also hide in bunches and cause a taint to the juice of winegrapes (Basnet *et al.* 2015)	Quality and production
Hop[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Hazelnut[1]	Nuts	Feeding causes blank nuts (i.e. kernels do not develop) kernel shrivelling, or corking of kernel (Hedstrom *et al.* 2014)	Quality and production

Host	Affected plant part	Impact description	Quality or production losses
			losses
Kiwi[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Lettuce[3]		Listed as a food source for BMSB in laboratory studies only	
Lilac[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Lima bean[3]	Fruit	Causes discolouration and distortion of the pods (Rice *et al.* 2014)	Quality
Loquat[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Maize/sweet corn[1]	Ears	On sweet corn BMSB is reported to cause damage to kernels (described as sunken, collapsed or discoloured) even at low population levels and infections also caused a reduction in kernel numbers/ear and reduced ear length (Cissel *et al.* 2015). Damage to field corn (i.e. maize) is the same with collapsed grains occurring sue to feeding by BMSB (Rice *et al.* 2014).	Quality and yield losses
Maple[3]	Seeds	Nymphs reported on the seeds of maple in Switzerland (Wermelinger *et al.*, 2008).	
Millet (*Panicum miliaceum*)[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Nectarine and peach[1]	Fruit	Feeding causes corking injuries to peaches, which can be seen just under the surface of the skin. The fruit can also become distorted (Leskey *et al.* 2012b). Fruit abscission can also occur (Lee *et al.* 2013).	Quality
Okra[3]	Fruit	Feeding causes pods to become distorted/deformed or pimpled (Kuhar *et al.* 2012)	Quality
Olive[3]		Reported to feed on olives, no details about significance of this crop as a host plant (Haye *et al.* 2015).	
Ornamentals – various[3]	Various	Juneberry (*Amelanchier lamarckii*) and Butterfly bush (*Buddleja davidii*) were slightly affected. Japanese angelica tree (*Aralia elata*), Garden nasturtium (*Tropaeolum majus*), Dead man's fingers (*Decaisnea fargesii*) and Japanese Stewartia (*Stewartia pseudocamellia*) were heavily infested by BMSB in Switzerland. Infestations reportedly lead to the death of a *Stewartia pseudocamellia* plant (Wermelinger *et al.* 2008)	Can cause plant death

Host	Affected plant part	Impact description	Quality or production losses
Paulownia[3]		BMSB vectors witches' broom phytoplasma (Yuan 1984).	Vector of phytoplasma
Pistachio[3]		Reported to feed on pistachio, no details about significance of this crop as a host plant (Haye *et al.* 2015).	
Pea[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	
Peanut[3]		Listed as a food source for rearing stinkbugs. No information on its status as a field host.	
Pear[1]	Fruit	Some orchards in the United States have reported >25% of fruit being damaged by BMSB and in some areas this was significantly higher (Nielsen and Hamilton 2009). Feeding causes depressions and corking, feeding damage is greater when BMSB feeds on fruit <30mm (Lee *et al.* 2013).	Quality
Pecan[3]		Pecan is reported as a host of this pest however no information was provided on its economic impact (USDA APIS 2010).	
Persimmon[3]	Fruit	Fruit becomes discoloured and distorted as a result of BMSB feeding (Kim and Park 2015; Lee *et al.* 2013). Fruit abscission can also occur (Lee *et al.* 2013).	Quality
Plum[3]		Listed by Lee *et al.*2013 as a host of BMSB. No details on impact.	
Quince [3]		Listed by Lee *et al.*2013 as a host of BMSB. No details on impact.	
Raspberries[1]	Fruit and flowers	In parts of the United States BMSB is replacing the endemic stink bugs feeding on raspberry. BMSB feeds on the fruiting structures (Basnet *et al.* 2014). The fruit often will not come free of the fruiting structures and will appear shrivelled. Feeding early in the season can cause death of buds. Late season feeding causes collapse of individual drupelets and the insects droppings can also impart a bad taste to fruit (Rice *et al.* 2014)	Quality
Soybean[2]	Fruit, Stay-green syndrome affects leaves	BMSB damage appears as brown or black puncture wounds on stems, leaves and blooms. BMSB feed on the seeds by piercing the pods. This causes pods to become flattened and distorted or aborted. BMSB typically feeds on the edges of soybean paddocks and can produce a “stay green” syndrome where the infested plants remain green longer than non-infested plants (Pennsylvania State University Entomological notes, 2012). Also associated with delayed maturity and reduced yields due to see damage (Quaries 2014).	Production losses

Host	**Affected plant part**	**Impact description**	**Quality or production losses**
Sorghum[3]		While there is no reference to damage or yield loss caused to sorghum, this crop is significant as it is listed as a trap crop in the US i.e. BMSB are highly attracted to it (Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact).	
Strawberries[1]	Berries	80% yield losses due to BMSB damage reported in Lee *et al.* (2013)	
Sunflower[2]	Seed	Listed as having been used as trap crop as it is highly attractive to BMSB (Soergel *et al.* 2015). Listed by Lee *et al.* 2013) as a host of BMSB. No details on impact.	
Tea[3]	Leaves	Reported to feed on tea leaves (Lee *et al.* 2013)	
Tomato[1]	Fruit	Feeding causes blemishes (discoloured corkish or spongy areas) on the skin as well as internal damage (Kuhar *et al.*, 2012). Damage to ripe tomatoes appears as whitish yellow feeding sites. Damage to green tomatoes appears as a pinprick surrounded by a light discoloured area (www.stopbmsb.org).	Quality
Vegetable beans[3]	Fruit	Pods become distorted/deformed, with sunken areas forming around feeding sites. 10-15% of pods were affected in research plots in Virginia and Maryland (Kuhar *et al.* 2012)	Quality
Walnut[3]		Reported to feed on walnut, no details about significance of this crop as a host plant (Haye *et al.* 2015).	
Wheat[3]		Listed by Lee *et al.* 2013 as a host of BMSB. No details on impact.	

[1] Major host; high impact of BMSB on this host

[2] Moderate host; moderate impact of BMSB on this host

[3] Limited impact and/or limited information of economic damage on this host

Appendix 4: Additional information on monitoring tools for BMSB[12]

- Brown Marmorated Stinkbug (BMSB) traps, lures and the methyl (2E,4E,6Z)-decatrieonate (MDT) adult-aggregation pheromone available from AgBio Inc., 877 268-2020.

- Dead-INN Pyramid Trap (4ft) with MDT 1x lure available from AgBio. Traps, http://www.agbio-inc.com/dead-inn-pyramid-trap.html. AgBio has worked directly with USDA to develop this commercial trap and lure.

- USDA recommends the Hercon Vaportape II kill strip (purchased from Gemplers, 800 382-8473 or www.gemplers.com). Insecticide strips are available for use in Australia (see http://australianalmonds.com.au/documents/Industry/Fact%20Sheets/Carpophilus%20Monitoring%20Guidelines%20-%20Almonds%202014-15.pdf)

- Further information on trap deployment for monitoring for BMSB is outlined in the Oregon State University Extension Service Factsheet (Wiman *et al.* 2016).

[12] From PHA (2016) 'Response Strategy for Brown Marmorated Stink Bug (Halyomorpha halys)