Australian Government
Department of Agriculture

Final pest risk analysis for brown marmorated stink bug (*Halyomorpha halys*)

December 2019

Cataloguing data

Australian Government Department of Agriculture2019, *Final pest risk analysis for brown marmorated stink bug (*Halyomorpha halys*)*, Department of Agriculture, Canberra.

This publication is available at agriculture.gov.au.

Australian Government Department of Agriculture
GPO Box 858 Canberra ACT 2601

Switchboard: +61 2 6272 3933 or 1800 900 090

Email: plant@agriculture.gov.au

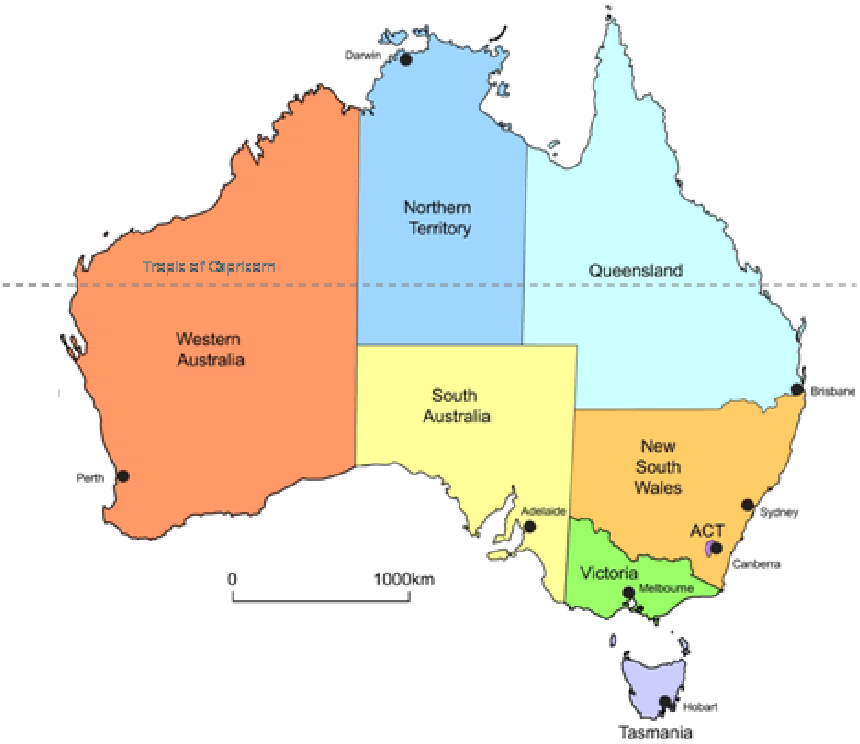
Contents

Figures

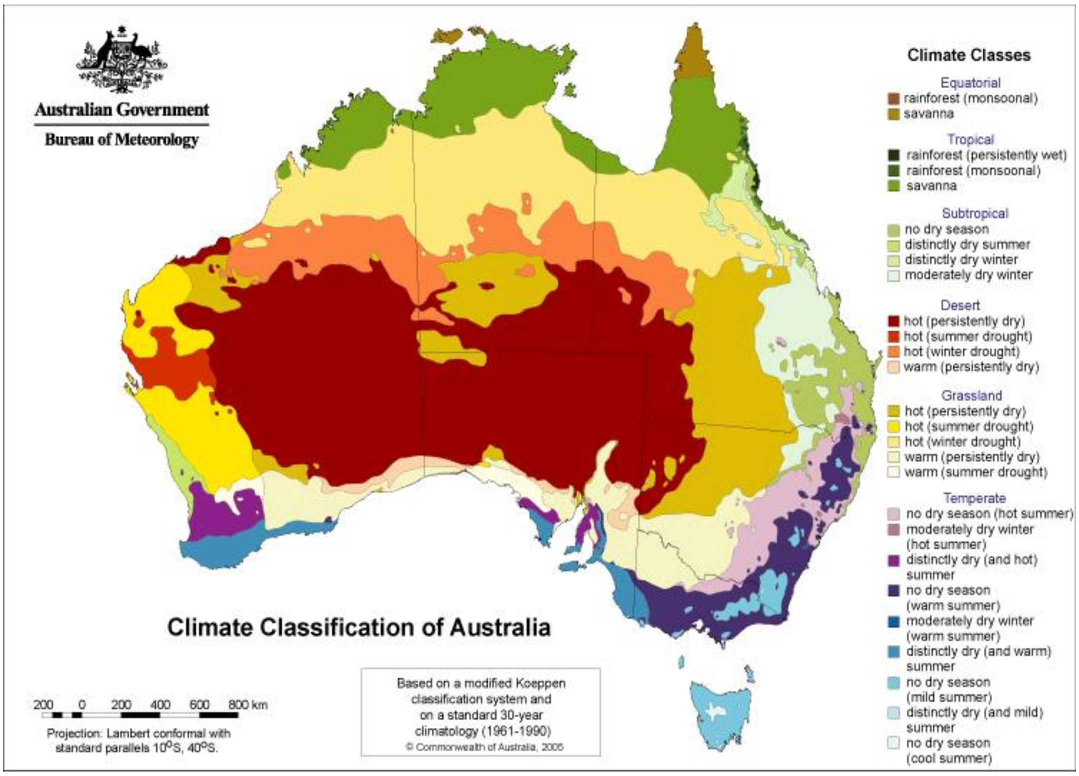
Tables

Maps

Map 1 Map of Australia



Map 2 A guide to Australia's bio-climatic zones



Acronyms and abbreviations

Term or abbreviation	Definition
ALOP	Appropriate level of protection
BIRA	Biosecurity Import Risk Analysis
BMSB	Brown marmorated stink bug
FAO	Food and Agriculture Organization of the United Nations
IPPC	International Plant Protection Convention
ISPM	International Standard for Phytosanitary Measures
NPPO	National Plant Protection Organisation
NZ MPI	New Zealand Ministry for Primary Industries
PRA	Pest risk analysis
SPS Agreement	WTO Agreement on the Application of Sanitary and Phytosanitary Measures
USA	United States of America
USDA	United States Department of Agriculture
WTO	World Trade Organization

Summary

The Department of Agriculture has prepared this final report to assess the biosecurity risk to Australia of *Halyomorpha halys* (brown marmorated stink bug; BMSB) entering as a hitchhiker pest on inanimate goods from all countries with established BMSB populations. This final report does not consider BMSB risk on specific horticultural products such as fresh fruit or cut flowers, as risks from these products are considered in specific analyses.

The department initiated this pest-specific risk analysis following the introduction of emergency measures, implemented in response to increased incidents of BMSB at the border and changes in the international status of this pest. BMSB is an invasive pest that has spread from its native range in East Asia to form established populations in North America and Europe. In December 2014, very large numbers of BMSB began arriving with goods imported from the United States. These infestations were difficult to manage at the Australian border and presented an increased biosecurity risk.

Since the publication of the draft risk analysis, the BMSB risk profile has changed significantly. BMSB has continued to spread in the United States and Europe, and population densities have increased in many regions. As BMSB has spread and increased in numbers, not only have the number of BMSB arriving at the border increased substantially, but new trade pathways have become at-risk. This rapidly changing risk has created a range of challenges for the department to predict and manage risk of BMSB.

The department has responded to this increasing and changing BMSB risk by developing a range of new approaches to offshore and onshore biosecurity systems. In particular, the department now requires at-risk goods such as vehicles and machinery which cannot be contained on arrival to be treated offshore. This report details the new approaches to analysing overseas pest reports and trade data to predict future risk profiles and accurately target emerging risk.

In addition to the measures implemented for target risk goods from the United States, the department has subsequently implemented offshore measures for target risk goods from Italy in 2017–18, and from an additional seven European countries in 2018–19. The department currently requires a range of seasonal risk management approaches, including offshore measures, for target risk goods from 33 countries in Asia, Europe and North America for the 2019–20 season.

This final risk analysis assesses the likelihood of entry, establishment and spread of BMSB as a hitchhiker pest on goods, and the consequences if it were to establish and spread in Australia. The likelihoods were assessed for two different seasonal periods based on the insect's overwintering and summer season biologies and for goods originating from countries in both the northern and southern hemispheres.

This final report recommends the importation of goods into Australia from all countries with established BMSB populations be permitted, subject to meeting a range of biosecurity conditions.

This final report recommends a range of risk management measures combined with operational systems, to reduce the risks posed by BMSB on goods and to achieve the appropriate level of

protection (ALOP) for Australia. Depending on the specific nature and origin of the at-risk goods, one or more of the following risk management measures will be applied:

- enhanced surveillance
- sulfuryl fluoride fumigation
- methyl bromide fumigation
- heat treatment
- approved safeguarding arrangements.

The recommended measures are the same as the measures currently in place to manage the risk of BMSB, and the department considers that these measures are adequate to mitigate the risk posed by BMSB on imported at-risk goods from countries where BMSB populations are established.

Written technical submissions on the draft report were received from three stakeholders. The final report takes into account stakeholder comments on the draft report. The department has made a number of changes to the risk analysis following consideration of stakeholder comments on the draft report and subsequent review of the literature. These changes include:

- Amendments to how the end of the season for goods from the northern hemisphere is expressed. In order to remove uncertainty about the end date of the season, the department has changed the expression for the risk period, but still recognises the existence of a risk period that diminishes. Based on feedback received from stakeholders on the draft report, as well as from our experience with BMSB at the Australian border, this final report recommends the end of season risk on the basis of date of arrival of goods in Australia. The risk period for BMSB is now considered to end on 31 May for goods arriving in Australia, which better reflects the overall risk periods of BMSB importation, distribution and establishment. Text has been added to sections 4.1.1 and 4.1.2 to support and explain the change in how the end of season is defined.

- Revisions to the treatment conditions. Stakeholder comments noted that evidence to support treatment conditions proposed in the draft report was not publicly available. While specific treatment data has not been made public since the publication of the draft report, the department has continued to work to ensure treatments are effective, and additional information has been reviewed and cited to further support the treatments. The specified treatment conditions have been modified slightly since the draft report.

- The addition of 'Appendix C Summary of Recommendations for measures for cargo for the 2018–19 BMSB season', which summarises the methods for assessing risk and the outcomes of that assessment for BMSB during the 2018–19 season.

- The addition of 'Appendix D Issues raised in stakeholder comments', which summarises key technical issues raised by stakeholders and how they were considered in the final report.

- Additional technical information, updated interception records, minor corrections, rewording and editorial changes for consistency and clarity.

1 Introduction

1.1 Australia's biosecurity policy framework

Australia's biosecurity policies aim to protect Australia against the risks that may arise from exotic pests entering, establishing and spreading in Australia, thereby threatening Australia's unique flora and fauna, as well as those agricultural industries that are relatively free from serious pests.

The risk analysis process is an important part of Australia's biosecurity policies. It enables the Australian Government to formally consider the level of biosecurity risk that may be associated with proposals to import goods into Australia. If the biosecurity risks do not achieve the appropriate level of protection (ALOP) for Australia, risk management measures are proposed to reduce the risks to an acceptable level. If the risks cannot be reduced to an acceptable level, the goods will not be imported into Australia until suitable measures are identified.

Successive Australian Governments have maintained a stringent, but not a zero risk, approach to the management of biosecurity risks. This approach is expressed in terms of the ALOP for Australia, which is defined in the *Biosecurity Act 2015* as providing a high level of protection aimed at reducing risk to a very low level, but not to zero.

Risk analyses may take the form of a biosecurity import risk analysis (BIRA) or a review of biosecurity import requirements (such as scientific review of existing policy and import conditions, pest-specific assessments, weed risk assessments, biological control agent assessments or scientific advice).

Further information about Australia's biosecurity framework is provided in the *Biosecurity Import Risk Analysis Guidelines 2016* located on the Australian Government Department of Agriculture website.

1.2 This pest risk analysis

1.2.1 Background

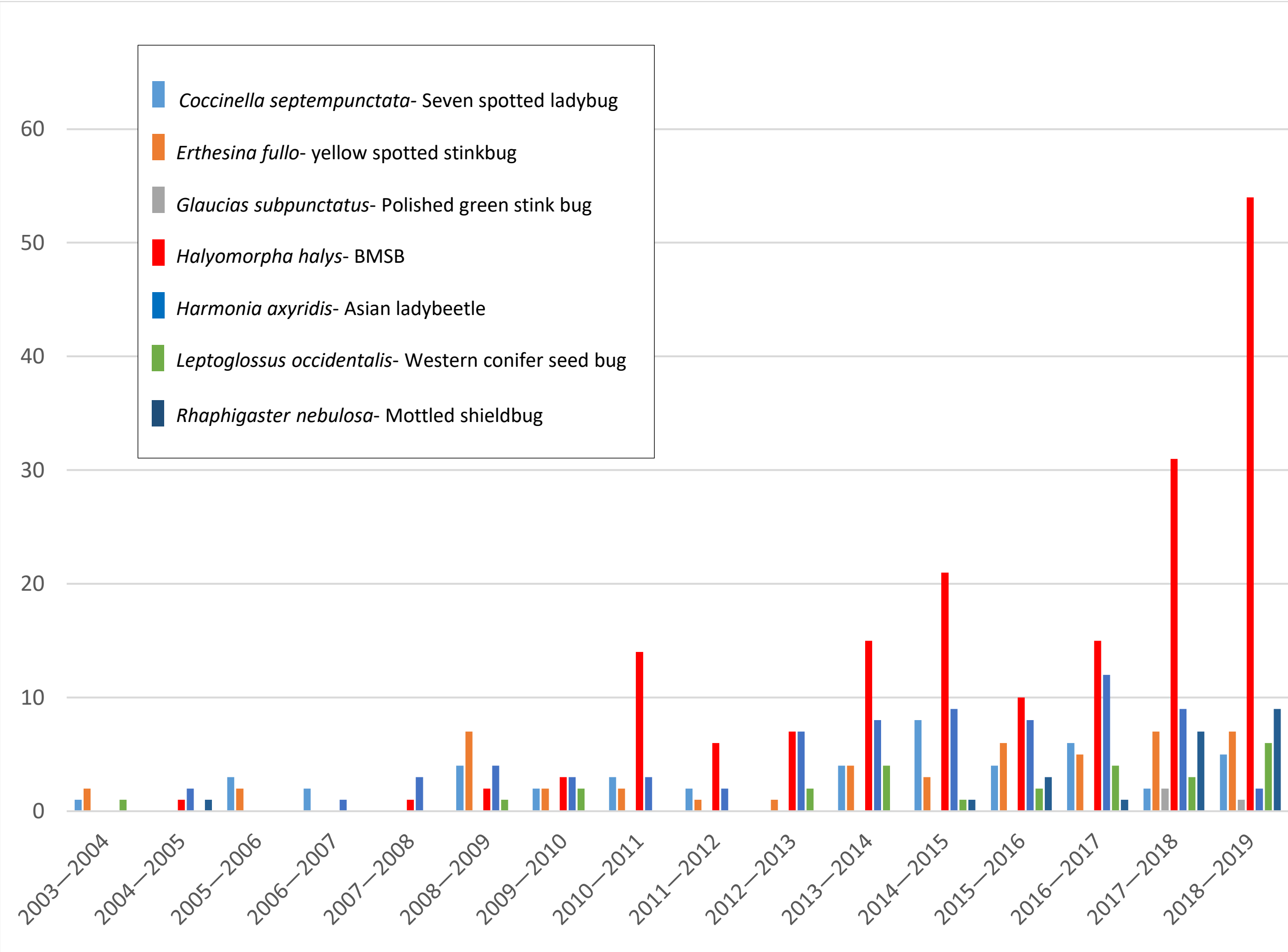
The insect *Halyomorpha halys* (brown marmorated stink bug; BMSB) is exotic to Australia and an identified quarantine pest for Australia (Biosecurity Australia 2010; DAFF 2004). Live BMSB adults have been intercepted as hitchhikers on various goods from several countries, leading to application of onshore treatments to mitigate the biosecurity risk.

The size of an interception of BMSB can vary and was previously typically recorded qualitatively by biosecurity officers at the border as 'few', 'moderate', or 'large'. An interception classed as 'few' typically had one to four BMSB, a 'moderate' interception typically had between three and 10 individual BMSB, and a 'large' interception contained more than 10 individual BMSB. Beginning in the 2017–18 season, full counts of BMSB were recorded for all BMSB incidents. The term 'incident' is used in this report to refer to interceptions of BMSB that are considered to be part of the same infestation. For example, an incident can involve as few as one BMSB found in one item, or hundreds of BMSB found in multiple pieces of machinery sent from the same supplier in the same shipment. Each of these two examples would be considered as one incident.

There were few incidents of live BMSB hitchhikers prior to 2014 (Figure 1). Those few were intercepted on various goods which originated in countries within the native range for BMSB, such as China and Japan, and from the United States (USA) where BMSB was establishing as an invasive pest. Until this time, the number of live BMSB incidents, and the size of the incidents, did not exceed the size and number of a range of other overwintering hitchhiking pest insect incidents, such as other exotic stinkbugs and ladybeetles (Figure 1) which also overwinter as adults and are also intercepted and treated at the border as part of appropriate day-to-day risk management. These other overwintering pest species have not been intercepted at the same levels of contamination as BMSB, but some species, such as Asian ladybeetle (*Harmonia axyridis*) and western conifer seed bug (*Leptoglossus occidentalis*) have expanded their distribution globally. The department is monitoring the risk of all exotic contaminating pests on all pathways, and may take further actions to ensure that risks from these pests are also managed.

The number of BMSB incidents recorded during 2010–11 was higher than expected, and mostly from the USA (Figures 1 and 2), however, this mostly involved 'few' or 'moderate' numbers of individual BMSB, which were appropriately managed onshore.

Figure 1 The number of live incidents of the top seven exotic overwintering insect pests, including BMSB, found on goods originating from all countries from 1 September 2003 to 30 May 2019.



Beginning in December 2014, the numbers of BMSB in incidents on goods arriving from the USA increased substantially. For the first time, incidents consisted of very large numbers of infestations of live BMSB. These large infestations during 2014–15 involved entire ships carrying hundreds of vehicles, and many hundreds or possibly thousands of BMSB throughout the holds. Some of these large infestations generated multiple quarantine management actions as the infested ships brought cargo to several ports around Australia. This level of infestation was unprecedented for any species of hitchhiking pest.

These large infestations proved difficult for the department to manage at the border as part of the usual quarantine processes, and presented an increased biosecurity risk. Every incident involving live BMSB was managed with treatments appropriate to the goods in question. The department implemented emergency measures on 31 December 2014, which initially covered 'break bulk' (that is, non-containerised) cargo from specified ports in the USA, and included enhanced inspections and onshore treatments. On 22 January 2015, the department announced updated emergency import conditions requiring mandatory offshore pre-shipment treatment of break bulk and containerised machinery and vehicle cargo sourced and/or shipped from specified USA ports (including interim arrangements for vessels in transit), and arriving in Australia on or after 23 February 2015.

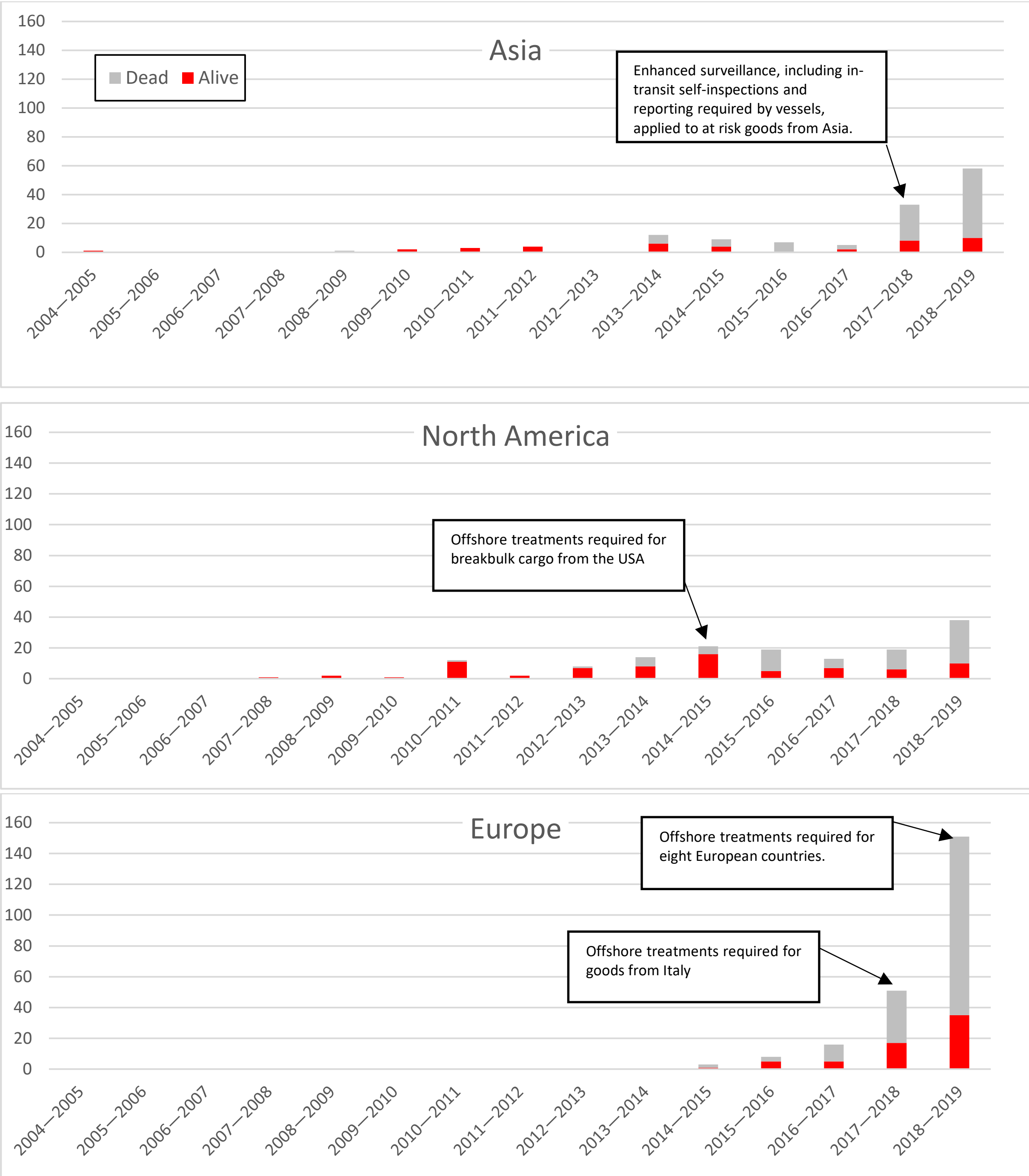
On 4 February 2015, the department provided advance notice to industry that the pre-shipment treatment requirements would apply to high risk cargo arriving in Australia from all ports in the USA on or after 9 March 2015. These emergency measures ceased at the end of April 2015 due to the seasonal nature of BMSB (as detailed in Section 3.1.4).

Similar measures involving offshore treatment requirements were again put into place for at-risk goods loaded in the USA from 1 September 2015 to 30 April 2016. These measures led to a significant decrease in the number of BMSB found in the 2015–16 season (Figure 2), and no live BMSB were found on any goods treated under these offshore measures. All live incidents from the USA since the 2015–2016 season have been on goods not subject to mandatory offshore treatments (for example, personal effects), or on goods that failed to meet the minimum departmental treatment requirements. As a result, the 2015–16 measures were used as the basis for the 2016–17 season measures, and subsequently for the 2017–18 and 2018–19 seasons, as detailed on the department website and summarised in Appendix E. These measures have helped to reduce the number of incidents of live BMSB arriving from the USA (Figure 2).

Based on the reports of increasing severity of BMSB pest problems in Italy and the increasing numbers of BMSB found in goods imported from Italy, offshore treatment requirements for break bulk goods, in line with requirements for the USA, were announced for Italian break bulk cargo for the start of the season on 1 September 2017. However, beginning in November 2017, increasing numbers of consignments of containerised goods from Italy were found to be infested with large numbers of live BMSB. Therefore, on 17 January 2018, the department extended offshore treatment requirements to include all containerised cargo from Italy. Not all offshore treatments were performed correctly, and a number of remedial measures had to be applied to goods from Italy on arrival.

For the 2018–19 season, in-depth analysis was conducted to review the countries most likely to be sources of BMSB-infested cargo, and to better identify categories of cargo most likely to be infested. A summary of the methods and results of this analysis is provided in Appendix C. To help ensure that offshore treatments were conducted appropriately, an offshore treatment provider's scheme was developed. Further details on this scheme can be found on the department's website at http://www.agriculture.gov.au/import/before/brown-marmorated-stink-bugs

Figure 2 The number of incidents of live and dead BMSB found on goods from Asia, North America and Europe from 1 September 2004 to 30 May 2019.



The Inspector General of Biosecurity (IGB) has conducted an independent review into the department's response to BMSB, and the report of the review is available on the IGB website (http://www.igb.gov.au). A key recommendation of this review was that the department should continue to cooperate closely with New Zealand in risk profiling and risk assessment for BMSB of countries, pathways and goods; in developing and administering risk mitigation measures such as offshore quality systems and in identifying gaps in scientific knowledge and prevention, preparedness and response measures. The department has cooperated closely with New Zealand, and the information shared has led to an aligned view on risk countries and treatment rates, although complete alignment of measures is not feasible due to differing trade patterns, legislative frameworks and biosecurity systems.

For the 2019—20 BMSB risk season, heightened biosecurity measures have been applied to certain goods manufactured in, or shipped from target risk countries, and/or vessels that berth at, load or tranship from target risk countries. Target risk countries that require offshore treatment include Canada and the United States of America, as well as 30 European countries listed in Table 6 in Chapter 4 pest risk assessment. Some native range countries are also included on the target risk country list, but heightened vessel surveillance to verify absence of pests in vehicles and machinery will be the only measure applied. Target high risk and risk goods from these countries may be subject to random onshore inspections to verify freedom from BMSB contamination. Target high risk and risk goods are identified by chapter level tariff codes. These are detailed in tables 9 and 10 in Appendix D.

The measures apply from 1 September 2019 that arrive in Australian territory by 31 May 2020 (inclusive). Goods shipped between 1 September and 30 April need to be treated, and will be referred for intervention if they arrive by 31 May 2020. Further details and current information can be found on the department website at
http://www.agriculture.gov.au/import/before/brown-marmorated-stink-bugs

BMSB has also been reported in Chile in the southern hemisphere where it has limited distribution, and is under official control and active management (Faúndez & Rider 2017). There are other countries which are likely to have changing BMSB pest status in the near future. The department will continue to imports of all goods from all countries for all exotic overwintering pests, including BMSB, as risks from these pest species are increasing with trade volumes and changes in overseas distributions. The department also monitors relevant sources of information including news reports and scientific literature. If particular categories of goods arrive from any country and are infested with BMSB or other exotic overwintering species, or reports suggest significant changes in pest status, the department will review any change in the status of countries and/or goods and, if supported by sufficient evidence, will set import conditions which may vary from those currently described in this report.

1.2.2 Scope

The scope of this risk analysis is the biosecurity risk that may be associated with BMSB and the importation of goods from all countries with established BMSB populations. Countries known to have established BMSB populations are listed in Section 3.1.2.

BMSB is a plant-feeding insect and is naturally found on a large number of plant hosts (Appendix B). Although there have been no recorded incidents of BMSB on plants or plant parts at Australia's border, importation of plants and plant parts is a potential pathway for the entry of this insect pest.

Live plants (for example, nursery stock) and cut flowers are imported subject to a range of appropriate measures, such as methyl bromide fumigation, that are intended to mitigate risks from all life stages of plant feeding insects including BMSB. Therefore the BMSB pathway on live plants and cut flowers is not considered further in this risk assessment.

BMSB has previously been considered as a potential pest on several imported horticultural commodities, including risk analyses of apples from China (Biosecurity Australia 2010), persimmon fruit from Japan, Korea and Israel (DAFF 2004) and unshu mandarins from Japan (Biosecurity Australia 2009). Risk analyses conducted on horticultural imports take into account the specific plant part being harvested and imported, the biology of BMSB (and other relevant pests) in relation to the harvested plant part, conditions of harvest, post-harvest processing, and any other relevant issues directly relating to the commodity and exporting country. This process will continue to identify risks from BMSB on each specific horticultural pathway, and therefore pathways such as these are not considered further here.

A large and growing body of work is being published regarding BMSB as an invasive pest in North America and Europe. This risk analysis considers this new information and re-assesses the consequences of BMSB, as well as the likelihoods of entry, establishment and spread of BMSB as a hitchhiker pest. The background information used to assess risks from BMSB is presented in Chapter 3 and the risk assessment is presented in Chapter 4 Pest risk assessment.

1.2.3 Existing policy

Pest risk assessments already exist for BMSB as it has previously been assessed as a quarantine pest in several fresh fruit commodity risk analyses. In six of these, *Fuji apples from Japan* (AQIS 1998), *Fresh unshu mandarin fruit from Shizuoka Prefecture in Japan* (Biosecurity Australia 2009), *Fresh apple fruit from the People's Republic of China* (Biosecurity Australia 2010), *Table grapes from the People's Republic of China* (Biosecurity Australia 2011a), *Table grapes from the Republic of Korea* (Biosecurity Australia 2011b), and *Fresh table grapes from Japan* (Department of Agriculture 2014), BMSB was considered to not be on the pathway, and therefore not assessed further. In *Persimmon fruit (*Diospyros kaki *L.) from Japan, Korea and Israel* (DAFF 2004) the consequences (direct and indirect) of BMSB were estimated as **Low**, however this assessment was conducted prior to the impacts of BMSB as an exotic pest in North America and Europe becoming known.

Existing import requirements for goods entering Australia can be found on the department's Biosecurity Import Conditions (BICON) system on the department website (https://bicon.agriculture.gov.au/BiconWeb4.0).

1.2.4 Key Consultation and engagement activities

Since beginning emergency measures in 2014, extensive and comprehensive consultation has been conducted on all aspects of BMSB risk and risk mitigation. This has included email correspondence, teleconferences and attendance at meetings and conferences. Scientific experts from around the world have been consulted to better understand BMSB risk relative to specific countries and goods, likely consequences to Australia, effective treatments for BMSB and appropriate surveillance techniques. Domestic primary industry stakeholders have been consulted to communicate findings on BMSB risk, onshore and offshore risk management, import requirements, likely consequences and surveillance and preparedness activities. International trading partners have been consulted regarding Australia's BMSB status, risk assessments, and offshore risk management requirements. The following specific examples are highlights of these many consultation and engagement activities.

International

24 January 2015—Prior to implementing offshore emergency measures in 2015, a representative from the department along with representatives from the New Zealand Ministry for Primary Industries (NZ MPI) visited the USA for 10 days to discuss BMSB issues with affected United States companies and the United States Department of Agriculture (USDA). They also assessed the ability of United States exporters to meet offshore treatment requirements.

21 November 2015—A department representative visited the USA from 21 November 2015 to 2 December 2015 with two NZ MPI representatives. This second joint trip aimed to re-examine the implementation of risk management measures at the key vehicle export port areas of Savannah and Baltimore, and to reaffirm the risk pathway nodes. The trip was also used to evaluate the offshore treatment processes being used to mitigate the risk of these hitchhiker pests being exported to both countries, in motor vehicles in particular. The trip also aimed to reinforce industry awareness in the USA of the then current hitchhiker pest issues, particularly for exporters and port authorities.

2 to 3 August 2016—Officers from the department met MPI representatives in New Zealand to discuss measures for the 2016–17 BMSB risk season, and hitchhiker and contaminant pest management.

23 May to 6 June 2017—Officers from the department travelled with representatives from NZ MPI and visited northern Italy and other sites in Europe to liaise with Italian counterparts and to visit key ports and other facilities in relation to BMSB pathway management.

21 August 2017—The department announced that the BMSB emergency measures would be extended to containerised and break bulk cargo from all European ports which had loaded cargo manufactured or stored in Italy. This change followed incidents with large numbers of BMSB on bulk and containerised cargo exported from Italy, and took effect for the 2017–18 season.

29 August 2017—The draft report was released for a 60 day consultation period closing on 27 October 2017. The department received three submissions on the draft report. All submissions were carefully considered and, where relevant, changes were made to the final report. A summary of major stakeholder comments and how they were considered is contained in Appendix D.

December 2017 through March 2018—Ongoing incidents of live BMSB in goods with certification of sulfuryl fluoride treatment led to a series of letters, teleconferences and meetings with exporters, offshore treatment providers, Italian government officials and scientists, and peak industry bodies. This engagement sought to clarify a range of issues regarding treatment and documentation requirements, as well as import measures and surveillance tools.

8 March 2018—The department advised it would no longer accept goods treated with sulfuryl fluoride fumigation from Italian treatment providers, and directed these goods for onshore treatment.

1 September 2018—The department further extended the BMSB emergency measures to include high risk goods from all European ports which were manufactured or stored in seven additional countries: Hungary, Romania, Georgia, Germany, France, Greece and Russia.

Intelligence gathering and expert consultation

13 May 2015—Officers from the NZ MPI and the department held a meeting in Canberra to discuss practical considerations around bringing Australia and New Zealand treatment requirements for BMSB into alignment. The season of risk, treatment of BMSB-infested goods, new information on effective treatments, surveillance, onshore preparedness and BMSB biology were the main topics of discussion.

7 June 2015—An officer from the department travelled to the USA to gain up to date information on BMSB biology. The trip included giving a presentation outlining the risk from BMSB and required measures at a national BMSB conference in Washington DC, and meeting with USDA researchers, followed by trips to Florida and California to meet with BMSB researchers.

Late January and early February 2019—The department held a series of meetings and workshops in Canberra with representatives from New Zealand MPI to discuss control measures for the 2019–20 season to ensure better alignment between the two countries requirements.

11–14 March 2019—Department staff attended and presented at the "International Conference Brown Marmorated Stink Bug (BMSB) – Phytosanitary Regulatory Framework" in Tbilisi, Georgia. BMSB pest status in a number of countries was discussed with relevant international experts who attended.

18–28 May 2019—Department staff visited the Republic of Georgia to work with experts on BMSB preparedness, trapping and surveillance, monitoring and management strategies.

25–29 August 2019—Department staff attended a scientific workshop and conference on BMSB attended by scientists from around the world. Participation in this event gave an opportunity to learn from the expert evaluation of the Georgian measures, particularly by experiencing first hand end-of-season measures against BMSB after having already seen the beginning-of-the-season monitoring and control activities in May.

Industry stakeholders

During the 2014–15 BMSB emergency response, the department worked with industry stakeholders (including shipping lines, importers, brokers, stevedores, ports and representative bodies) to manage the risks associated with BMSB. Industry cooperation during the emergency response included adapting to new measures such as on-board inspection, thermal fogging and fumigation. To assist with communication in the 2014–15 season, the department set up a dedicated 1800 BMSB telephone enquiry line, published up-to-date information on its website, and communicated changes to the measures directly to industry representative bodies.

In the lead-up to and during the 2015–16 season, the department presented to industry at meetings and conferences and had articles published in industry magazines and on industry websites. Industry provided input into the 2014–15 Emergency Season Post-Implementation Review, and their feedback was considered when determining the 2015–16 season measures. Industry input was again sought in the development of the 2016–17 measures which commenced 1 September 2016.

From 5–6 July 2018, face-to-face information sessions were held in Sydney and Melbourne with industry stakeholders to provide input into the 2018–19 seasonal measures.

From March 2018 the Department of Agriculture Cargo Consultative Committee (DCCC) held a series of meetings and teleconferences to provide updates on BMSB measures, and opportunities to raise questions and provide feedback, including seeking feedback into the Inspector-General of Biosecurity review into BMSB.

2 Method for pest risk analysis

This chapter sets out the method used for the pest risk analysis (PRA) in this report. The department has conducted this PRA in accordance with the International Standards for Phytosanitary Measures (ISPMs), including ISPM 2: *Framework for pest risk analysis* (FAO 2007) and ISPM 11: *Pest risk analysis for quarantine pests* (FAO 2013) that have been developed under the SPS Agreement (WTO 1995).

A PRA is 'the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it' (FAO 2015). A pest is 'any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products' (FAO 2015). This definition is also applied in the *Biosecurity Act 2015*.

Biosecurity risk consists of two major components: the likelihood of a pest entering, establishing and spreading in Australia from imports; and the consequences should this happen. These two components are combined to give an overall estimate of the risk.

Unrestricted risk is estimated taking into account the existing commercial production practices of the exporting country and that, on arrival in Australia, the department will verify that the consignment received is as described on the commercial documents and its integrity has been maintained.

Restricted risk is estimated with phytosanitary measure(s) applied. A phytosanitary measure is 'any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests' (FAO 2015).

A glossary of the terms used in this risk analysis is provided at the end of this report.

The PRA is conducted in the following three consecutive stages: initiation, pest risk assessment and pest risk management.

2.1 Stage 1 Initiation

Initiation identifies the pest(s) and pathway(s) that are of quarantine concern and should be considered for risk analysis in relation to the identified PRA area. For this PRA, the 'PRA area' is defined as all of Australia.

This report is a pest-initiated PRA that considers the risk of one pest (BMSB) that could enter as a hitchhiker pest (Appendix A). The department has previously conducted pest categorisation (multiple risk analyses) and has established that BMSB is a quarantine pest for Australia (Section 1.2.3). The pest risk assessment for BMSB is set out in Chapter 4.

2.2 Stage 2 Pest risk assessment

A pest risk assessment (for quarantine pests) is the 'evaluation of the probability of the introduction and spread of a pest and of the magnitude of the associated potential economic consequences' (FAO 2015).

The following three, consecutive steps were used in the pest risk assessment:

2.2.1 Pest categorisation

Pest categorisation identifies which of the pests with the potential to be on the commodity are quarantine pests for Australia and require pest risk assessment. A 'quarantine pest' is 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 (FAO 2015).

The process of pest categorisation is summarised by the IPPC in the five elements outlined below:

- identity of the pest
- presence or absence in the PRA area
- regulatory status
- potential for establishment and spread in the PRA area
- potential for economic consequences (including environmental consequences) in the PRA area.

The results of pest categorisation are set out in Appendix A. Quarantine pests identified during categorisation were carried forward for pest risk assessment.

2.2.2 Assessment of the probability of entry, establishment and spread

Details of how to assess the 'probability of entry', 'probability of establishment' and 'probability of spread' of a pest are given in ISPM 11 (FAO 2013). The SPS Agreement (WTO 1995) uses the term likelihood rather than probability for these estimates. In qualitative PRAs, the department uses the term 'likelihood' for the descriptors it uses for its estimates of likelihood of entry, establishment and spread. The use of the term 'probability' is limited to the direct quotation of ISPM definitions.

A summary of this process is given below, followed by a description of the qualitative methodology used in this risk analysis.

Likelihood of entry

The likelihood of entry describes the likelihood that a quarantine pest will enter Australia as a result of trade in a given commodity, be distributed in a viable state in the PRA area and subsequently be transferred to a host. It is based on pathway scenarios depicting necessary steps in the sourcing of the commodity for export, its processing, transport and storage, its use in Australia and the generation and disposal of waste. In particular, the ability of the pest to survive is considered for each of these various stages.

For the purpose of considering the likelihood of entry, the department divides this step into two components:

- **Likelihood of importation**—the likelihood that a pest will arrive in Australia when a given commodity is imported.
- **Likelihood of distribution**—the likelihood that the pest will be distributed, as a result of the processing, sale or disposal of the commodity, in the PRA area and subsequently transfer to a susceptible part of a host.

Factors to be considered in the likelihood of importation may include:

- distribution and incidence of the pest in the source area
- occurrence of the pest in a life-stage that would be associated with the commodity
- mode of trade (for example, bulk, packed)
- volume and frequency of movement of the commodity along each pathway
- seasonal timing of imports
- pest management, cultural and commercial procedures applied at the place of origin
- speed of transport and conditions of storage compared with the duration of the lifecycle of the pest
- vulnerability of the life-stages of the pest during transport or storage
- incidence of the pest likely to be associated with a consignment
- commercial procedures (for example, refrigeration) applied to consignments during transport and storage in the country of origin, and during transport to Australia.

Factors to be considered in the likelihood of distribution may include:

- commercial procedures (for example, refrigeration) applied to consignments during distribution in Australia
- dispersal mechanisms of the pest, including vectors, to allow movement from the pathway to a host
- whether the imported commodity is to be sent to a few or many destination points in the PRA area
- proximity of entry, transit and destination points to hosts
- time of year at which import takes place
- intended use of the commodity (for example, for planting, processing or consumption)
- risks from by-products and waste.

Likelihood of establishment

Establishment is defined as the 'perpetuation for the foreseeable future, of a pest within an area after entry' (FAO 2015). In order to estimate the likelihood of establishment of a pest, reliable biological information (for example, lifecycle, host range, epidemiology, survival) is obtained from the areas where the pest currently occurs. The situation in the PRA area can then be compared with that in the areas where it currently occurs and expert judgement used to assess the likelihood of establishment.

Factors to be considered in the likelihood of establishment in the PRA area may include:

- availability of hosts, alternative hosts and vectors
- suitability of the environment
- reproductive strategy and potential for adaptation
- minimum population needed for establishment
- cultural practices and control measures.

Likelihood of spread

Spread is defined as 'the expansion of the geographical distribution of a pest within an area' (FAO 2015). The likelihood of spread considers the factors relevant to the movement of the pest, after establishment on a host plant or plants, to other susceptible host plants of the same or different species in other areas. In order to estimate the likelihood of spread of the pest, reliable biological information is obtained from areas where the pest currently occurs. The situation in the PRA area is then carefully compared with that in the areas where the pest currently occurs and expert judgement used to assess the likelihood of spread.

Factors to be considered in the likelihood of spread may include:

- suitability of the natural and/or managed environment for natural spread of the pest
- presence of natural barriers
- potential for movement with commodities, conveyances or by vectors
- intended use of the commodity
- potential vectors of the pest in the PRA area
- potential natural enemies of the pest in the PRA area.

Assigning likelihoods for entry, establishment and spread

Likelihoods are assigned to each step of entry, establishment and spread. Six descriptors are used: high; moderate; low; very low; extremely low; and negligible (Table 1). Definitions for these descriptors and their indicative probability ranges are given in Table 1. The indicative probability ranges are only provided to illustrate the boundaries of the descriptors and are not used beyond this purpose in qualitative PRAs. These indicative probability ranges provide guidance to the risk analyst and promote consistency between different pest risk assessments.

Table 1 Nomenclature of likelihoods.

Likelihood	Descriptive definition	Indicative range
High	The event would be very likely to occur	0.7 < to ≤ 1
Moderate	The event would occur with an even likelihood	0.3 < to ≤ 0.7
Low	The event would be unlikely to occur	0.05 < to ≤ 0.3
Very low	The event would be very unlikely to occur	0.001 < to ≤ 0.05
Extremely low	The event would be extremely unlikely to occur	0.000001 < to ≤ 0.001
Negligible	The event would almost certainly not occur	0 < to ≤ 0.000001

Combining likelihoods

The likelihood of entry is determined by combining the likelihood that the pest will be imported into the PRA area and the likelihood that the pest will be distributed within the PRA area, using a matrix of rules (Table 2). This matrix is then used to combine the likelihood of entry and the likelihood of establishment, and the likelihood of entry and establishment is then combined with the likelihood of spread to determine the overall likelihood of entry, establishment and spread.

For example, if the likelihood of importation is assigned a descriptor of 'low' and the likelihood of distribution is assigned a descriptor of 'moderate', then they are combined to give a likelihood of 'low' for entry. The likelihood for entry is then combined with the likelihood assigned for establishment of 'high' to give a likelihood for entry and establishment of 'low'. The likelihood for entry and establishment is then combined with the likelihood assigned for spread of 'very low' to give the overall likelihood for entry, establishment and spread of 'very low'. This can be summarised as:

importation x distribution = entry [E]	**low x moderate = low**
entry x establishment = [EE]	**low x high = low**
[EE] x spread = [EES]	**low x very low = very low**

Table 2 Matrix of rules for combining likelihoods.

	High	Moderate	Low	Very low	Extremely low	Negligible
High	High	Moderate	Low	Very low	Extremely low	Negligible
Moderate		Low	Low	Very low	Extremely low	Negligible
Low			Very low	Very low	Extremely low	Negligible
Very low				Extremely low	Extremely low	Negligible
Extremely low					Negligible	Negligible
Negligible						Negligible

Time and volume of trade

One factor affecting the likelihood of entry is the volume and duration of trade. If all other conditions remain the same, the overall likelihood of entry will increase as time passes and the overall volume of trade increases.

The department normally considers the likelihood of entry on the basis of the estimated volume of one year's trade. This is a convenient value for the analysis that is relatively easy to estimate and allows for expert consideration of seasonal variations in pest presence, incidence and behaviour to be taken into account. The consideration of the likelihood of entry, establishment and spread and subsequent consequences takes into account events that might happen over a number of years even though only one year's volume of trade is being considered. This difference reflects biological and ecological facts, for example where a pest or disease may establish in the year of import but spread may take many years.

The use of a one year volume of trade has been taken into account when setting up the matrix that is used to estimate the risk and therefore any policy based on this analysis does not simply apply to one year of trade. Policy decisions that are based on the department's method that uses the estimated volume of one year's trade are consistent with Australia's policy on appropriate level of protection and meet the Australian Government's requirement for ongoing quarantine protection. If there are substantial changes in the volume and nature of the trade in specific commodities then the department will review the risk analysis and, if necessary, provide updated policy advice.

In assessing the volume of trade in this risk analysis, the department assumed that a substantial volume of trade will occur.

2.2.3 Assessment of potential consequences

The objective of the consequence assessment is to provide a structured and transparent analysis of the potential consequences if the pests or disease agents were to enter, establish and spread in Australia. The assessment considers direct and indirect pest effects and their economic and environmental consequences. The requirements for assessing potential consequences are given in Article 5.3 of the SPS Agreement (WTO 1995), ISPM 5 (FAO 2015) and ISPM 11 (FAO 2013).

Direct pest effects are considered in the context of the effects on:

- plant life or health
- other aspects of the environment.

Indirect pest effects are considered in the context of the effects on:

- eradication, control
- domestic trade
- international trade
- environment

For each of these six criteria, the consequences were estimated over four geographic levels, defined as:

Local—an aggregate of households or enterprises (a rural community, a town or a local government area).

District—a geographically or geopolitically associated collection of aggregates (generally a recognised section of a state or territory, such as 'Far North Queensland').

Regional—a geographically or geopolitically associated collection of districts in a geographic area (generally a state or territory, although there may be exceptions with larger states such as Western Australia).

National—Australia wide (Australian mainland states and territories and Tasmania).

For each criterion, the magnitude of the potential consequence at each of these levels was described using four categories, defined as:

Indiscernible—pest impact unlikely to be noticeable.

Minor significance—expected to lead to a minor increase in mortality/morbidity of hosts or a minor decrease in production but not expected to threaten the economic viability of production. Expected to decrease the value of non-commercial criteria but not threaten the criterion's intrinsic value. Effects would generally be reversible.

Significant—expected to threaten the economic viability of production through a moderate increase in mortality/morbidity of hosts, or a moderate decrease in production. Expected to significantly diminish or threaten the intrinsic value of non-commercial criteria. Effects may not be reversible.

Major significance—expected to threaten the economic viability through a large increase in mortality/morbidity of hosts, or a large decrease in production. Expected to severely or irreversibly damage the intrinsic 'value' of non-commercial criteria.

The estimates of the magnitude of the potential consequences over the four geographic levels were translated into a qualitative impact score (A-G) using Table 3. For example, a consequence with a magnitude of 'significant' at the 'district' level will have a consequence impact score of D.

Table 3 Decision rules for determining the consequence impact score based on the magnitude of consequences at four geographic scales.

	Geographic scale			
Magnitude	Local	District	Region	Nation
Indiscernible	A	A	A	A
Minor significance	B	C	D	E
Significant	C	D	E	F
Major significance	D	E	F	G

Note: In earlier qualitative PRAs, the scale for the impact scores went from A to F and did not explicitly allow for the rating 'indiscernible' at all four levels. This combination might be applicable for some criteria. In this report, the impact scale of A to F has been changed to become B-G and a new lowest category A ('indiscernible' at all four levels) was added. The rules for combining impacts in Table 4 were adjusted accordingly.

The overall consequence for each pest is achieved by combining the qualitative impact scores (A–G) for each direct and indirect consequence using a series of decision rules (Table 3). These rules are mutually exclusive, and are assessed in numerical order until one applies.

Table 4 Decision rules for determining the overall consequence rating for each pest.

Rule	The impact scores for consequences of direct and indirect criteria	Overall consequence rating
1	Any criterion has an impact of 'G'; or more than one criterion has an impact of 'F'; or a single criterion has an impact of 'F' and each remaining criterion an 'E'.	Extreme
2	A single criterion has an impact of 'F'; or all criteria have an impact of 'E'.	High
3	One or more criteria have an impact of 'E'; or all criteria have an impact of 'D'.	Moderate
4	One or more criteria have an impact of 'D'; or all criteria have an impact of 'C'.	Low
5	One or more criteria have an impact of 'C'; or all criteria have an impact of 'B'.	Very Low
6	One or more but not all criteria have an impact of 'B', and all remaining criteria have an impact of 'A'.	Negligible

2.2.4 Estimation of the unrestricted risk

Once the assessment of the likelihood of entry, establishment and spread and for potential consequences are completed, the unrestricted risk can be determined for each pest or groups of pests. This is determined by using a risk estimation matrix (Table 5) to combine the estimates of the likelihood of entry, establishment and spread and the overall consequences of pest establishment and spread. Therefore, risk is the product of likelihood and consequence.

When interpreting the risk estimation matrix, note the descriptors for each axis are similar (for example, low, moderate, high) but the vertical axis refers to likelihood and the horizontal axis refers to consequences. Accordingly, a 'low' likelihood combined with 'high' consequences, is not the same as a 'high' likelihood combined with 'low' consequences—the matrix is not symmetrical. For example, the former combination would give an unrestricted risk rating of 'moderate', whereas, the latter would be rated as a 'low' unrestricted risk.

Table 5 Risk estimation matrix.

Likelihood of pest entry, establishment and spread	Consequences of pest entry, establishment and spread					
	Negligible	Very low	Low	Moderate	High	Extreme
High	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Moderate	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Low	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk	High risk
Very low	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk
Extremely low	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk
Negligible	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk

2.2.5 The appropriate level of protection (ALOP) for Australia

The SPS Agreement defines the concept of an 'appropriate level of sanitary or phytosanitary protection (ALOP)' as the level of protection deemed appropriate by the WTO Member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory.

Like many other countries, Australia expresses its ALOP in qualitative terms. The ALOP for Australia, which reflects community expectations through government policy, is currently expressed as providing a high level of sanitary or phytosanitary protection aimed at reducing risk to a very low level, but not to zero. The band of cells in Table 5 marked 'very low risk' represents the ALOP for Australia.

2.3 Stage 3 Pest risk management

Pest risk management describes the process of identifying and implementing phytosanitary measures to manage risks to achieve the ALOP for Australia, while ensuring that any negative effects on trade are minimised.

The conclusions from pest risk assessment are used to decide whether risk management is required and if so, the appropriate measures to be used. Where the unrestricted risk estimate does not achieve the ALOP for Australia, risk management measures are required to reduce this risk to a very low level. The guiding principle for risk management is to manage risk to achieve the ALOP for Australia. The effectiveness of any proposed phytosanitary measures (or combination of measures) is evaluated, using the same approach as used to evaluate the unrestricted risk, to ensure the restricted risk for the relevant pest or pests to achieve the ALOP for Australia.

ISPM 11 (FAO 2013) provides details on the identification and selection of appropriate risk management options and notes that the choice of measures should be based on their effectiveness in reducing the likelihood of entry of the pest.

Examples given of measures commonly applied to traded commodities include:

- options for consignments—for example, inspection or testing for freedom from pests, prohibition of parts of the host, a pre-entry or post-entry quarantine system, specified conditions on preparation of the consignment, specified treatment of the consignment, restrictions on end-use, distribution and periods of entry of the commodity
- options preventing or reducing infestation in the crop—for example, treatment of the crop, restriction on the composition of a consignment so it is composed of plants belonging to resistant or less susceptible species, harvesting of plants at a certain age or specified time of the year, production in a certification scheme
- options ensuring that the area, place or site of production or crop is free from the pest—for example, pest-free area, pest-free place of production or pest-free production site
- options for other types of pathways—for example, consider natural spread, measures for human travellers and their baggage, cleaning or disinfestations of contaminated machinery
- options within the importing country—for example, surveillance and eradication programs
- prohibition of commodities—if no satisfactory measure can be found.

Risk management measures are identified for any quarantine pest where the level of biosecurity risk does not achieve the ALOP for Australia. These are presented in Chapter 5: Pest risk management, of this report.

3 Background information

This chapter details information on BMSB that is relevant to the pest risk assessment process (Chapter 4).

3.1 Pest information

3.1.1 Taxonomy

Halyomorpha halys (Stål, 1855) is an hemipteran insect in the Pentatomidae family. Insects in this group are commonly referred to as stink bugs or shield bugs. The common name of *H. halys* is 'brown marmorated stink bug' (BMSB).

Other combinations and synonyms of *Halyomorpha halys* include *Pentatoma halys* (Stål, 1855), *Poecilometis mistus* (Uhler, 1860), *Dalpada brevis* (Walker, 1867) and *D. remota* (Walker, 1867) (Rider 2014). Other authors have misidentified *Halyomorpha mista*, *H. brevis* and *H. remota* as *H. halys* (Rider 2014). BMSB has also been frequently confused with *H. picus*, an Indian species (Rider, Zheng & Kerzhner 2002). The name *H. mista* has been used in Japan until recently (Rider, Zheng & Kerzhner 2002). However, only one species of *Halyomorpha* is found in eastern China, Japan and Korea, and therefore all records from this area should be referred to as *H. halys* (Hoebeke & Carter 2003; Rider 2014; Rider, Zheng & Kerzhner 2002).

3.1.2 Distribution and invasion history of BMSB

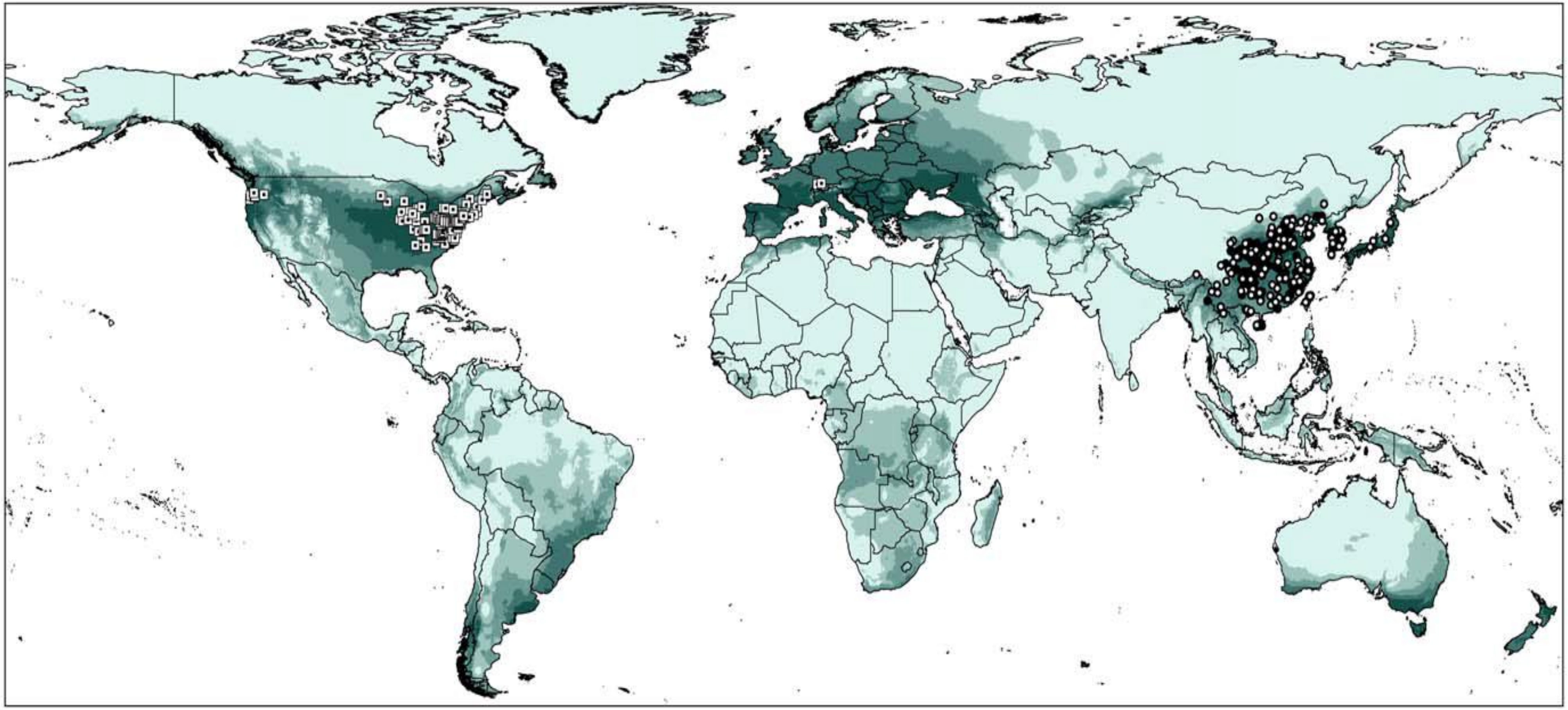
The native range of BMSB is East Asia. Countries in the native range include China, South Korea and Japan (Lee et al. 2013). There are records of BMSB extending south to the subtropical areas of China (Zhu et al. 2012; Zhu et al. 2016), although it is difficult to find the insects in these areas (Kim Hoelmer [Research Entomologist, USDA/ARS Beneficial Insects Introduction Research Unit] 2015, pers. comm., 9 June; Xu et al. 2014). BMSB collected in these southern areas may have been dispersed by human-mediated activities from more northern latitudes (Xu et al. 2014). However, other work suggests that southern populations have their own distinctive population genetics (Zhu et al. 2016). Most reports of BMSB as a pest in Asia come from more temperate regions, that is, Japan, Korea and northern China (Lee et al. 2013). There are other *Halyomorpha* species with distributions that extend into the tropical parts of Asia, including *H. picus,* which may be visually similar to *H. halys* and cause potential confusion regarding the southerly distribution limits of *H. halys*.

BMSB has spread to other parts of the world in recent decades (Haye et al. 2015). Climate matching studies indicate that most temperate areas in both the northern and southern hemisphere have suitable climates for BMSB establishment, including areas in Europe, North America, South America, Africa, New Zealand and southeast and southwest Australia (Fraser, Kumar & Aguilar 2017; Haye et al. 2015; Zhu et al. 2012; Zhu et al. 2016).

Some models show high suitability for BMSB in subtropical and tropical regions (for example, Kriticos et al. (2017). However, day lengths longer than 13-14 hours appear to be important for the BMSB life-cycle (Walgenbach 2015), and BMSB is not recorded as a serious pest in subtropical or tropical regions. There is no evidence that BMSB has spread naturally or via human–mediated dispersal into tropical regions of east Asia, despite a long period of potential opportunity. This is in contrast to the global spread of BMSB through temperate regions.

Map 3 The potential geographic distribution of BMSB based on niche modelling.

-



Dark green colour represents high suitability, light green indicates low suitability. Circles and squares represent selected native and invasive records of BMSB, respectively, current at the time of original publication, (taken from Zhu et al. (2012).

A breeding population of BMSB was first officially reported outside its native range in 2001 in Allentown, Pennsylvania, USA, but was considered to have been present in the area since at least 1996 (Rice et al. 2014). Since then, breeding populations have spread to many states in the continental USA (Rice et al. 2014) as well as the Canadian provinces of Ontario (Gariépy, Fraser & Scott-Dupree 2014) and British Colombia (Abram et al. 2017).

Not only has the insect spread into new areas in North America, but population densities in infested areas have continued to increase (Leskey & Nielsen 2018; Nielsen 2013). Initial detections in the USA were based on homeowner reports, when BMSB entered homes in autumn. However, as population densities increased, not only were more nuisance reports recorded, but also damage to crops and other plants (Leskey et al. 2012a; Rice et al. 2014).

In the USA, BMSB has now been reported in most states. Since the publication of the draft report, BMSB has continued to spread and cause severe pest problems in new areas. Larger populations are still mainly located in the eastern USA and the Pacific Northwest, but BMSB is now also rated as causing agricultural and nuisance problems in Midwestern and Central states, including Michigan, Minnesota and Utah (StopBMSB.org 2016).

Other areas in the USA have lower populations of BMSB. For example, BMSB is only rarely found, and is unknown as a crop or nuisance pest in the coastal plain region in the states of North Carolina and Virginia, but in other areas of those states BMSB reaches high population densities (Bakken et al. 2015). This differential trend has apparently continued to date (Vaughn 2019).

In California, BMSB breeding populations have established in Los Angeles county and the city of Sacramento. In Sacramento and surrounding areas the spread of BMSB is continuing; prior to 2017 there were no reports of large populations and damage levels comparable to the Mid-Atlantic states (Ingels & Daane 2018; Rijal & Duncan 2017), but more recent reports suggest that pest problems may now be beginning to emerge in this region (Eddy 2018; Rijal & Gyawaly 2018). The BMSB population in Los Angeles has been present since at least 2006, but so far has not expanded into agricultural areas, and has generated few reports of being a nuisance pest (Lara et al. 2016; Lara et al. 2018; Mark Hoddle [Department of Entomology, University of California Riverside] 2015, pers. comm., 15 June; Rijal & Duncan 2017). Finally, while BMSB adults have been found on vehicles entering Florida many times (Halbert & Hodges 2011; Russell 2012), a small breeding population has only recently been confirmed as present in central Florida (Penca & Hodges 2018).

In the above instances, it remains unknown why BMSB populations are lower in some areas than elsewhere. While it is possible that BMSB populations in these areas will increase to pest levels over time, other factors such as temperature, day length, humidity and local vegetation characteristics have also been considered to be possible factors that limit BMSB populations (Bakken et al. 2015; Mark Hoddle [Department of Entomology, University of California Riverside] 2015, pers. comm., 15 June; Amanda Hodges, [University of Florida] 2015, pers. comm., 12 June; Nielsen, Fleischer & Chen 2016; Venugopal et al. 2016; Zhu et al. 2016).

Sharp declines in the number of BMSB trap captures have been documented after periods of high temperatures of 38°C or more for seven days (Ingels & Daane 2018), consistent with the increasing mortality of BMSB at temperatures of 35°C and higher (Aigner & Kuhar 2016; Scaccini et al. 2018) and the thermal maximum of about 33°C to 36°C for development (Baek et al. 2017; Nielsen, Shearer & Hamilton 2008).

BMSB has also established in Canada, including in southern Ontario, Quebec and British Colombia, most likely from overland spread of the USA population (Abram et al. 2017; Chouinard et al. 2018; Gariépy, Fraser & Scott-Dupree 2014). Although BMSB has not been reported as a pest of agricultural crops in Canada, it has been reported as a minor nuisance pest (Abram et al. 2017; Gariépy, Fraser & Scott-Dupree 2014) and has been found in various crop plants (Abram et al. 2017; Chouinard et al. 2018).

In Europe, BMSB was first officially reported in Zurich, Switzerland in 2007, but is thought to have been established in the area at least since 2004 (Gariépy et al. 2013). From this time BMSB has spread rapidly in Europe and other neighboring countires. There are now many countries reporting established BMSB populations of varying sizes. For example, BMSB is now reported to have caused nuisance problems in France (Connexion Journalist 2018) and Spain (Roca-Cusachs et al. 2018). New populations have been reported in Belgium, the Czech Republic and the Netherlands (Claerebout et al. 2019) as well as Kazakhstan (Esenbekova 2017) and Turkey (Güncan & Gümüs 2019). Agricultural damage has been reported in Germany (Zimmermann et al. 2018), Greece (Andreadis et al. 2018), Hungary (Vetek et al. 2014), Russia and Georgia (Musolin et al. 2018).

Given the exponential increase in the number of BMSB intercepted by Australia in cargo in the past few seasons, the lack of movement controls on most types of cargo in Europe, and the many land borders that do not present a barrier to natural dispersal, it is now anticipated that all European countries and other neighboring countires with a suitable climate will have established BMSB populations within a few years.

Some European countries with land borders adjacent to countries with large BMSB populations have not yet reported established BMSB populations, but it is unclear to what extent monitoring and reporting is occurring in each instance. For example, BMSB was first found in Belgium in 2011, but not reported until 2019 (Claerebout et al. 2019). Based on photos uploaded to various websites, BMSB may be recently established at low levels in more European countries than have yet been reported in peer-reviewed articles (Claerebout et al. 2019).

In the southern hemisphere, BMSB is present in the metropolitan area of Santiago, Chile (Faúndez & Rider 2017) and is under official control (SAG 2017). No other populations of BMSB are currently known in the southern hemisphere.

Genetic analysis of the invasive BMSB population in the eastern USA suggests the most likely source of this insect was the Beijing region of China (Xu et al. 2014). In the western USA, there may be genetic evidence of other introductions from Asia (Lara et al. 2016). In Europe, different countries have different BMSB population genetics, suggesting multiple introductions from different sources (Cesari et al. 2018; Gariépy et al. 2015).

Genetic studies have shown that the Swiss BMSB population is different to that in the United States population and is likely to have come from a different part of Asia, but the source location could not be determined (Gariépy, Haye & Zhang 2014). In Hungary, BMSB population genetics suggest that its source was either the population in the USA, or the same Asian source as that of the United States population (Gariépy et al. 2015). In Italy, two genetically distinct populations have been reported, one consistent with an overland spread of the Swiss population and the other being the same as Hungary's population (Cesari et al. 2014; Cesari et al. 2018; Gariépy et al. 2015). A large population diversity has been found around Athens in Greece, with no clear source identified (Cesari et al. 2018; Gariépy et al. 2015). As this population is near the very busy port of Piraeus, multiple and/or large introductions are considered the most likely cause of this genetic diversity (Gariépy et al. 2015).

3.1.3 BMSB lifecycle

BMSB, like most stink bugs, has a life cycle which includes eggs laid in a mass, five flightless nymphal instars, and a final winged adult stage (Figure 3). Eggs are approximately 1.3 millimetres in diameter, 1.6 millimetres long and laid in a cluster of typically 20 to 30 eggs (Hoebeke & Carter 2003). Approximate body lengths for each nymphal stage are: first instar 2.4 millimetres, second instar 3.7 millimetres, third instar 5.5 millimetres, fourth instar 8.5 millimetres and fifth instar 12.0 millimetres (Hoebeke & Carter 2003). Adults range from 12 millimetres to 17 millimetres long and from 7 millimetres to 10 millimetres wide (Hoebeke & Carter 2003).

Figure 3 Life stages of *Halyomorpha halys* (brown marmorated stink bug; BMSB).

Left to right: eggs, five nymphal stages (first to fifth instar), adult male and adult female. Image: Michael Lewis, Center for Invasive Species Research, used with permission.

BMSB overwinter as pre-reproductive adults which become active and emerge from overwintering sites in spring. A schematic overview of the life history of BMSB relative to seasonal conditions is shown in Figure 4. Emergence seems to be mainly in response to increasing temperatures although changing day length may play some role (Bergh & Leskey 2014). In Asia, Europe and the USA, emergence has been recorded as occurring mainly during the months of March to April and into May (Bergh et al. 2017; Haye et al. 2014; Nielsen & Hamilton 2009a; Watanabe 1980). However, some individuals may remain in overwintering sites until early June (Acebes-Doria, Leskey & Bergh 2016; Bakken et al. 2015; Bergh & Leskey 2014; Bergh et al. 2017; Kobayashi & Kimura 1969; Zhang et al. 1993). Variation in activity commencement can occur within one overwintering aggregation, that is, some adults may begin departing the aggregation in early spring, with others remaining until late spring (Bergh & Leskey 2014; Bergh et al. 2017).

The reason(s) why BMSB show differential emergence from a single overwintering site are not clear, but it is thought that BMSB with depleted overwintering reserves are most likely to exit overwintering sites earlier (Funayama 2012b). BMSB that emerge from overwintering sites earlier in the season have been shown to have higher lipid, glycogen and sugar levels than those that emerge later in May and June (Skillman 2017). An experiment in Japan found that almost all naturally emerged overwintered adults provided with only water in the field from late April could survive until late May (Funayama 2012b).

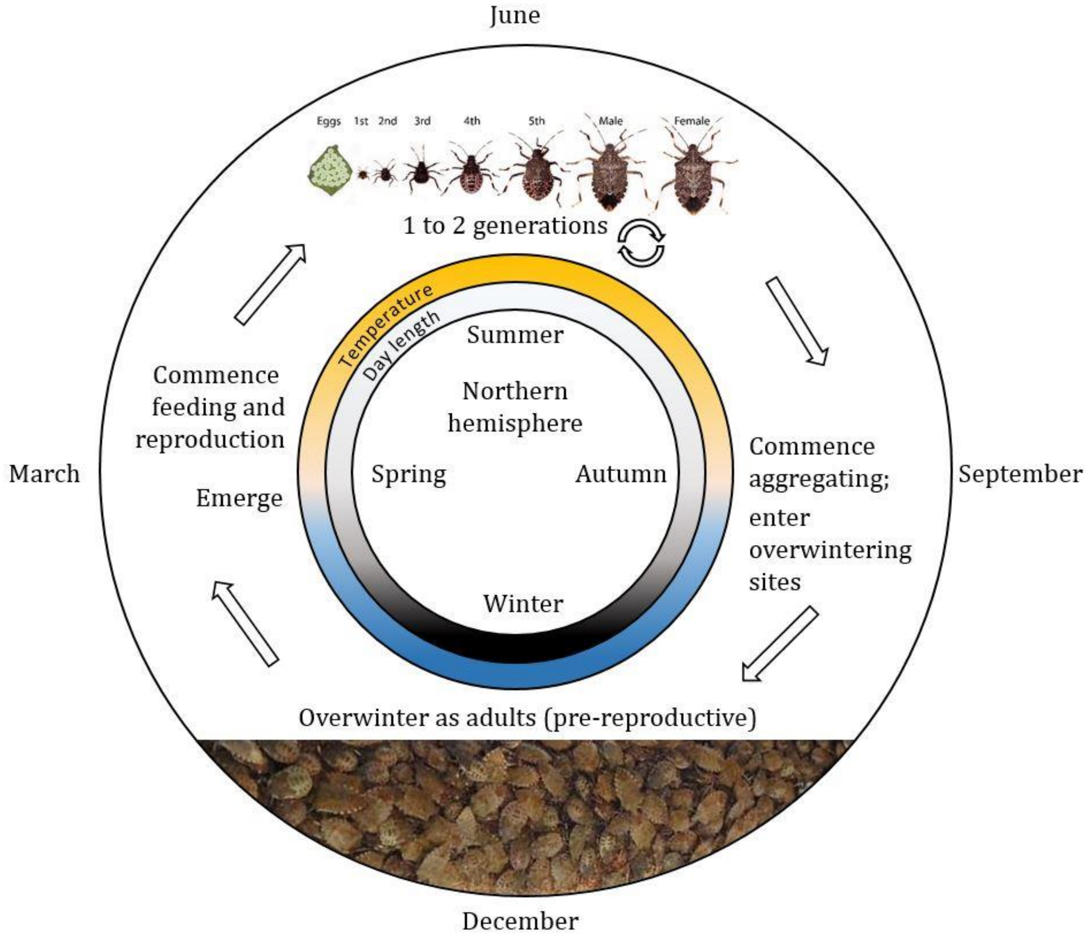
Females emerge from overwintering sites with undeveloped ovaries and require an additional 120 to 190 degree days (as defined in the glossary; usually one to two weeks in the field) to feed and become reproductively mature (Lee et al. 2013; Lowenstein & Walton 2018; Nielsen & Hamilton 2009a). Food sources are important for ovarian development and a varied diet may be required; hosts that support juvenile development will not always support ovarian development (Watanabe 1979). BMSB adults were reported to begin feeding when temperatures exceeded 17°C (Li et al. 2007). This is close to the minimum reported temperature of 16.3°C required for females to develop mature ovaries (Watanabe 1980).

Photoperiod is also important for ovary maturation in adult BMSB. Normal ovarian development is typically reported to occur during photoperiods of 14 hours or longer, and while some development may occur at 13 or 13.5 hours, almost none was reported at 12 hours (Bakken et al. 2015; Haye et al. 2014; Niva & Takeda 2003; Watanabe 1979, 1980; Yanagi & Hagihara 1980). Nymphs reared in the laboratory under conditions of 12 hours light did not mature ovaries as adult females, and had different coloration and fat body content compared to nymphs reared under conditions of 16 hours of light (Niva & Takeda 2003; Watanabe 1979).

A recent model of BMSB population growth suggests that a 13.5 hour photoperiod is required to trigger ovarian development, and this threshold closely fits observed population dynamics (Nielsen, Fleischer & Chen 2016). Watanabe (1980) concluded that only photoperiods from late April to mid-August were suitable for ovarian development in central Japan. Watanabe (1980) suggested that a chilling period was also a requirement; unchilled insects (collected in October in Japan) did not develop mature ovaries, irrespective of photoperiod exposure. Fujiie (1985) found long photoperiods and warm temperatures would bring females collected in November in Japan immediately out of diapause without a further chilling requirement. Fujiie (1985) also found that BMSB matured ovaries in both long and short photoperiods after being naturally chilled overwinter (collected February to March in Japan) and then warmed to 20°C to 30°C. Fujiie (1985) provides the only known report of diapausing females kept under short photoperiods (12 hour) being able to mature ovaries. This result was produced with a low number of experimental replicates, and has not been independently verified.

The change to reproductive maturity cannot be reversed, and sexually mature females cannot enter diapause (Cira et al. 2018; Nielsen, Fleischer & Chen 2016).

Figure 4 Schematic representation of the life history of *Halyomorpha halys* (brown marmorated stink bug; BMSB) in the northern hemisphere in relation to time of year.



Seasonal changes in the northern hemisphere in temperature (blue/cold to orange/hot temperature) and day length (black/short to white/long photoperiod) are indicated (inner two circles), as these are both important factors in the lifecycle of BMSB.

In general, BMSB females are only known to produce eggs consistently under long day conditions (Medal et al. 2012; Niva & Takeda 2003; Watanabe 1979, 1980). Current information suggests that overwintering adults can be brought out of diapause at any time if exposed to appropriate temperature and photoperiod. For example, adults collected in the USA in early October were brought out of diapause in a laboratory by exposure to intense lighting for 16 hours per day at 26°C (Medal et al. 2012). BMSB can be continuously reared in the laboratory without diapause or chilling under conditions of 16 hours light and a temperature of 26°C (Amanda Hodges [University of Florida] 2015, pers. comm., 12 June; Jesus Lara [Department of Entomology, University of California Riverside] 2015, pers. comm., 15 June; Julio Medal [Florida Department of Agriculture] 2015, pers. comm., 12 June).

BMSB mate away from overwintering sites (Kawada & Kitamura 1983). It is not known if BMSB mate before females reach sexual maturity. However, given that mating occurs away from overwintering sites and pheromone traps are less attractive to diapausing and newly-emerged overwintering BMSB (Leskey et al. 2015; Morrison et al. 2017a), it is likely that mating only occurs after females have developed mature ovaries. Once mated, females lay light green egg masses, usually of 20-30 eggs, on the undersides of leaves (Kawada & Kitamura 1983; Nielsen, Shearer & Hamilton 2008). Females can lay many egg masses and have the potential to produce over 400 eggs in their lifetime (Kawada & Kitamura 1983), although lifetime averages of 100 to 200 eggs are commonly reported (Haye et al. 2014; Medal, Smith & Santa Cruz 2013; Nielsen, Hamilton & Matadha 2008). There has been one report of potential parthenogenesis (reproduction by an unmated female) in BMSB, recorded as part of a study in China (Fengjie et al. 1997), however, this is the only known record of this phenomenon. As parthenogenic reproduction is not commonly documented in the pentatomid family, and BMSB has been well studied for many years without any further reports of parthenogenesis, it may be that this is a rare or atypical case.

First instar larvae emerge from eggs three to six days after oviposition, and remain associated with the egg mass while they probe the egg shells for bacterial symbionts (Tang et al. 2012; Taylor et al. 2014). This behaviour is common in stink bugs, and allows the passage of necessary gut symbionts from one generation to the next. Transmission of gut symbionts in this manner has been confirmed for BMSB (Kenyon, Meulia & Sabree 2015; Tang et al. 2012; Taylor et al. 2014). First instar larvae moult three to five days after hatching to become second instars, which disperse from egg masses and begin feeding on host plants. Third instar larvae moult 12 to 13 days after egg hatch, and fourth and fifth instars emerge 19 to 20 days and 26 to 27 days after egg hatch, respectively (Rice et al. 2014). Under laboratory conditions at 25°C constant temperature, time to egg hatching was about one week, then one week each for instars one to four to develop, and two weeks for fifth instar nymphs to develop to adults (Medal, Smith & Santa Cruz 2013).

Although a small proportion of nymphs can reach maturity by feeding on leaves of plants alone, nymphs appear to require fruiting structures of plant hosts to achieve good survival and development rates (Acebes-Doria, Leskey & Bergh 2016). Nymphs also have better survival and development rates when provided with a varied diet consisting of multiple plant hosts (Acebes-Doria, Leskey & Bergh 2016).

Development times are temperature dependent. In their native range, development from egg to adult has been estimated to require between 471 and 630 degree days, with a minimum developmental threshold of 11°C to 14°C (Baek et al. 2017; Lee et al. 2013). The observed characteristics of the invasive populations in North America and Europe fall within this range (Haye et al. 2014; Nielsen, Shearer & Hamilton 2008). Researchers in Korea have reported that BMSB could develop to fourth instars at 33.5°C, but failed to reach the adult stage at this temperature (Baek et al. 2017). Eggs also failed to hatch at 35°C (Baek et al. 2017).

Increasing temperatures above 40°C have been documented to cause high mortality of BMSB with relatively short exposure times. In studies of non-diapausing BMSB in the United States, average BMSB mortality after 4 hours of exposure at 40°C averaged 38 per cent, while at 42°C for four hours mortality averaged 91 per cent. At 45°C mortality averaged 22 per cent after 15 minutes and no BMSB survived 1 hour of exposure to 45°C, and at 50°C no BMSB survived for the shortest time period measured, 15 minutes (Aigner & Kuhar 2016).

Similar results have been reported in a study conducted in Italy (Scaccini, Duso & Pozzebon 2019). This study investigated the effects of high temperatures on adult survival of BMSB depending on adult type, either entering (beginning overwintering) or exiting (ending overwintering) diapause. Temperatures to achieve 99 per cent mortality (LT99) at set time periods were calculated based the experimentally determined response of BMSB to heat. The LT99 temperatures for BMSB entering and exiting diapause respectively were 56.1 to 56.6°C for 2.5 minutes exposure, 47.2 to 48.0°C for 15 minutes, 46.3 to 46.8°C for 30 minutes, and 44.3 to 44.8°C for one hour (Scaccini, Duso & Pozzebon 2019).

In the USA, development from egg to adult was estimated to require 538 degree days (with an additional 148 degree days for females to reach sexual maturity) and to have a developmental threshold of approximately 14°C (Nielsen, Shearer & Hamilton 2008). In the field in Allentown, Pennsylvania, USA this translates to a duration of about eight to ten weeks.

In Europe, development from egg to adult was estimated to require 588 degree days and to have a developmental threshold of approximately 13°C (Haye et al. 2014). In Zurich, Switzerland under naturally fluctuating temperatures, development from egg to adult required between 60 and 131 days (Haye et al. 2014). A recent study has shown that development rates and degree day requirements vary between nymphs that mature under long days into summer reproductive adults or short days into wintering diapause adults, with short day conditions resulting in faster development from nymphs to winter diapause adults (Musolin et al. 2018).

Two estimates for the mean longevity of BMSB were reported to be 301 days and more than 365 days (Lee et al. 2013), which included all life stages and an overwintering period. One study found that actively mating and egg-laying adults lived for 90 to 150 days (Kawada & Kitamura 1983). Adults kept in standard rearing colony conditions (16 hours light, 25°C) are reported to live for about two to three months (Amanda Hodges [University of Florida] 2015, pers. comm., 12 June; Jesus Lara [Department of Entomology, University of California Riverside] 2015, pers. comm., 15 June; Julio Medal [Florida Department of Agriculture] 2015, pers. comm., 12 June; Medal, Smith & Santa Cruz 2013).

BMSB completes one generation per year in colder parts of Asia (Lee et al. 2013), Switzerland (Haye et al. 2014) and most of the USA (Rice et al. 2014). However, in areas where summers are warmer and longer, BMSB is reported to be able to produce a second generation. This has been reported in some parts of Asia (Lee et al. 2013), and two generations have been reported in West Virginia, USA (Nielsen & Hamilton 2009a) and Italy (Bariselli, Bugiani & Maistrello 2016). Four to six generations per year have been reported in the Guangdong province of southern China (Hoffmann 1931). However, this is the only known report of this insect completing more than two generations per year. Since the method for determining the number of generations per year was not reported, this reference is not considered a reliable report for the typical number of BMSB generations in a year.

In the mid-Atlantic states of the USA, overwintered adults are first found on host plants in April, and egg masses are laid in mid-June (Nielsen & Hamilton 2009a, b). Summer adults appear from early July with a peak from August to September, and summer adults aggregate and enter overwintering sites from September to October (Hamilton 2009; Nielsen & Hamilton 2009a). In Zurich, overwintered adults become active in April and egg masses first appear in mid to late June; summer adults first appear in mid-August and adults enter overwintering sites from September to October (Haye et al. 2014).

3.1.4 Overwintering aggregation formation of BMSB

In autumn, decreasing temperature and day length trigger pre-reproductive BMSB adults to aggregate in large numbers prior to entering overwintering sites. In the natural geographic range at Toyama, Japan, a five year study found that BMSB began to arrive at overwintering sites in late September, with peak arrival numbers in mid- to late October, and migration ending by late November (Watanabe et al. 1994). Other reports suggest that BMSB may begin moving toward overwintering sites at the end of August (Zhang et al. 1993).

Temperature and day length both play an important role in triggering this movement. BMSB arrivals near an aggregation site were first observed when daily minimum temperatures dropped below 15°C and days were warm with maximum temperatures around 25°C (Watanabe et al. 1994). The majority of BMSB arrived when the minimum temperature was below 10°C and the days were cool and clear (Watanabe et al. 1994). These insects spent one to two weeks outside the overwintering sites before entering to form aggregations; for example, on 29 September 1988, no BMSB were found in overwintering sites but on 6 October the first BMSB were recovered (Watanabe et al. 1994).

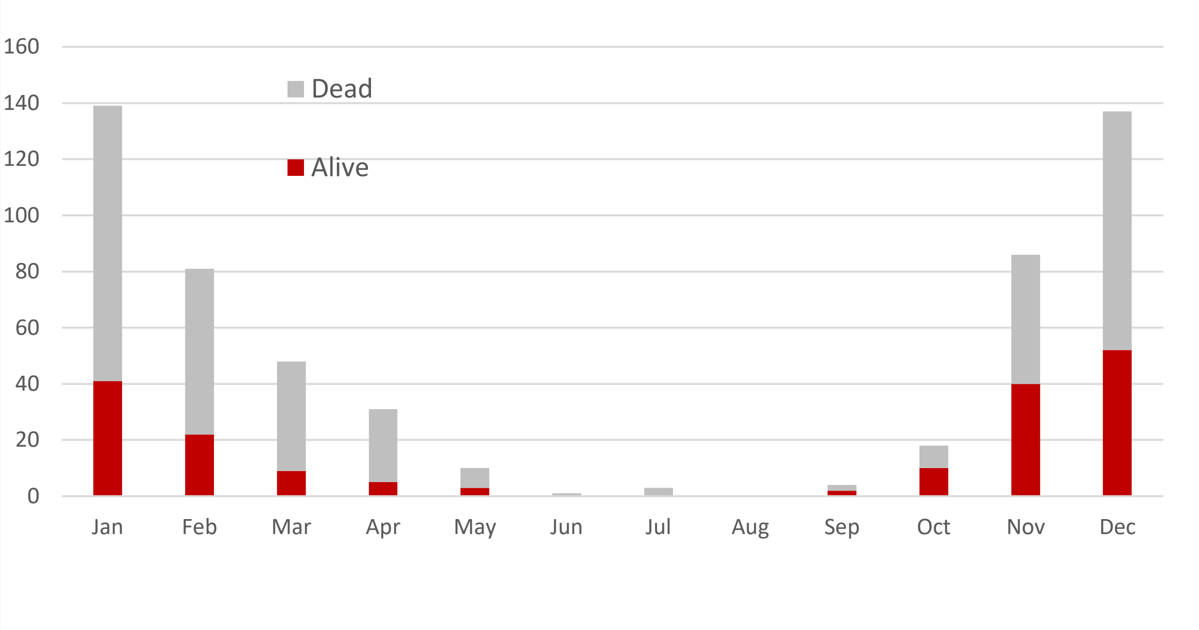
Observations in the invaded range are consistent with the reports of Watanabe et al. (1994). During the years 2012, 2013 and 2015, Berg and Quinn (2018) observed over 16,000 adult BMSB on a building surface in Virginia, with 88% of observations occurring between 15 September and 15 October. On a daily basis, peak counts occurred in the afternoon, with the majority arriving between 2 pm and 6 pm. On a day-to-day basis, numbers reached an initial peak within one to two days of 21 September, the autumnal equinox, and remained high until about the end of the first week of October. This observed peak time period matched peak counts in unpublished citizen science data for counts on homes in the mid-Atlantic states (Bergh & Quinn 2018).

Berg and Quinn (2018) also reported a study of BMSB landings on various 1 m^2 panels during the period 21 September to 5 October. Weather conditions described as ideal for BMSB flight comprised temperatures of 24°C to 30°C, relative humidity of 40% to 50%, and wind speeds of 2 to 14km per hr. During this period an average of about 35 BMSB per day were observed landing on 1 m^2 black panels over a one hour observation time between 2:30pm and 3:30pm.

BMSB has been shown to die near or at its freezing point, and is therefore categorised as a chill intolerant insect (Cira et al. 2016). Based on several studies, BMSB mortality becomes very high between -15°C and -20°C (Cira et al. 2018; Scaccini et al. 2018). BMSB collected from colder regions later in the year, or exposed to cold shocks, have a greater cold tolerance, suggesting that cold resistance can be somewhat variable (Cira et al. 2018; Lowenstein & Walton 2018). BMSB are likely to be able to overwinter in regions with minimum temperatures well below those measured in laboratory studies, by utilising their habit of aggregating in a range of sheltered locations (Cira et al. 2016).

Incidents of BMSB arriving at the Australian border are consistent with the overwintering biology of BMSB in the northern hemisphere. Live BMSB have only been found on goods arriving between the months of September and May, with the peak occurring between November and February (Figure 5).

Figure 5 The number of incidents of live and dead BMSB found on all goods from all countries by month from 1 September 2003 to 30 May 2019.



Diapausing BMSB adults prefer to settle in dark areas (Toyama, Ihara & Yaginuma 2010). Cold temperatures keep BMSB inactive and therefore they are likely, having entered cold, dark areas, to remain under such conditions (Toyama, Ihara & Yaginuma 2010). BMSB adults also have a preference to aggregate at any temperature (Toyama, Ihara & Yaginuma 2006). This appears to be mediated by smell or touch; if antennae are removed, BMSB no longer form aggregations (Toyama, Ihara & Yaginuma 2006).

In Asia, BMSB is reported to naturally overwinter on ground in leaf litter, inside tree holes and under tree bark (Lee et al. 2014). Surveys of natural habitats in the USA found that BMSB overwinter in dead, standing trees with thick tree bark that provide protective crevices for shelter, particularly oak (*Quercus*) and locust (*Robinia*) species (Lee et al. 2014). It was noted that BMSB appeared to prefer dry conditions for overwintering sites (Lee et al. 2014).

BMSB is also attracted to, and uses, human-made structures for overwintering both in its native range (Kobayashi & Kimura 1969; Watanabe et al. 1994) and in invaded regions in the USA (Leskey et al. 2012a; Rice et al. 2014) and Europe (Haye et al. 2014). Structures near suitable habitat such as forests, orchards and fields are the most likely to be heavily infested, suggesting that BMSB adults do not typically move over great distances to find overwintering sites.

A recent report found that built structures are likely to be crucial for overwintering survival during extreme temperature events, and potentially contribute to the ability of BMSB to spread through temperate areas (Cira et al. 2016). At this time there is no specific information available to determine whether particular qualities make some overwintering sites more attractive than others, although one survey has found that brown coloured homes with wood or stone surfaces attracted more overwintering BMSB than other colour/material combinations (Hancock et al. 2015).

This preference for darker surfaces was also noted by Berg and Quin (2018) who found that adult density was highest on shaded northern and eastern walls, and the recessed doorways of building exteriors, regardless of aspect; they also noted that significantly greater numbers of adults alighted on black panels than on a taupe (brown-grey) coloured concrete wall within an open panel.

Experimental studies show that BMSB tend to move upwards on a surface when seeking overwintering sites (Chambers 2018). This is was also found in an observational study which identified that progressively more overwintering BMSB were found from the first floor to the top floor of a four storey dormitory, indicating a stronger preference for the higher parts of structures (Cambridge, Payenski & Hamilton 2015).

The ability of BMSB to enter into and exit from overwintering sites is restricted by the size of the openings. In Japan, Wanatabe et al. 1994 studied BMSB overwintering aggregations in attractive overwintering ‘slit traps’. These traps were constructed with layers of wooden panelling 90 cm wide by 180 cm long, and gaps of about 3 mm for BMSB to enter. Hundreds of BMSB were recovered from these traps by December, the end of the aggregation period.

In another study, the ability of overwintering BMSB to exit various sized apertures was shown to be limited by their body size (Chambers et al. 2019). The average heights of overwintering BMSB males and females were measured as 3.5 mm to 4.0 mm and pronotal (‘shoulder’) widths as 7.5 mm to 8.3 mm. This study found holes smaller than 7 mm in diameter and slits less than 3 mm in height prevented movement of most BMSB, while holes 9 mm in diameter and slits 5 mm in height allowed essentially free movement of BMSB (Chambers et al. 2019). This study also noted that BMSB kept in boxes were strongly attracted to any crack permitting light, even if it was too small to allow the BMSB to exit.

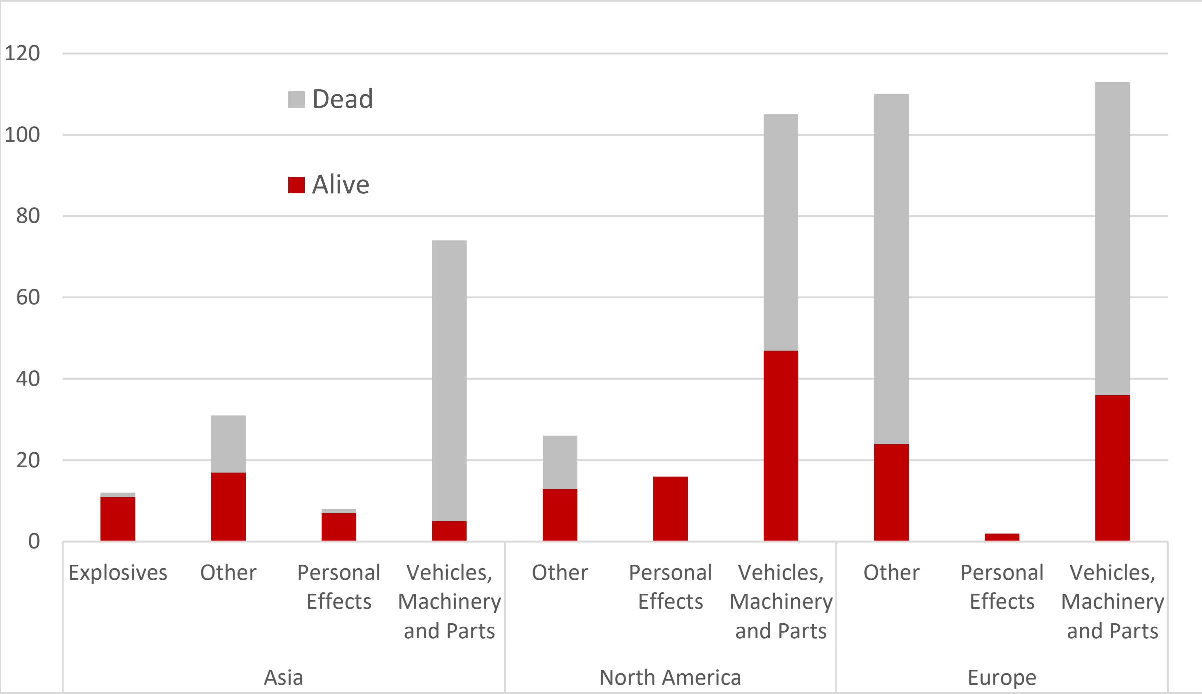
Incidents of BMSB at the Australian border are consistent with the recorded aggregation biology of BMSB. BMSB have mainly been found on goods identified as ‘machinery, vehicles and parts’ (which include items such as boats, cars, lawnmowers, motorcycles and transport vehicles) as well as on a range of other goods, which include items such as terracotta pots, plastic chairs, stacks of timber, air conditioner compressors and containers of explosives. All goods where large infestations of BMSB have been found share the common features of having internal gaps or spaces, and of having been stored outdoors or under limited shelter. BMSB has been found to a lesser extent on personal effects, which can include both luggage and personal goods shipped to Australia, for example, such as when moving house (Figure 6).

In some instances, only dead BMSB have been found. The presence of dead BMSB is likely to indicate either that these goods were a site of BMSB overwintering in a past season and some mortality of insects occurred, or that the BMSB died due to stresses experienced on the voyage to Australia. Also, since 2014, many goods at risk of BMSB infestation are now subject to offshore treatments, and dead BMSB found in such goods is considered an indication that live BMSB were present at the time of treatment.

The presence of either live or dead BMSB adults on such goods indicates that they were accessible to BMSB seeking overwintering sites. In the case of machinery, vehicles and parts, and other goods carrying large infestations, goods may have been stored outside, or in semi-sealed enclosures such as garages, barns or sheds. Similarly, personal effects infested with BMSB may have been stored in areas such as sheds, attics or garages which are areas of dwellings documented to be potentially heavily infested with BMSB (Leskey et al. 2012a). The types of goods that may become infested with BMSB are referred to as ‘at-risk’ goods.

Overall there is no evidence to suggest that there are any significant variations in the overwintering biology of BMSB populations in the native range, and there is no evidence that BMSB populations in the invaded regions behave differently to BMSB in native regions. The department's experience with the times of year that BMSB is found in goods arriving at the border, and the types of goods BMSB is found in, are broadly consistent from country to country.

Figure 6 The number of live and dead incidents of BMSB recorded on various types of goods from identified regions from 1 September 2003 to 30 May 2019.



'Vehicles machinery and parts' includes new and used vehicles, and machinery such as lawnmowers, boats and boat trailers. 'Personal effects' include luggage at airports and shipments of household goods including larger items and used vehicles. 'Other goods' include a wide range of goods that do not group into consistent types; these include roofing tiles, explosives, plastic chairs, galvanized wire and fitness equipment.

3.1.5 Natural dispersal abilities

Dispersal capacity and behaviour of BMSB has been studied in the laboratory and the field (Lee & Leskey 2015; Lee, Nielsen & Leskey 2014; Wiman et al. 2014b). In the laboratory, flight capacity of adults was measured using flight mills for field-collected BMSB populations (Wiman et al. 2014b). Although the maximum distances recorded for 24 hour flights were up to 66 kilometres for a male and 75 kilometres for a female, 85 per cent of all flights measured were of less than 5 kilometres (Wiman et al. 2014b).

A potentially more realistic estimate of short term dispersal capacity would be the distance travelled in one sustained flight. In general, the total distance for a single flight event was comparable for females (0.59km) and males (0.57km), but summer adults flew significantly further (0.72km) than overwintered adults (0.47km) (Wiman et al. 2014b). Notably, of a total of 789 insects tested, only three overwintered adults flew a distance further than 5km in a single flight, with none flying further than 8km. Eight summer adults flew more than 5km, with none flying further than 13km.

The use of flight mills to measure insect flight distances is known to not necessarily accurately represent true insect flight, and Wiman et al. (2014b) considered their figures were likely to be overestimations for single flight events, given that BMSB attached to the mills were unable to land. Nevertheless, the single flight results of Wiman et al. (2014b) are consistent with a field release-recapture study which found a maximum dispersal of BMSB adults of 2 kilometres, with the majority of recaptured insects flying 500 metres or less (Zhang et al. 1993).

In the field, BMSB has been recorded flying at an average speed of 3 metres per second (Lee 2015). The likelihood of sustained flight was found to be significantly affected by wind speed, ambient temperature and light intensity (Lee & Leskey 2015). In the field, only 3% of BMSB tested would take flight at temperatures between 10°C to 15°C, while 61 % would take flight at temperatures in the 15°C to 20°C range, and up to 87% in the 25°C to 30°C range. The prevailing flight direction of BMSB was predominantly in the opposite direction to the sun's position, particularly in the morning (Lee & Leskey 2015).

BMSB nymphs can walk several metres in an hour and may disperse between host plants and even crop fields (Lee, Nielsen & Leskey 2014; Venugopal, Dively & Lamp 2015). In the laboratory, third instars had either similar or greater walking capacity compared with other immature stages and adults (Lee, Nielsen & Leskey 2014). However, in the field, fifth instars moved nearly twice as far as third instars (Lee, Nielsen & Leskey 2014). Nymphs exhibited significantly longer walking distances above 25°C (Lee, Nielsen & Leskey 2014). BMSB nymphs were strongly attracted to their aggregation pheromone in the field, and would cross areas without food plants to reach the pheromone attractant (Lee, Nielsen & Leskey 2014).

3.1.6 Feeding biology and economic impacts of BMSB

BMSB is an herbivore, and both nymph and adult BMSB feed by inserting their narrow elongated mouth parts into plant tissues, sucking out plant fluids or lacerated tissue (Peiffer & Felton 2014; Wiman et al. 2014a).

BMSB is a generalist and has been recorded feeding on over 100 plant hosts in the USA (Bergmann et al. 2015) and on over 100 plant species in Asia (Lee et al. 2013). A partial list of host plants of BMSB is provided in Appendix B. This list is very likely to continue to grow as BMSB expands its range in North America and Europe. For example, the Chinese pistachio tree (*Pistacia chinensis*) has a native distribution that overlaps with the native range of BMSB (Tang et al. 2012). However, this species was not known as a BMSB host until adults and nymphs were found feeding on a street tree in Sacramento, California (Ingels 2014). Recent surveys in the USA also listed several new genera not previously identified as host plants (Bergmann et al. 2016). A significant difference was also noted relating to the more limited association of BMSB with gymnosperms in the USA compared with Asia (Bergmann et al. 2016).

Feeding may occur on leaves, shoots, stems and even through the bark of trees such as maple and catalpa (Rice et al. 2014). However, both nymphs and adults preferentially feed on developing and ripe fruits and seeds of their plant hosts (Martinson et al. 2015). This mode of feeding, and preference for fruits, directly leads to economic damage to a wide range of crops.

BMSB feeding damage varies from crop to crop, but in green vegetables like beans, pea and okra, feeding sites may cause scarred, faded, sunken areas and deformed pods (Rice et al. 2014; Zobel, Hooks & Dively 2016). In cotton, developing bolls are damaged by BMSB feeding resulting in wart-like growths on inner carpel walls, stained lint, and shrivelled seeds (Kamminga et al. 2014). In tomatoes and capsicum, feeding causes white spongy areas on the skin, and internal tissue damage may develop (Rice et al. 2014). Feeding injury to fruits like pome fruit and stone fruit may cause sunken areas and deformations in developing fruit ('cat facing'), brown spots, and in apples corky spots that may be confused with the symptoms of calcium deficiency (Leskey et al. 2012c; Rice et al. 2014). In other crops such as berries, corn, nuts and soybean, feeding often causes either deformation of the developing fruit/seed or the collapse of the berry or seed (Hedstrom et al. 2014; Leskey et al. 2012a; Rice et al. 2014; Tooker 2013). Soybean plants damaged by BMSB exhibit a 'stay-green' syndrome where affected plants do not senesce at the same time as unaffected plants; this can complicate and delay harvesting (Tooker 2013). In all cases not only does BMSB feeding directly damage crops, but the piercing feeding injuries provide a route for other pathogens and rots such as bacteria and fungi to enter the fruit and cause further damage (Kamminga et al. 2014; Leskey et al. 2012a; Rice et al. 2014; Tooker 2013).

BMSB is known to transmit the phytoplasma responsible for *Paulownia* witches' broom disease, which is limited to Asia (Lee et al. 2013). While this disease is not known to be present in Australia, a closely related witches' broom disease does affect *Paulownia* trees in Australia (Bayliss et al. 2005). The ability of BMSB to spread other plant diseases has been raised as a concern, but to date no instances of BMSB spreading other diseases have been reported (Rice et al. 2014).

In Asia, BMSB is a pest of many crops including apple (Funayama 1996; Le, Min & Xiang'ge 2008; Zhang et al. 2007), cherry (Watanabe 1996), citrus (Mainali et al. 2014; Ohira 2003), grape (Ohira 2003), pear (Qin 1990; Wang & Wang 1988; Zhang et al. 1993), peach (Ohira 2003; Qin 1990; Zhang et al. 2007) and persimmons (Kim & Park 2015; Ohira 2003), as well as vegetable crops including asparagus, cucumber, capsicum, eggplant, pea and sweet corn (Fukuoka, Yamakage & Niiyama 2002).

In the USA and Europe, evidence has accumulated that BMSB reaches high population densities in edge habitats such as forests or field borders, where there is often a wide range of good host plants (Bakken et al. 2015). The structure of the landscape, particularly the size and shape of forest areas adjacent to crops, has been found to influence the level of damage caused by BMSB in tomatoes (Rice et al. 2017; Tebbe et al. 2016). Both adults and nymphs are able to move into a crop from neighbouring habitats and cause damage when the crop plants reach a suitable stage of development (Venugopal et al. 2015). Often crops at the edge of a field or orchard suffer much greater BMSB damage than those in the centre. This edge effect has been documented in a range of crops including apple (Joseph et al. 2014), corn (Tooker 2013), grapes (Basnet et al. 2015), hazelnut (Moraglio, Bosco & Tavella 2018), peaches (Blaauw, Polk & Nielsen 2015), and soybean (Tooker 2013).

In the USA, where effective natural enemies of BMSB are absent and populations now can reach high densities, significant damage due to BMSB has been reported in a wide range of crops (Zobel, Hooks & Dively 2016) including apples (Joseph et al. 2014), capsicum (Kuhar et al. 2012), field corn (Tooker 2013), green beans (Kuhar et al. 2012), okra (Kuhar et al. 2012), peach (Leskey et al. 2012a), sweet corn (Cissel et al. 2015; Kuhar et al. 2012), soybean (Owens et al. 2013; Tooker 2013) and tomatoes (Kuhar et al. 2012). Examples of BMSB damage on fresh produce are shown in Figure 7.

In 2010, losses to the mid-Atlantic apple crop from BMSB were estimated at US$37 million (Herrick 2016), and in the same year some growers lost their entire crop of stone fruit (Leskey et al. 2012a). In Beltsville, Maryland in 2011, nearly 100 per cent of sweet corn ears in early to mid-season plantings were injured by BMSB (Kuhar et al. 2012).

There are a range of other crops where field and/or experimental evidence suggests that BMSB could become a significant pest in the USA, but in which large economic losses due to this pest have not been reported. These include almonds (Eddy 2018), blueberries (Wiman et al. 2015) (although to date BMSB has not become a serious pest in blueberries (Rodriguez-Saona, Vincent & Isaacs 2019), cotton (Kamminga et al. 2014) and pistachio (Lara et al. 2016). BMSB can directly damage grapes as fruit on the vine, (Basnet et al. 2015; Smith, Hesler & Loeb 2014) and also cause taint in wine when bunches are crushed (Mohekar, Osborne & Tomasino 2018; Tomasino et al. 2013).

Hazelnuts were identified earlier as a crop that could potentially be impacted by BMSB in the USA (Hedstrom et al. 2014). Subsequently, BMSB has been recorded as causing damage to hazelnuts in the USA and Italy (Bosco, Moraglio & Tavella 2018), but in particular has emerged as a serious pest of hazelnuts in the Republic of Georgia (Bosco, Moraglio & Tavella 2018; Murvanidze et al. 2018).

Figure 7 Examples of BMSB damage on fresh produce.

From top left, external BMSB damage to nectarine, external injury to apple (sunken areas on the surface), and brown necrotic areas, internal evidence of surface feeding (photos by Doug Pfeiffer). Second row: BMSB on outside of corn ear, kernel damage and tomato damage (David Wright: corn photos, Eric Day: tomato). Photos from Day and colleagues, published by Virginia Cooperative Extension, Virginia Tech, and Virginia State University (Day et al. 2011).

BMSB has been recorded on citrus in China (Yu & Zhang 2007), Japan (Fujiie 1985) and Korea (Choi, Kim & Lim 2000; Kim, Jang & Kim 2015). In one laboratory study, BMSB nymphs reached maturity feeding solely on ripe oranges, but with only a 14 per cent survival rate and producing adults that could not reproduce (Mainali et al. 2014). Further research in California and Florida suggests that citrus is not a preferred host (Amanda Hodges [University of Florida] 2015, pers.

comm., 12 June; Mark Hoddle [Department of Entomology, University of California Riverside] 2015, pers. comm., 15 June; Poplin 2013). Nevertheless, in parts of Asia, BMSB is considered to cause economic damage to citrus fruits if feeding/probing occurs at critical times during fruit formation (Choi, Kim & Lim 2000; Kim, Jang & Kim 2015).

BMSB has been reported damaging sweet orange, mandarins, lemons and grapefruit in Sochi, Russia and Abkhazia (Musolin et al. 2018). Since BMSB tends to move between many host plants over the course of a year, damage to citrus probably occurs mainly in localities where surrounding vegetation supports a high BMSB population density which can move into an orchard, as opposed to having populations building up in a citrus orchard itself.

In Europe the rapidly expanding BMSB population has been recorded causing damage in apples, cherries, kiwifruit, peaches, pears and plum in Italy (Gabriele Zecchin [Plant Protection Service, Veneto Region] 2016, pers. comm., 13 May; Maistrello et al. 2014; Maistrello, Bariselli & Mazzoli 2014; Pizzinat et al. 2015), kiwi fruit in Greece (Andreadis et al. 2018), hazelnuts in Italy and Georgia (Bosco et al 2018), and commercial plantings of capsicum in Switzerland (Sauer 2012).

BMSB causes a secondary impact when it forms aggregations in autumn and enters overwintering sites such as homes and other structures. This nuisance behaviour has been documented in its native range in Japan (Kobayashi & Kimura 1969; Watanabe et al. 1994). In the eastern USA where pest populations have been recorded, very large numbers of BMSB have created significant issues for property owners (Inkley 2012). Beyond general annoyance, BMSB entering dwellings in autumn have been documented to cause economic damage with their defensive secretions, such as staining materials and falling into and rendering food inedible (Kobayashi & Kimura 1969). Some people may also have allergic reactions to BMSB, particularly in autumn with large numbers entering their home (Mertz et al. 2012).

3.1.7 Control measures

In Asia, BMSB has been targeted for many years as a pest of crops as well as a nuisance pest that enters homes (Kobayashi & Kimura 1969; Qin 1990; Yanagi & Hagihara 1980). In Asia, pyrethroids and neonicotinoids such as bifenthrin, fenpropathrin, and dinotefuran have been recommended for control of BMSB in commercial management programs (Funayama 2012a; Lee, Wright & Leskey 2013). Use of insecticide-soaked barriers and slit traps have been investigated for reducing the number of BMSB entering homes in Japan (Watanabe et al. 1994).

While a range of natural enemies of BMSB have been documented in Asia, there does not appear to be any systematic use of these to limit BMSB populations, although research is continuing (Lee et al. 2013; Morrison et al. 2017b; Zhang et al. 2017).

In the USA, a range of insecticides have been tested for control of BMSB, with studies producing conflicting results for some pesticides (Bergmann & Raupp 2014; Leskey et al. 2012b; Nielsen, Shearer & Hamilton 2008). For example, Nielsen et al. (2008) found that BMSB had a high rate of recovery from initial knockdown for a range of compounds including bifenthrin and other pyrethroids. However, Leskey et al. (2012b) reported that while knockdown recovery occurred for some pyrethroids, it did not for others such as bifenthrin. Leskey et al. (2012b) also noted that a large proportion of BMSB recovered from knockdown by the neonicotinoid acetamiprid, although Bergmann & Raupp (2014) documented no recovery from acetamiprid knockdown.

This variation in response to the same insecticides may be explained by the variation in methods between studies, and highlights that a range of biotic and abiotic factors are likely to drive the overall effectiveness of particular pesticides in specific cropping systems. Currently, some of the pesticides recommended for effective BMSB control in peach and pome fruit orchards in the USA include the neonicotinoids acetamiprid, clothianidin, dinotefuran and thiamethoxam, the pyrethroids beta-cyfluthrin, bifenthrin, fenpropathrin and lambda-cyhalothrin, and the organophosphate dimethoate (Nielsen 2013). A review of chemical control options and their performance against BMSB was recently published (Kuhar & Kamminga 2017).

Management of BMSB in apples and stone fruit in the USA was initially difficult; not all insecticides tested provided effective control of BMSB (Leskey, Short & Lee 2014; Nielsen, Shearer & Hamilton 2008). Also, many growers in 2011 resorted to calendar spraying of apples and stone fruit, with weekly spray intervals required to manage BMSB (Leskey et al. 2012c). This frequent spraying of broad spectrum insecticides disrupted integrated pest management (IPM) practices. Developing new pest management practices in these crops after the emergence of BMSB as a key pest is the subject of ongoing research (Blaauw, Polk & Nielsen 2015; Leskey et al. 2015; Quarles 2014).

Some general recommendations for chemical control have been made (Bergh et al. 2016). These recommendations include rotating different classes of insecticides with different modes of action, and using insecticides with the best effectiveness against BMSB later in the season, since the overwintering generation of BMSB tends to be more susceptible to insecticides than the summer generation. As many of the effective insecticides for BMSB have relatively short residual activity, alternate-row-middle applications (an application method where the sprayer does not pass down every alley during an application) at about seven day intervals may improve control.

Weekly border sprays (insecticide treatment to orchard perimeter plus the first full row) in peach orchards have been shown to be as effective as alternate-row-middle application for protecting fruit. Additionally, perimeter-based management tactics, such as orchard border row sprays and pheromone-based ‘attract-and-kill’ methods are being evaluated, and show promise for BMSB management in apple production. Insecticidal control of BMSB has also been reported to be difficult in Italy due to the pest's mobility through the landscape and tendency to aggregate (Bariselli, Bugiani & Maistrello 2016).

Because the number of chemical control options is limited for organic producers, there has also been research, predominantly in the USA, into the use of trap crops to limit BMSB damage to organic crops. This research is in preliminary stages and no effective systems have yet been recommended by researchers (Mathews & Hallack 2012; Nielsen et al. 2016; Soergel et al. 2015). A review of chemical control options for organic production systems has been published (Kuhar & Kamminga 2017).

Since the publication of the department's draft report, a large body of work has been published on natural enemies of BMSB and potential biological control agents. In overview, while BMSB in invaded ranges in Europe and North America are attacked by native predators and parasites, the mortality rate is usually considered insufficient to reduce populations to below pest levels (Morrison et al. 2018; Pezzini, Nystrom Santacruz & Koch 2018; Stahl et al. 2019). There has been particular focus on the potential biological control agent *Trissolcus japonicus*, a very small wasp that parasitises BMSB eggs by laying its own eggs inside them, killing BMSB eggs before nymphs can hatch. In Asia this species attacks various stink bugs and is the primary parasite of BMSB egg masses.

Trissolcus japonicus was brought into quarantine in the USA for research, but was subsequently found in the environment attacking BMSB egg masses in Maryland (Talamas et al. 2015). Genetic analysis showed that the wasps in the environment came from a different population to the wasps held in quarantine (Bon et al. 2017). As *T. japonicus* is not approved for release in the United States, populations are only allowed to be moved within state borders. Nevertheless, in 2018 *T. japonicus* was recorded for the first time in Canada (Abram et al. 2019). In 2017, *T. japonicus* was reported in Switzerland attacking BMSB egg masses (Stahl et al. 2019), and in Italy in 2018 *T. japonicus,* along with another Asian species (*Trissolcus mitsukurii*), was found attacking BMSB egg masses (Peverieri et al. 2018).

New Zealand has conducted a pre-emptive biological control research program to evaluate *T. japonicus* for release should BMSB become established. During host specificity testing it was found that eggs of six Australian native species present in New Zealand were also attacked. Two of the attacked Australian natives, *Cermatulus nasalis* and *Oechalia schellenbergii,* are predatory bugs, and are generally considered to be beneficial insects. Nevertheless, New Zealand made the decision that these off-target effects would be acceptable, and has approved the conditional release of *T. japonicus*, should BMSB become established in New Zealand (New Zealand Environmental Protection Authority 2018).

Trissolcus mitsukurii was introduced into Australia in 1962 to control the green vegetable bug *Nezara viridulis*. It was released in every state and territory and the Australian Capital Territory. Following introductions, it was recovered in the field in 1964 in ACT, South Australia and NSW (Clarke 1990). Confirmation is required regarding the continued presence of this insect in Australia, and the Australian population's potential to attack BMSB egg masses, however in the event that BMSB were to enter Australia, it may exert some parasitic effect.

3.1.8 Monitoring and surveillance

One common theme in BMSB monitoring and surveillance is the difficulty in distinguishing between BMSB and other stink bug species. As noted in the taxonomy section above, in its native range, BMSB has often been misidentified and misclassified. In the USA, BMSB was collected for a number of years but misidentified as the native stink bug *Euschistus servus* (Rice et al. 2014). It was only after large numbers of BMSB began entering houses, a behaviour different from that observed for the native stink bug, that a more careful inspection of the insects revealed the presence of BMSB (Leskey et al. 2012a; Rice et al. 2014).

In Europe, misidentification as a native pentatomid, *Rhaphigaster nebulosa*, apparently also masked the presence of BMSB for several years across a number of countries (Mueller, Landau Luescher & Schmidt 2011). In addition, previously available keys to European stink bugs identified BMSB as *Pentatoma rufipes* until an updated key was published (Wyniger & Kment 2010).

In Australia and New Zealand, guides have been written to help distinguish BMSB from local stink bugs (Department of Agriculture and Water Resources 2015a; NZ MPI 2014).

The ability to delimit BMSB populations in the USA and Europe was also hampered by the lack of sensitive traps or surveillance techniques. As noted above, BMSB has a wide range of host plants and moves between them readily through the season. BMSB is cryptically coloured and hides in foliage, which can make visual detection difficult. Standard surveying techniques such as use of beat trays and sweep nets are potentially unreliable for BMSB relative to other stink bugs, which may be due to their strong startle response (Kamminga et al. 2014; Li et al. 2007), or to the location of the insect in higher tree tops and possibly, their greater activity at night time (Leskey et al. 2012c).

Trained detector dogs have been successfully used in the USA to locate BMSB sheltering in dead trees in woodland habitats (Lee et al. 2014), and the department has begun a detector dog program to assist in BMSB inspection and surveillance activities.

Light traps have been used successfully in warmer months in both Asia and the USA, when BMSB adults fly at night time (Katayama, Fukuda & Nozawa 1993; Moriya, Shiga & Mabuchi 1987; Nielsen et al. 2013). Light is also attractive to BMSB that emerge from overwintering aggregations such as attics and move into living areas of homes (Aigner & Kuhar 2014). Black light traps used for monitoring a range of pests in New Jersey were anecdotally able to detect the presence of BMSB in an area approximately 18 months before homeowner complaints began (Nielsen et al. 2013).

In the USA and Europe, research has been done to determine the best trapping methods to detect BMSB in fields. This has been complicated by the fact that BMSB is attracted to different stimuli at different times of the year, although a combination of multiple pheromones is effective overall through the summer months (Leskey et al. 2015). An increasing body of knowledge is being published on BMSB pheromones, lures and trapping potential, as recently reviewed by Weber et al. (2017). There is still no known lure or trap that can reliably attract or capture reproductively immature BMSB newly emerged from overwintering sites (Morrison et al. 2017a).

In the USA and Europe, trapping and surveys are mainly focused on pest management, and identifying a treatment threshold where the numbers of BMSB trigger a pest management decision. There have been some preliminary studies designed to detect recently arrived BMSB during periods when populations are very small, such as in the initial stage of establishment (Vandervoet et al. 2019). These have shown that use of higher concentrations of attractant chemicals leads to a larger number of trap captures overall and to greater sensitivity in areas with low BMSB population densities (Acebes-Doria et al. 2018).

Both the department, and several state jurisdictions have deployed pheromone traps in locations in Australia where live BMSB have been detected in goods post-border. In a few instances, individual BMSB have been captured in pheromone traps deployed in these locations. To date, all trap captures have occurred within a short time after the traps were deployed and over extended periods no further BMSB have been found either in traps or by other sampling methods, or through public awareness campaigns (see https://www.outbreak.gov.au/current-responses-to-outbreaks/brown-marmorated-stink-bug for full details); however a range of other, local stink bug species have continued to be found.

In several instances captured BMSB were found to be reproductively immature, at times of the year (late December – early March) when any BMSB established in Australia would be expected to be reproductively mature. This suggests that the captured BMSB had probably recently arrived from the northern hemisphere, and would most logically be associated with the nearby post-border detections. These BMSB were all captured soon after post border actions were undertaken, and although traps were maintained for an extended period, and a range of other surveillance activities undertaken, no further BMSB have been found. Therefore, it is considered that pheromone traps can be an effective method to detect even very small numbers of BMSB in a local environment.

The department is continuing to work with states and territories and international partners to ensure that trap types, placements and other detection methods are up to date and reflect best practice management for BMSB.

4 Pest risk assessment

Brown marmorated stink bug (BMSB) is not present in Australia. Changes in the international pest status of BMSB and an increased frequency of incidents of this pest at the Australian border, as discussed in Section 1.2, have led to initiation of this pest risk analysis. This chapter assesses the likelihood of the entry (importation and distribution), establishment and spread of BMSB, and the economic, including environmental, consequences this pest may cause if it were to enter, establish and spread in Australia.

The likelihoods of importation and establishment have been assessed on a seasonal basis due to the temporal record of BMSB incidents at the border (Figure 5), and the known biology of BMSB (Chapter 3). These likelihoods were assessed for different time periods for goods from the northern hemisphere (Section 4.1) and the southern hemisphere (Section 4.2).

The potential consequences of the establishment of BMSB in Australia are not expected to be affected by whether the origin of the pest is either the northern or southern hemisphere. Therefore a single assessment of the potential consequences is presented in Section 4.3 and used to determine the unrestricted risk estimate for each hemisphere and time period (Section 4.4).

4.1 BMSB in the northern hemisphere

BMSB is currently well established in many regions of the northern hemisphere. For goods from the northern hemisphere, likelihoods were assessed for (i) the months of September to May (early autumn to mid spring in the northern hemisphere) and (ii) the months of June to August (late spring to late summer in the northern hemisphere; see Figure 4).

4.1.1 Likelihood of entry

The likelihood of entry is considered in two parts, the likelihood of importation and the likelihood of distribution, which consider pre-border and post-border issues, respectively.

Likelihood of importation during September to May

The likelihood that BMSB will arrive in Australia from areas in the northern hemisphere with established BMSB populations with the importation of at-risk goods during the period September to May is assessed as **High**.

Likelihood of importation during June to August

The likelihood that BMSB will arrive in Australia with the importation of at-risk goods from areas in the northern hemisphere with established BMSB populations during the months of June to August is assessed as **Very Low**.

The following information provides supporting evidence for these assessments.

- Live adult BMSB have been found on goods entering Australia from regions with known BMSB populations since 2004 (Figure 1 and 2).
- Live BMSB could enter on goods at any time of year, but behavioural factors associated with the BMSB life cycle predict that the likelihood of entry has seasonal attributes.
- During spring to late summer (the months of June to August in the northern hemisphere), BMSB are active, feeding and completing their lifecycle on host plants (Haye et al. 2014; Lee et al. 2013; Rice et al. 2014). During this period, these insects are not usually associated with structures or goods. Because the insects are active and require food, any insects that may randomly land on such goods will not find the goods attractive, and are also likely to be

disturbed and leave as goods are moved and loaded for shipping. No live BMSB have been found at the Australian border on any pathways during the months of June to August (Figure 5).

- During autumn (September to late November in the northern hemisphere) aggregations of BMSB form on and in structures and non-plant goods as BMSB enter overwintering sites and commence diapause (Kobayashi & Kimura 1969; Watanabe et al. 1994; Zhang et al. 1993). Complex new vehicle parts, such as a cabin, gearbox or harvester header, manufactured and stored during the months when BMSB are seeking overwintering sites may become sites of hidden infestation. Goods that are manufactured during winter (from December onwards in the northern hemisphere) are unlikely to become infested with BMSB until the following autumn.
- BMSB overwinter while the weather is cold, and when overwintering they are mostly immobile. Overwintering BMSB are not always disturbed by the loading and shipping of goods in which they are sheltering.
- The main pathways on which BMSB and other exotic overwintering insect pests are likely to enter Australia is on vehicles and machinery, and other goods with complex structures that are generally stored in limited shelter (Figure 6). All incidents of live BMSB have occurred on goods that arrived from the northern hemisphere during the months of September to May (Figure 5). For sea-freighted items, incidents of BMSB correspond to ship loading times approximately between September and April, corresponding to autumn through to early spring in the northern hemisphere.
- Although overwintering BMSB are expected to remain mostly immobile in overwintering sites throughout transit to Australia, in the case of large infestations even a small percentage of BMSB crawling on or near goods that are infested can be detected visually. Therefore, it is considered unlikely that goods that are very heavily infested (with hundreds to thousands of live individuals) would be offloaded and distributed to their final destination without BMSB being intercepted.
- BMSB overwinter without access to food or water for many months before dispersing and finding a food source (Funayama 2012b; Rice et al. 2014). Shipping times for sea freight from ports in the northern hemisphere to Australia (approximately three to five weeks for a direct voyage) are typically much shorter than the BMSB overwintering period. Therefore, overwintering aggregations of BMSB hidden within goods could be expected to survive while the goods are shipped to Australia, particularly when loaded early in the northern hemisphere autumn.
- Sea freight shipped to Australia from the northern hemisphere must cross the tropics. During this time the interior of the transport ship usually warms to above 9°C. BMSB are expected to become active above this temperature (Li et al. 2007; Toyama, Ihara & Yaginuma 2006, 2010). Active BMSB are likely to more quickly metabolise their winter energy reserves (Funayama 2013). This is considered likely to increase the chance of mortality of BMSB in transit and decrease the overall condition of live BMSB arriving in Australia, particularly later in the season.
- A less common pathway on which BMSB might enter Australia is on personal effects (which can include both luggage and personal goods shipped to Australia, such as when moving house). The number of incidents and the number of BMSB intercepted per incident have been much lower on this pathway compared to the pathways of vehicles and machinery and other goods with complex structures. Personal effects are subject to a range of risk management measures, such as inspection at customs and immigration control points, which mitigate various risks, including of overwintering hitchhiking pests such as BMSB.

BMSB on goods from North America

- Incidents of BMSB arriving on goods at the Australian border from the USA increased substantially in December 2014 when multiple incidents were intercepted, and involved large numbers of live BMSB. Since the publication of the draft report, the number of incidents of BMSB per season from both the USA and Canada have increased. The increase mainly represents dead BMSB intercepted on treated cargo from the USA (Figure 2).
- Management of BMSB is being undertaken in the USA and Canada, including through the use of insecticides and natural predators. However, BMSB continues to expand its range and population density in both countries.
- Given the continued expansion of BMSB into new regions of the USA and Canada, and the growth of the population in invaded regions, it is anticipated that, without adoption of control measures, significant and multiple infestations of live overwintering BMSB will continue to be found every season on machinery, vehicles and machine parts and other at-risk goods from these two countries.

BMSB on goods from Asia

- Incidents of BMSB arriving on goods at the Australian border from Asian countries pre-date incidents from North America and Europe, but there have been only a few incidents per year and these have involved significantly fewer numbers of pests (Figure 2).
- BMSB is native to Asia, and there are native predators, parasites and diseases that limit the BMSB population on that continent (Lee et al. 2013; Zhang et al. 2017).
- There is no information to suggest BMSB is rapidly expanding its distribution or its population density in its native range.
- In Asia, BMSB has been managed as a crop pest for many years and pesticide applications are used to limit BMSB populations in agricultural areas (Lee et al. 2013).
- The infestation of goods with overwintering BMSB is dependent on goods being manufactured and stored in areas where BMSB reaches high population densities. It is possible that the types of goods and the location of their manufacture and storage (that is, rural versus city locations) in Asia prior to export to Australia may contribute to a significantly different BMSB infestation risk profile compared to goods exported from North America and Europe.
- Particular goods from particular sources in Asia have been found to consistently carry BMSB and other exotic overwintering insect pests. These goods are now subject to various controls (for example, heightened surveillance of explosives and ships carrying used vehicles) in order to achieve ALOP.

BMSB on goods from Europe

- Europe recorded its first population of BMSB approximately 10 years after the USA (Wermelinger, Wyniger & Forster 2008). In recent years, the number of European countries reporting the presence of BMSB has increased (Haye et al. 2015), as has the number and size of incidents of BMSB at the Australian border on goods originating in Europe (Figure 1). Since the publication of the draft report the number and size of incidents have now exceeded the levels originating from North America.
- To date the rapid spread of BMSB has continued in Europe, with a subsequent large increase in the number of incidents. As most of Europe is considered to be highly suitable for BMSB, and there are not concerted programs in place to prevent spread within Europe, it is expected that this pest will spread rapidly and continue to cause increasingly frequent and large infestations in at-risk goods.

- BMSB is most likely to arrive in goods from European countries which are known to have a BMSB population, or share a land border with a country known to have a large BMSB population and have a suitable climate for BMSB. The department has identified 30 European countries that fit this risk definition for the 2019–20 season (Table 6).

Table 6 European countries identified as at risk for BMSB infestation of goods in the 2019-20 season.

Albania	France	Netherlands
Andorra	Georgia	North Macedonia
Armenia	Germany	Romania
Austria	Greece	Russia
Azerbaijan	Hungary	Serbia
Belgium	Italy	Slovakia
Bosnia and Herzegovina	Kosovo	Slovenia
Bulgaria	Liechtenstein	Spain
Croatia	Luxembourg	Switzerland
Czechia	Montenegro	Turkey

Summary: BMSB enter overwintering sites during autumn where they form aggregations with other BMSB and remain immobile until the spring. Overwintering sites that are attractive to BMSB include goods such as vehicles, machinery and mechanical parts. Overwintering BMSB are not always disturbed by loading or shipping of the goods to Australia. The history of BMSB incidents at the Australian border demonstrates that BMSB can have a high association with at-risk goods (such as vehicles, machinery and mechanical parts) loaded and shipped to Australia during autumn to spring (the months of September to May in the northern hemisphere). For the reasons outlined, the likelihood of importation of BMSB on goods during the months of September to May from the northern hemisphere, in association with at-risk goods, is assessed as '**High'**.

BMSB actively feed and complete their lifecycle on host plants during spring and summer. BMSB are very unlikely to form aggregations in, or be associated with, any non-living goods during this time. The history of BMSB incidents at the Australian border demonstrates that BMSB are very unlikely to be associated with goods from the northern hemisphere arriving during the months from June to August. For these reasons, the likelihood of importation of BMSB during the months of June to August from the northern hemisphere in association with at-risk goods is assessed as '**Very Low'**.

Likelihood of distribution during September to May

The likelihood that BMSB will be distributed within Australia in a viable state as a result of the processing, sale or disposal of infested goods from countries in the northern hemisphere with established BMSB populations, and subsequently transfer to a susceptible part of a host during the months of September to May is assessed as **High**.

Likelihood of distribution during June to August

The likelihood that BMSB will be distributed within Australia in a viable state as a result of the processing, sale or disposal of infested goods from countries in the northern hemisphere with established BMSB populations, and subsequently transfer to a susceptible part of a host during the months of June to August is assessed as **Moderate**.

The following information provides supporting evidence for these assessments.

- Overwintering aggregations of BMSB can contain large numbers of individual insects in a diapausing state. Large numbers of live BMSB have been previously intercepted at the Australian border.
- BMSB loaded in mid-autumn to mid-winter (October to January in the northern hemisphere) will have recently entered overwintering sites and can be expected to have relatively high nutritional reserves. Overwintering BMSB can survive for several months without food and water through the winter when temperatures are cold (Haye et al. 2014; Lee et al. 2013). Therefore, during this period a high proportion of BMSB are expected to be able to survive the transit time through the tropics to the southern hemisphere late spring to summer, and subsequently be able to disperse to host plants.
- By February to March, BMSB from the northern hemisphere will have spent longer overwintering and will have lower nutritional reserves (Funayama 2012b; Skillman 2017). Therefore, during this period a lower proportion of BMSB are expected to be able to survive the transit time through the tropics to late summer in the southern hemisphere and subsequently be able to disperse to host plants in Australia. This is likely to restrict successful dispersal for small BMSB infestations, however, very large infestations of BMSB are likely to have sufficient numbers of individuals to allow some dispersal.
- BMSB emerge from overwintering sites as the weather warms and day length increases (beginning in March and continuing through spring in the northern hemisphere (Bergh et al. 2017; Lee et al. 2013). Under artificial conditions, BMSB can be brought out of diapause at any time by warm temperatures and long photoperiods (Medal et al. 2012; Watanabe 1979). The arrival of overwintering BMSB from the northern hemisphere into Australia when temperatures are warmer and day lengths are longer is likely to mimic the natural change in season, and prompt dispersal behaviours. However, this response is not immediate and usually takes place over many weeks (Kobayashi & Kimura 1969; Zhang et al. 1993). Therefore, it is likely that some BMSB will stay with goods that are infested when they are offloaded at ports in Australia and then seek out hosts either at the port or site of final delivery.
- BMSB that emerge from overwintering sites need to find water within a few days, and food within one month in order to survive (Funayama 2012b). Therefore, it is expected BMSB will need to find food and water sources within days to weeks of arrival in warmer months in Australia.
- BMSB adults emerging from overwintering sites, as well as summer-feeding adults, can fly several kilometres (Wiman et al. 2014b; Zhang et al. 1993), making it likely that BMSB arriving at any time of year will be able to disperse from infested goods to a suitable food source. However, few BMSB individuals are expected to take flight at temperatures lower than 15°C.
- A few individual BMSB have been captured near host plants in the Australian environment several hundred metres away from post border incidents involving goods known to have been contaminated with live BMSB, in the months of December – March, demonstrating their potential to disperse from goods to host plants. On-going surveillance for all these post-borer incidents have resulted in no further interceptions.
- BMSB is highly polyphagous, with hundreds of recorded host plants across a wide range of plant families, including many weed, ornamental and crop plants grown across Australia

(see Appendix B). This makes it very likely that BMSB will be able to find a suitable host plant soon after dispersing from infested goods.

- Many potentially infested vehicles and machinery items are likely to be moved from ports to rural and suburban areas soon after arrival. Transported BMSB are highly likely to find host plants suitable for their survival and development to sexual maturity in these locations.

Summary: Overwintering BMSB are able to survive for many months without food or water before dispersing to host plants in the spring. BMSB are known to survive on cargo shipped to Australia, and are likely to have sufficient nutritional reserves to support dispersal to a susceptible host. BMSB infestations can be very large in size, increasing the number of insects that may be able to successfully disperse. The temperatures and day lengths in Australia when most BMSB infestations arrive (September to May) are likely to promote dispersal from the overwintering sites. BMSB emerging from overwintering sites are able to disperse large distances by flight. BMSB has a wide host range, which means that suitable hosts are likely to be within range of most dispersing BMSB infestations. For the reasons outlined, the likelihood of distribution of BMSB during the months of September to May from at-risk goods is assessed as '**High**'.

On arrival in Australia during the months of June to August, BMSB are less likely to be able to leave infested goods as temperatures will be relatively low, particularly in temperate areas. Any dispersing BMSB are less likely to be able to transfer to a suitable host plant as many host species will be dormant. BMSB that arrive at the end of their overwintering period are expected to have relatively depleted nutrient reserves, and thus will have a low likelihood of survival until conditions are favourable for distribution. For these reasons, the likelihood of distribution of BMSB during the months of June to August from at-risk goods is assessed as '**Moderate**'.

Overall likelihood of entry

The overall likelihood of entry is determined by combining the likelihood of importation with the likelihood of distribution using the matrix of rules shown in Table 2.

The likelihood that BMSB will enter Australia as a result of trade in at-risk goods from areas in the northern hemisphere with established BMSB populations during the months of **September to May** and be distributed in a viable state to a susceptible host is assessed as **High**.

The likelihood that BMSB will enter Australia as a result of trade in at-risk goods from areas in the northern hemisphere with established BMSB populations during the months of **June to August** and be distributed in a viable state to a susceptible host is assessed as **Very Low**.

4.1.2 Likelihood of establishment

BMSB is an invasive pest that has successfully established in countries outside its native range. Environmental and seasonal factors will influence the likelihood of establishment of BMSB in Australia.

Likelihood of establishment during September to May

The likelihood that BMSB will establish in Australia with the importation of at-risk goods from areas in the northern hemisphere with established BMSB populations during the months of September to May is assessed as **High**.

Likelihood of establishment during June to August

The likelihood that BMSB will establish in Australia with the importation of at-risk goods from areas in the northern hemisphere with established BMSB populations during the months of June to August is assessed as **Very Low**.

The following information provides supporting evidence for these assessments.

- BMSB has successfully invaded both North America and Europe from Asia. Population genetics studies suggest that BMSB may have independently entered and established in Europe on at least two occasions and perhaps on several, and the same may be true in the USA (Gariépy et al. 2015; Lara et al. 2016). However, all these invasions occurred within the northern hemisphere, so that BMSB would not have been likely to have experienced a sudden change in season. Due to characteristics of BMSB overwintering biology, transfer from the northern to southern hemisphere presents additional barriers to BMSB establishment. However, BMSB has now been reported in Chile (Faúndez & Rider 2017), demonstrating that the pest can successfully establish in the southern hemisphere.
- BMSB is known to be sensitive to temperature (Aigner, Walgenbach & Kuhar 2015; Baek et al. 2017; Nielsen, Shearer & Hamilton 2008) and may be less abundant in areas with higher temperatures (Nielsen, Fleischer & Chen 2016; Venugopal et al. 2016). In the USA BMSB has only recently established in limited populations in Florida (Penca & Hodges 2018), and in Asia BMSB is not commonly found in the southern latitudes of its native range (Xu et al. 2014).
- Arid inland areas of Australia are subject to hot and dry climates (BOM 2017) with sparse vegetation that is unlikely to support BMSB (Kriticos et al. 2017; Zhu et al. 2012). Tropical areas of Australia experience high temperatures and are at latitudes at which BMSB is not expected to establish based on its native and current invasive distribution. These areas of Australia are therefore considered unsuitable for BMSB establishment. Climate models show arid regions are generally considered unsuitable for BMSB (Haye et al. 2015; Kriticos et al. 2017; Nielsen, Fleischer & Chen 2016; Zhu et al. 2012; Zhu et al. 2016).
- The local vegetation is also known to strongly influence the local abundance of BMSB (Venugopal et al. 2016; Wallner et al. 2014).

Two other key factors are considered to be important in influencing the likelihood of BMSB establishment in Australia: the time of year of arrival of BMSB in Australia, and the size of the arriving infestation. The following assessments further consider these factors.

Likelihood of establishment based on seasonal time of arrival

- Overwintering females in and from the northern hemisphere are in reproductive diapause during the period from September until March to May.
- Photoperiod and temperature are important factors in the lifecycle of BMSB. BMSB can be brought out of diapause at any time and begin mating and laying eggs if exposed to sufficiently warm temperatures and long photoperiods (Medal et al. 2012), that is, there is no minimum period required for overwintering.
- Females that arrive in Australia between September and May are expected to require more than 13 hours of daylight, access to food plants, and at least 148 degree days above 16°C (typically about one to two weeks) to mature their ovaries before they can successfully mate and reproduce (as discussed in Chapter 3).
- BMSB adults were reported to begin feeding when temperatures exceeded 17°C (Li et al. 2007).

- During the Australian spring and summer, overwintering BMSB that arrive are very likely to be able to break diapause due to suitable day length and temperatures (BOM 2017; Geoscience Australia 2017).
- Overwintering BMSB that arrive in Australia between the March and September equinoxes will experience day lengths of less than 12 hours and are unlikely to be able to break diapause until day lengths exceed 13 hours. In the months of June, July and August the average daily temperatures in the most suitable areas of southern Australia for the establishment of BMSB are frequently below the development threshold temperature of 16°C (BOM 2017), and many potential host plants will be dead, dormant or in a non-fruiting phase.
- Major ports and cities that receive the majority of BMSB risk goods are Brisbane, Perth, Melbourne and Sydney. In the month of May, the average daily temperature (mean minimum and maximum temperatures) for Brisbane is 18.3°C (13.0°C to 23.6°C), Perth 16.1°C (10.4°C to 21.8°C), Melbourne 12.5°C (8.3°C to 16.7°C) and Sydney 15.6°C (11.0°C to 20.1°C). In the month of June average daily temperature for Brisbane is 16.1°C (10.8°C to 21.3°C), Perth 14.0°C (9.0 to 19.0°C), Melbourne 10.0°C (6.2°C to 13.7°C) and Sydney 12.9°C (8.7°C to 17.1°C) (BOM climate averages tables, airport weather stations, accessed 15/05/2019).
- After emergence from diapause, BMSB must find a suitable host plant on which to feed in order to survive, reach reproductive maturity and develop eggs (Nielsen, Hamilton & Matadha 2008). Since BMSB has a wide host range (Appendix B), it is considered likely to be able to find a suitable host to support survival and reproduction, particularly over the period September to May in Australia when many hosts would be in leaf and producing fruits.
- BMSB will not begin attracting mates until reproductive maturity is reached, one to two weeks after feeding begins (Leskey et al. 2015; Morrison et al. 2017a). During this time, it is likely that BMSB adults will disperse between food plants independently of each other. The likelihood that BMSB will survive to reproductive maturity and be able to find a mate is therefore highly dependent on the local population density of both BMSB and host plants.
- If mating occurs, eggs laid by females will have to successfully hatch and nymphs must mature through five instars to reach reproductive maturity. Since BMSB has a wide host range, it is considered likely that gravid females would be able to find a suitable host to support the development of nymphs.
- In laboratory studies, BMSB typically has a 50 per cent to 80 per cent survival rate from egg to adult (Haye et al. 2014; Medal, Smith & Santa Cruz 2013; Nielsen, Shearer & Hamilton 2008). It is likely that in the field, survival rates would be significantly lower and strongly influenced by local weather conditions and availability of suitable hosts.
- The maximum lifespan (including a period of overwintering) of BMSB is about one year (Lee et al. 2013; Zhang et al. 1993), and overwintering BMSB in reproductive diapause would have hatched from eggs in the northern hemisphere summer, for example, in August of the previous year at the latest (Bakken et al. 2015; Haye et al. 2014; Lee et al. 2013).
- Thus the biology of BMSB, and seasonality and climate of Australia in environmentally suitable regions, indicate that the likelihood of BMSB establishing in Australia is higher during the Australian spring and summer (September to May), and lower during the Australian autumn and winter (June to August).

Likelihood of establishment based on size of infestation

- BMSB typically form overwintering aggregations which may compromise a few individuals to thousands of adults.

- Small numbers of BMSB present a very low to negligible risk of establishment. If only a few individuals were introduced to a locality, it is considered very unlikely that they would successfully find a mate after reaching reproductive maturity.
- As the number of adults in an aggregation increases, the likelihood of establishment also increases. Pre-reproductive adults will have dispersed away from goods that are infested and found host plants on which to feed. During this time, some mortality of BMSB is expected. After about one to two weeks, surviving females that have fed and developed mature ovaries will be ready to mate with males. However, the lower the number of arriving individuals and the further they have dispersed from the overwintering site, the lower is the likelihood that individuals will successfully find a mate.
- An untreated aggregation of hundreds or more individuals arriving on goods during the southern hemisphere spring to summer period (September to May) is considered to have a high likelihood of establishment, as many of the requirements for establishment, as discussed above, will be likely to occur.
- Individual reproductively mature females that were to arrive during June to August may have mated in the northern hemisphere spring/summer and be able to lay viable eggs. However, interception records suggest that adult BMSB are unlikely to arrive in Australia during June to August.

Summary: Goods loaded during the northern hemisphere autumn to early spring and arriving in Australia during the time period September to May can harbour live BMSB in the form of overwintering pre-reproductive adults, as demonstrated by the history of incidents of BMSB at the border. These insects will arrive in Australia during the southern hemisphere spring and summer, when climatic conditions (particularly temperature and day length) and host availability in temperate regions are considered suitable to support BMSB feeding and development. For the reasons outlined, the likelihood of establishment of BMSB during the months of September to May is assessed as '**High**'.

BMSB arriving as overwintering aggregations in goods from the northern hemisphere in the period of June to August are expected to be near the end of their overwintering period, and require immediate access to suitable food and climatic conditions in order to complete their lifecycle. The day length, temperature and host plant status in temperate Australia are all likely to be unsuitable for successful BMSB establishment at these times of year. For the reasons outlined, the likelihood of establishment of BMSB during the months of June to August is assessed as '**Very Low**'.

4.1.3 Likelihood of spread

The likelihood that BMSB will spread within Australia, based on a comparison of factors in the source and destination areas that affect the expansion of the geographic distribution of the pest, is assessed as **High**.

The following information provides supporting evidence for this assessment.

- BMSB has successfully invaded North America and Europe. In both instances, spread has been documented from a restricted area of introduction to a much larger geographic area (Haye et al. 2015; Rice et al. 2014). Studies of population genetics have concluded that most of the increase in BMSB populations on both continents, including across international land borders, has been due to the spread of established BMSB populations (Cesari et al. 2014; Gariépy et al. 2015; Gariépy et al. 2013; Xu et al. 2014).

- The reproductive capacity of BMSB can be large, with females capable of laying several hundred eggs and completing up to two generations per year (Lee et al. 2013; Nielsen, Shearer & Hamilton 2008). This would allow populations to build up quickly under suitable climatic conditions and where hosts are available, increasing the rate of both natural and human-assisted spread within Australia. In New Jersey, the BMSB population density was estimated to increase at a rate of 75 per cent per year based on black light trap captures (Nielsen et al. 2013).
- Adult BMSB can potentially fly many kilometres to find new food plants and overwintering sites (Lee & Leskey 2015; Wiman et al. 2014b). BMSB has been shown to be able to spread long distances within and between countries with human assistance, for example, by hitchhiking on vehicles (Amanda Hodges [University of Florida] 2015, pers. comm., 12 June; Halbert & Hodges 2011; Leroy Whilby [Florida Department of Agriculture] 2015, pers. comm., 12 June).
- Spread of BMSB into new areas has also been positively correlated with proximity to roads and railroads (Beers et al. 2019; Wallner et al. 2014). It can be difficult to distinguish between instances of natural and human-assisted spread and both appear to play a role at smaller spatial scales (Nielsen et al. 2013; Wallner et al. 2014). Overall, invasive BMSB populations have been shown to spread across large regions such as states of the USA within a few years, with pest problems beginning to be reported a few years after the first establishment in a locality (Beers et al. 2019; Haye et al. 2015; Leskey et al. 2012a; Nielsen et al. 2013; Wallner et al. 2014).
- While areas of southeast Australia, including Tasmania, and southern Western Australia may provide suitable habitat for BMSB (see Map 3), it is considered unlikely that BMSB would be able to naturally disperse between Tasmania and the mainland, or between east and west Australia. Movement of BMSB into each of these areas is likely to require human assistance.
- As detailed above (section 4.1.2), the climate and habitat in tropical and arid inland regions of Australia are considered unsuitable for BMSB, and therefore successful spread is unlikely to occur into these areas. However, the regions where BMSB is likely to spread within Australia include major metropolitan centres and important agricultural production areas with suitable hosts in most states.
- To date, no Australian native plant has been recorded as a host for BMSB, in spite of many native Australian plants being grown in areas of Asia, Europe and the USA. Given the wide host range of BMSB, it may be that some native Australian plant species could support BMSB populations, but based on available information the likelihood of BMSB spreading into areas with predominantly native vegetation (for example, national parks) is considered lower than for urban or agricultural areas where known hosts are grown.

Summary: BMSB has readily spread in North America and Europe. This is consistent with its reproductive rate, dispersal abilities, overwintering biology and wide plant host range. These factors are all expected to contribute to the potential to spread in the regions of Australia most suitable for BMSB, which are also regions with large population centres and significant plantings of at-risk crops. BMSB is known to be associated with cargo and goods, so human-assisted spread over long distances is also considered likely. For these reasons, the likelihood of spread of BMSB is assessed as '**High**'.

4.1.4 Overall likelihood of entry, establishment and spread

The overall likelihood of entry, establishment and spread is determined by combining the likelihoods of entry, of establishment and of spread using the matrix of rules shown in Table 2Error! Reference source not found..

For at-risk goods from areas in the northern hemisphere with established BMSB populations, the overall likelihood for the entry, establishment and spread of BMSB in Australia during the months of **September to May** is estimated to be **High**.

For at-risk goods from areas in the northern hemisphere with established BMSB populations, the overall likelihood of entry, establishment and spread of BMSB in Australia during the months of **June to August** is estimated to be **Extremely Low**.

4.2 BMSB in the southern hemisphere

Some areas in the southern hemisphere are considered to be suitable for the establishment of BMSB, as discussed in Section 3.1.2, and BMSB has been reported from Chile (Faúndez & Rider 2017).

As seasons are aligned between Australia and other countries in the southern hemisphere, any BMSB that arrive from southern hemisphere origins will be able to continue their lifecycle without the seasonal disruption that occurs when moving between hemispheres. Therefore, the timing of risk periods and some risk likelihoods will vary compared with those for BMSB arriving from the northern hemisphere. In the absence of interception data for BMSB originating in the southern hemisphere, the risk period for BMSB entry to Australia has been extended to include the equivalent seasonal period of November and December.

For goods from countries in the southern hemisphere with BMSB, likelihoods were assessed for the months of March to December (autumn to early summer in the southern hemisphere) and the months of January to February (mid to late summer in the southern hemisphere).

4.2.1 Likelihood of entry

The likelihood of entry is considered in two parts, the likelihood of importation and the likelihood of distribution, which consider pre-border and post-border issues, respectively.

Likelihood of importation during March to December

The likelihood that BMSB will arrive in Australia from areas in the southern hemisphere with established BMSB populations with the importation of at-risk goods during the months of March to December is assessed as **High**.

Likelihood of importation during January to February

The likelihood that BMSB will arrive in Australia from areas in the southern hemisphere with established BMSB populations with the importation of at-risk goods during the months of January to February is assessed as **Extremely Low**.

In addition to the information used to support assessment of the likelihood of entry from the northern hemisphere (Section 4.1.1), the following information provides additional evidence for southern hemisphere focussed assessments.

- In the southern hemisphere, BMSB are expected to enter overwintering sites during autumn (March to late May) and remain dormant until spring (September to October), and may therefore be associated with at-risk goods during this time.
- However, some BMSB may remain in overwintering sites and therefore be associated with at-risk goods during November and December, which is the seasonal equivalent to months of May and June in the northern hemisphere (Bergh et al. 2017). However, interception records of BMSB do not support any significant association of BMSB with goods arriving in Australia from the northern hemisphere during these months.
- There are currently no large established populations of BMSB in the southern hemisphere, and therefore no interception records are available to inform whether BMSB may be associated with at-risk goods during November and December.
- BMSB are expected to be actively feeding and completing their lifecycle on host plants during spring and summer (for example, November to February in the southern hemisphere).

- No live BMSB have been intercepted on goods arriving in Australia from the northern hemisphere during July or August, which is the seasonal equivalent to the months of January and February in the southern hemisphere.
- Sea freight shipped to Australia from the southern hemisphere will not always cross the equator and thus may not experience temperature or day length fluctuations that are expected when goods are shipped from the northern hemisphere. Therefore, it is expected that survival of diapausing BMSB associated with goods sourced from the southern hemisphere is likely to be higher than for diapausing BMSB associated with goods that cross the equator.

Summary: BMSB are expected to have a high association with various at-risk goods (such as vehicles, machinery and mechanical parts) loaded during autumn to early spring (the months of March to October in the southern hemisphere). BMSB enter overwintering sites during autumn where they form aggregations with other BMSB and remain immobile until the spring. In some circumstances, BMSB have been shown to emerge from overwintering sites as late as early summer (December in the southern hemisphere). This information supports a likelihood rating of 'High' during March to December.

BMSB are expected to be actively feeding and completing their lifecycle on host plants during the southern hemisphere summer (particularly the months of January to February). BMSB are very unlikely to be associated with any non-living goods during this time period, as they are very unlikely to form aggregations on structures and non-plant goods during this stage of their lifecycle. No live BMSB have been intercepted on goods arriving in Australia from the northern hemisphere during the seasonally equivalent months. This information supports a likelihood rating of 'Extremely Low' during January to February.

Likelihood of distribution

The likelihood that BMSB will be distributed within Australia in a viable state as a result of the processing, sale or disposal of infested goods from countries in the southern hemisphere with established BMSB populations, and subsequently transfer to a susceptible part of a host at all times of year is assessed as **High**.

The information in Section 4.1.1 provides the supporting evidence for this assessment.

Summary: As seasons are aligned between Australia and other countries in the southern hemisphere, any BMSB that arrive will be able to continue their lifecycle without the seasonal disruption that occurs when moving between hemispheres. BMSB that arrive when actively feeding are expected to encounter similarly suitable conditions when they arrive in Australia. Overwintering BMSB that arrive in Australia are expected to remain in an overwintering state until they are stimulated to leave these sites by environmental cues such as temperature and day length. When this occurs, it is expected that susceptible hosts will be available to support BMSB distribution. This information supports a likelihood rating of 'High'.

Overall likelihood of entry

The overall likelihood of entry is determined by combining the likelihood of importation with the likelihood of distribution using the matrix of rules shown in Error! Reference source not found..

The likelihood that BMSB will enter Australia as a result of trade in at-risk goods from areas in the southern hemisphere with established BMSB populations during the months of **March to December** and be distributed in a viable state to a susceptible host is: **High**.

The likelihood that BMSB will enter Australia as a result of trade in at-risk goods from areas in the southern hemisphere with established BMSB populations during the months of **January to February** and be distributed in a viable state to a susceptible host is: **Extremely Low**.

4.2.2 Likelihood of establishment

The likelihood that BMSB will establish in Australia with the importation of at-risk goods from areas in the southern hemisphere with established BMSB populations at all times of year is assessed as **High**.

The information in Section 4.1.2 provides the supporting evidence for this assessment.

Summary: As seasons are aligned between Australia and other countries in the southern hemisphere, any BMSB that arrive will be able to continue their lifecycle without the seasonal disruption that occurs when moving between hemispheres. BMSB that arrive when actively feeding are expected to encounter similarly suitable conditions when they arrive in Australia. Overwintering BMSB that arrive in Australia are expected to remain in an overwintering state until they are stimulated to leave those sites by environmental cues such as temperature and day length. When this occurs, it is expected that susceptible hosts will be available to support BMSB establishment. This information supports a likelihood rating of 'High'.

4.2.3 Likelihood of spread

The likelihood that BMSB will spread within Australia, based on a comparison of factors in the source and destination areas that affect the expansion of the geographic distribution of the pest is assessed as **High**.

- The likelihood of spread is not expected to differ between BMSB originating in the northern or southern hemispheres. The information used to support the assessment for BMSB from the northern hemisphere (Section 4.2.3) provides the supporting evidence for this assessment.

4.2.4 Overall likelihood of entry, establishment and spread

The overall likelihood of entry, establishment and spread is determined by combining the likelihoods of entry, of establishment and of spread using the matrix of rules shown in Table 5.

For at-risk goods from areas in the southern hemisphere with established BMSB populations during the months of **March to December**, the overall likelihood for the entry, establishment and spread of BMSB in Australia is assessed as **High**.

For at-risk goods from areas in the southern hemisphere with established BMSB populations during the months of **January to February**, the overall likelihood of entry, establishment and spread of BMSB in Australia is assessed as **Extremely Low**.

4.3 Consequences

The potential consequences of the establishment of BMSB in Australia have been estimated according to the methods described in Table 3. The potential consequences are not expected to differ as a result of the origin of BMSB being the northern or southern hemisphere.

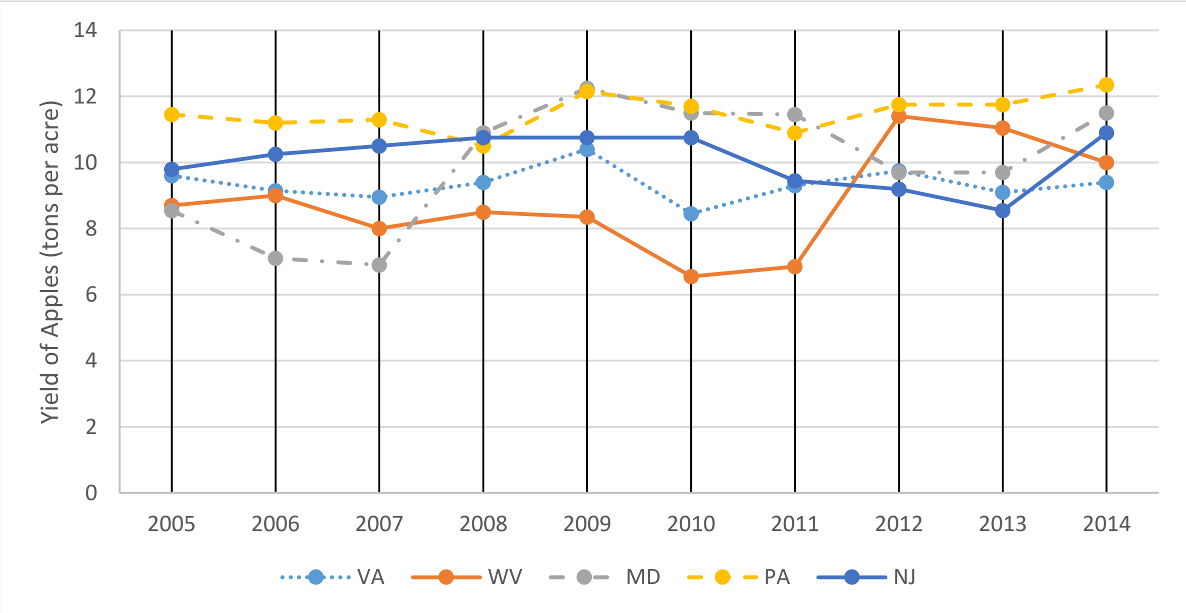
Based on the decision rules described in Table 4, that is, where the potential consequences of a pest with respect to one or more criteria are '**E**', the overall consequences are estimated to be **Moderate**.

Criterion	**Estimate and rationale**
Direct	
Plant life or health	**E—Major significance at the district level** In the USA, BMSB has reached very high population densities in certain districts and has a significant impact on the production of a range of crops. This was particularly true in the mid-Atlantic region of the USA during 2010, where large, newly emergent populations of BMSB went untreated and had severe impacts on a range of fruit production in some districts, including an estimated $37 million dollar loss for apples and a loss of up to 90 per cent of peach crops (Leskey et al. 2012a). However, production data shows that states affected by BMSB did not have sustained losses in yields for apples and peaches over a time period before and after 2010 (see Figure 8 and Figure 9). Although yield for a fruit crop is influenced by many factors and does not capture the effects of downgrading damaged fruit, it does demonstrate that at a state level, producers in the USA have been able to continue to maintain harvest rates in spite of the new impacts of BMSB. Those impacts are typically mitigated by increased spraying rates and use of appropriate pesticides (Leskey et al. 2012a; Leskey, Short & Lee 2014). However, increased use of pesticides leads to increased production costs and reduced profitability, and in some instances, such as organic production, effective control measures may not be available. Damage caused by BMSB to hazelnuts in the republic of Georgia has followed a very similar pattern; in 2016, the first year BMSB was found to be a serious pest, losses in hazelnut production were very high and estimated at a cost of between about US$50 to US$70 million dollars (Murvanidze et al. 2018). In subsequent years, increased spraying with broad spectrum insecticides (mainly bifentherin) has allowed orchards to recover their yields, but at an increased cost of production (Tavberidze 2018). The local climate and vegetation appears to play a significant role in the build-up of BMSB populations and their subsequent potential for damage to crops in the USA (Rice et al. 2017). For example, in states like South Carolina, certain districts have significant BMSB problems while in other districts of the state, BMSB is not a significant pest (Bakken et al. 2015). Although there are likely to be districts in Australia where BMSB could build to large and damaging populations, it is very unlikely that BMSB could build up to these levels uniformly across an entire region in Australia, such as a state. For example, in the USA, BMSB is associated with native and non-native woody deciduous hosts in unmanaged woodlands that allow the development of large populations (Bakken et al. 2015). These populations then move into commercial crops where they can cause significant damage (Leskey et al. 2012a). However, in Australia, native non-host woodlands, such as *Eucalyptus*, are less likely to support large BMSB populations. Therefore, impacts on commercial crops in Australia are likely to be limited to areas with suitable unmanaged host vegetation near areas of commercial production. The climatic suitability of some major production areas in temperate Australia (for example, the Riverland and Sunraysia districts) are considered to be poor for BMSB, as they are hotter and drier than climates that typically support large BMSB populations (Nielsen, Fleischer & Chen 2016; Zhu et al. 2012; Zhu et al. 2016). Overall, the impacts of BMSB may be major, but only for particular crops in particular areas with suitable climate and where non-crop hosts allow sustained BMSB population growth. This is best expressed as presenting a potential consequence of major significance at the district level.
Other aspects of the environment	**B—Minor significance at the local level.** Given the native range and climatic preferences of BMSB, it is not expected to be able to establish in tropical and/or arid areas such a central and northern Australia.

	Although BMSB can cause a great deal of economic damage to fruit crops and has a wide host range, it has not been documented as causing significant plant mortality or morbidity in natural ecosystems in the USA, in spite of feeding on a range of native plants in these ecosystems. BMSB is not known to feed on any native Australian plants, although given its wide host range, it is considered possible that some native plants may be suitable hosts for BMSB. Given the mode of feeding of BMSB and the damage caused by aborting, misshaping and blemishing fruit, the main effects on other aspects of the environment are most likely to be a reduction in fruit quality and may impact on seed set of native hosts (if any exist) in some localities.
Indirect	
Eradication, control	**E—Significant at the regional level** Because BMSB has a wide host range, dispersal capacity, and cryptic coloration, and there is currently a lack of highly sensitive detection techniques, the successful eradication of an established BMSB population is likely to require a significant effort across a large area. BMSB was recently reported and declared under official control in Santiago, Chile (SAG 2017) but further information on the eradication effort is not yet available. Control of BMSB in new areas was initially difficult as BMSB is relatively insensitive to many insecticides (Kuhar & Kamminga 2017; Lee, Wright & Leskey 2013). Management of this insect in the USA often required frequent calendar spraying (Leskey et al. 2012c). Insecticidal control of BMSB has also been reported to be difficult in Italy (Bariselli, Bugiani & Maistrello 2016; Leskey et al. 2012a). Large populations of BMSB have been associated with woody deciduous hosts in unmanaged woodlands in the USA (Bakken et al. 2015), making control more difficult. However, as discussed above, Australian vegetation and cropping landscapes are expected to be less suitable than those present in the USA and Europe where large BMSB populations have established. There has also been an associated increase in secondary pest outbreaks due to the use of pesticides for BMSB disrupting integrated pest management systems in the USA (Morrison, Mathews & Leskey 2016). However, management strategies are being developed to more effectively control BMSB and reduce crop injury, including through improved monitoring, use of attractants and targeted insecticide application (Bergh et al. 2016; Cira et al. 2017; Leskey 2017; Weber et al. 2017). The change in pest control efforts in the USA due to BMSB is best described as ‘significant at the regional level' as several states in the mid-Atlantic region have experienced significant impacts not only to producers of a range of crops but also to homeowners controlling infestations of overwintering BMSB. It is expected that in affected areas of Australia, BMSB control measures that are similar to those used in the USA would be required, and that overall impacts on pest management and production would also be similar.
Domestic trade	**E—Significant at the regional level** There are three geographically separated areas of Australia at risk from invasion of BMSB: southwest Australia, southeast Australia, and Tasmania (Zhu et al. 2012). It is likely that BMSB will only invade one of these areas in the first instance, and would not be expected to naturally disperse into the other at-risk areas due to the significant distances and natural geological barriers between these areas. BMSB would be expected to spread via human-assisted dispersal on at-risk goods, cargo and machinery. In order to manage risk from domestic BMSB populations, states with at-risk regions that are free from the pest may put risk mitigation measures in place, including specific measures on cargo pathways. These measures would be likely to have a significant impact on interstate trade and movement of people and personal effects.
International trade	**E—Minor at the national level** BMSB is now distributed in many climatically suitable regions in most at-risk countries in the northern hemisphere, and no current BMSB specific treatment measures are required for any countries in the northern hemisphere, therefore no impact on Australian trade with northern hemisphere countries is expected. In the southern hemisphere, only New Zealand and Chile currently regulate BMSB on at-risk goods. BMSB is currently under official control in Santiago, Chile (SAG 2017). If BMSB were to establish and spread in Australia in a manner similar to that seen in the USA, it is possible that Australian exporters would be required to treat at-risk goods exported to any countries that regulate overwintering BMSB on at-risk goods. As the goods of concern are generally manufactured products that harbor overwintering aggregations, as opposed to horticultural products such as fruit and vegetables, it is expected that only manufactured products would be subject to similar

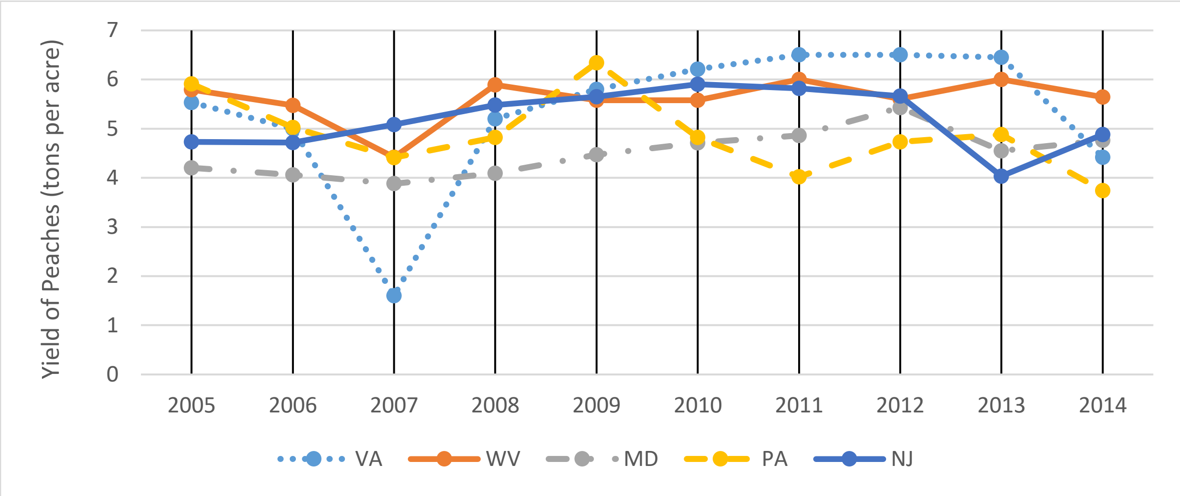
	requirements for any countries that regulate overwintering BMSB. For countries affected by Australia's BMSB requirements, trade in all goods has been able to continue, although costs have increased due to new requirements.
Environmental and non-commercial	**D—Significant at the district level** BMSB is known to feed on and damage ornamental and productive garden plants and trees; affected homeowners use a range of control measures to protect their plants (Bergmann & Raupp 2014; Sargent, Martinson & Raupp 2014). BMSB can be a nuisance pest for homeowners. Under suitable climatic and host conditions, BMSB can enter homes and structures in very large numbers seeking overwintering shelter (Inkley 2012). Once inside, BMSB can damage household goods by staining materials with their secretions and causing food spoilage, as discussed in Section 3.1.6. However, in Australia the discontinuous distribution of highly suitable hosts, lack of large native deciduous forests, and typically dry climate, are likely to limit BMSB populations and therefore the number of BMSB adults entering homes to overwinter, thus limiting impacts to local areas only.

Figure 8 The yield of apples (tons per acre) from the years 2005 to 2014 for selected states in the USA affected by BMSB.



States identified in Leskey et al. (2012a). States abbreviations are explained as follows: MD–Maryland, considered affected since 2008–2009; NJ–New Jersey, considered affected since 2008–2009; PA–Pennsylvania, considered affected since 2010; VA–Virginia, considered affected since 2010; WV–West Virginia, considered affected since 2008–2009. Production statistics taken from the USDA non-citrus fruits and nuts summary for the relevant years (USDA-NASS 2016).

Figure 9 The yield of peaches (tons per acre) from the years 2005 to 2014 for selected states in the USA affected by BMSB.



States identified in Leskey et al. (2012a). States abbreviations are explained as follows: MD–Maryland, considered affected since 2008–2009; NJ–New Jersey, considered affected since 2008–2009; PA–Pennsylvania, considered affected since 2010; VA–Virginia, considered affected since 2010; WV–West Virginia, considered affected since 2008–2009. Production statistics taken from the USDA non-citrus fruits and nuts summary for the relevant years (USDA-NASS 2016).

4.4 Unrestricted risk estimate

Unrestricted risk is the result of combining the likelihoods of entry, establishment and spread with the outcome of overall consequences. Likelihoods and consequences are combined using the risk estimation matrix (Table 5) and the outcome is summarised below in Table 7.

As indicated, the unrestricted risk estimate for BMSB on at-risk goods from areas in the **northern hemisphere** with established BMSB populations during the months of **September to May** has been assessed as '**Moderate**', and does not achieve the ALOP for Australia. Therefore, specific risk management measures are required for this pest on at-risk goods from the northern hemisphere during this time period.

The unrestricted risk estimate for BMSB on at-risk goods from areas in the **northern hemisphere** with established BMSB populations during the months of **June to August** has been assessed as '**Negligible**', which achieves the ALOP for Australia. Therefore, no specific risk management measures are required for this pest on at-risk goods from the northern hemisphere during this time period.

The unrestricted risk estimate for BMSB on at-risk goods from areas in the **southern hemisphere** with established BMSB populations loaded during the months of **March to December** has been assessed as '**Moderate**', and does not achieve the ALOP for Australia. Therefore, specific risk management measures are required for this pest on at-risk goods from the southern hemisphere during this time period.

The unrestricted risk estimate for BMSB on at-risk goods from areas in the **southern hemisphere** with established BMSB populations loaded during the months of **January to February** has been assessed as '**Negligible**', which achieves the ALOP for Australia. Therefore, no specific risk management measures are required for this pest on at-risk goods from the southern hemisphere during this time period.

Key to Table 7 Summary of unrestricted risk estimates for at-risk goods from areas with established BMSB populations.

Likelihoods for entry, establishment and spread

N	Negligible
EL	Extremely Low
VL	Very Low
L	Low
M	Moderate
H	High
EES	Overall likelihood of entry, establishment and spread
URE	Unrestricted risk estimate. This is expressed on an ascending scale from Negligible to Extreme.

Table 7 Summary of unrestricted risk estimates for at-risk goods from areas with established BMSB populations.

	Likelihood of						Consequences	URE
Time of year	**Entry**			**Establishment**	**Spread**	**EES**		
	Importation	Distribution	**Overall**					
Goods from the northern hemisphere								
September to May	H	H	**H**	H	H	H	M	**M**
June to August	VL	M	**VL**	VL	H	EL	M	**N**
Goods from the southern hemisphere								
March to December	H	H	**H**	H	H	H	M	**M**
January to February	EL	H	**EL**	H	H	EL	M	**N**

5 Pest risk management

This chapter provides information on measures and procedures for management of BMSB, which has been assessed in this report as having an unrestricted risk that does not achieve the ALOP for Australia.

5.1 Pest risk management measures and phytosanitary procedures

Pest risk management evaluates and selects measures to reduce the risk of entry, establishment or spread of quarantine pests for Australia where they have been assessed to have an unrestricted risk that does not achieve the ALOP for Australia.

In this chapter, the Department of Agriculture has identified risk management measures that may be applied to consignments of goods sourced from countries known or reasonably suspected to host populations of BMSB to achieve the ALOP. Application of these measures to imported goods will depend on the assessed level of risk of BMSB infestation. This risk may vary due to a range of factors, including the nature of the goods, the nature of the BMSB population in the source country and the history of interceptions. Finalisation of the import conditions may be undertaken with input from the Australian states and territories.

Any consignment that fails to meet Australia's import conditions will be subject to a suitable remedial treatment where an effective treatment is available and biosecurity risks associated with applying the treatment can be effectively managed, or the imported consignment will be re-exported or destroyed.

Since the publication of the draft report the department has worked closely with New Zealand Ministry for Primary Industries (New Zealand MPI) to ensure a consistent approach to BMSB pest risk managments, although complete alignment of measures is not feasible due to differing trade patterns, legislative frameworks and biosecurity systems. This outcome has been strongly supported by many importers and exporters.

5.2 Pest risk management for BMSB

This pest risk analysis identified BMSB as having an unrestricted risk that does not achieve the ALOP for Australia during the period September to May for at-risk goods originating from countries in the northern hemisphere considered likely to have established BMSB populations. In addition, the unrestricted risk does not achieve the ALOP for Australia during the period March to December for at-risk goods originating from countries in the southern hemisphere with established BMSB populations. At-risk goods are taken to include break-bulk cargo, vehicles and machinery, and any cargo that has been stored where infestation with BMSB is possible. Prior to the beginning of the 2018–19 BMSB season, the department conducted an internal review of at-risk countries and cargo, based on existing pest status information, previous interception data and overall trade volumes (Appendix C). During the 2018–19 season, over 97 per cent of BMSB that arrived on goods imported with a tariff code identifier were on goods that had been identified as 'high' or 'targeted' risk. As BMSB spreads around the world and patterns of production and movement of trade goods change, the department is continuously reviewing the risk status of all goods, and the specific goods considered at-risk for BMSB may change in the future.

BMSB could conceivably be hidden in any imported goods. These goods would likely have been stored outdoors, in sheds, warehouses or attics, in any country in the world with a BMSB population. However, when inspected, the majority of goods from these countries do not harbor BMSB, and in the few instances where BMSB are intercepted, only a very small number are usually found. In these goods BMSB is similar to the many different types of hitchhiking pests that are routinely managed at the border. Therefore, for some types of goods specific treatments are not justified and maintaining existing surveillance is considered an effective means of mitigating the risk associated with BMSB.

In the case of some other types of goods, such as vehicles, machinery and mechanical parts, where larger BMSB infestations may be difficult to detect, more stringent measures are recommended where those goods come from countries considered likely to have established BMSB populations.

The department considers that a range of risk management measures are required to reduce the risk posed by BMSB on at-risk goods imported into Australia so as to achieve the ALOP for Australia. Depending on the type of good and its origin, the following risk management measures are to be applied:

- enhanced surveillance
- sulfuryl fluoride fumigation
- methyl bromide fumigation
- heat treatment
- approved safeguarding arrangements.

Recommended risk management measures are based on the previously applied emergency measures and ongoing seasonal measures that have successfully managed BMSB on at-risk goods since 31 December 2014 (see Figure 2), and are consistent with the measures in place for the 2019–20 season. However, specific requirements for these measures have also been continually adjusted to take into account changing risk and new information. The timeline for specific measures is detailed in Appendix E.

Measures

The measures that are considered appropriate to mitigate the risk of live overwintering BMSB arriving on goods shipped to Australia and have been implemented for the 2019 – 20 season, are detailed below.

Based on best available evidence, including unpublished research results conducted by New Zealand MPI, the department is implementing the conditions as listed below for the 2019–20 season. A discussion of these treatment rates and some of the research results is given by Ormsby (2018). All treatment rates are either the same or slightly more stringent than previous department treatment rates.

A time window between treatment and loading may also be required to prevent re-infestation of goods by BMSB, as detailed below.

Treated and untreated goods should be kept physically segregated before loading and during transit to Australia to reduce the risk of live BMSB re-contaminating treated goods.

Enhanced surveillance

This measure is most appropriate for types of goods and/or goods from countries which are not considered likely to have large BMSB infestations intercepted at the Australian border. To mitigate the risk that larger infestations could cross the border undetected in difficult to inspect goods, it is recommended that goods known to have greater risk of BMSB infestation, from countries in the northern hemisphere, receive particular attention through enhanced surveillance during the risk period from 1 September (loading at port) to 31 May (arrival in Australia). This risk period would apply from 1 March to 31 December (loading at port) for goods known to carry greater risk of BMSB infestation from countries in the southern hemisphere.

Enhanced surveillance must be flexible, allowing the Department of Agriculture to target particular goods and countries when a change in risk profile occurs. Surveillance techniques may include the use of irritant chemicals to flush insects out from hiding places in complex cargo, in-transit BMSB traps on ships, and any other relevant BMSB detection methods or technologies which may be developed in the future.

Enhanced surveillance of in-transit ships and their cargo

Since the publication of the draft risk analysis the department has employed enhanced surveillance to ensure that ships carrying vehicles and machinery both from native range and invaded countries are free from live BMSB and other hitchhiker pests of biosecurity concern. This includes pre-arrival reporting and seasonal pest inspections.

Roll-on-roll-off (RoRo) Vessels from all countries of origin will be provided with a seasonal pest questionnaire as part of their pre-arrival reporting. RoRo vessels that have berthed at, loaded or transhipped cargo from target risk countries will be directed to perform a self-inspection and report their findings through the Seasonal Pest Questionnaire. Other vessels must report the detection of any insects as part of their ordinary pre-arrival reporting. When BMSB, or other actionable exotic species are reported, the vessels will be directed to perform two additional inspections over 48 hours. Where insects are detected, vessel masters must provide details of the number of insects found, where they were found (e.g. the deck/location), and whether they were alive or dead. Photos of all insects must be submitted along with the completed Seasonal Pest Questionnaire. All insects must be kept for presentation to a Biosecurity Officer on arrival in Australia.

Seasonal pest inspections are conducted by qualified department staff and are different to a routine vessel inspection. For a seasonal pest inspection, a vessel’s ramp and doors must remain closed (except to allow access for government officials). Cargo must not be discharged until the inspection has been completed, and approval is granted. If live insects, or a significant number of dead insects are detected, a seasonal pest inspection will be supplemented with a dual action insecticide treatment. This will require the application of a residual insecticide and a thermal pyrethrum fog.

The information gained from these enhanced surveillance methods is used to determine appropriate actions to manage the identified quarantine pests. In some instances, ships have been required to leave Australia without discharging cargo, as no appropriate onshore treatment could be applied in a safe and timely fashion.

Enhanced surveillance of landed cargo
In order to verify the pest free status of cargo and correct application of treatments, all target high risk and target risk goods will be subject to onshore intervention through random verification inspections. Break bulk goods will be directed for a full inspection at the wharf. Containerised goods will be directed for a 'seals intact and full unpack' supervised inspection at an approved arrangement site.

Where appropriate and safe to do so, inspection may include the use of aids, such as aerosol insecticides or thermal pyrethrum fog to agitate BMSB and other overwintering pests to facilitate detection. The department has trained detector dogs to detect BMSB, and where appropriate, these dogs may be used.

Where BMSB or other pests are intercepted the goods will be directed for onshore treatment (if permitted) or export.

Sulfuryl fluoride fumigation
Both New Zealand and the department had the same overall conditions for sulfuryl fluoride during the 2018–19 season. Based on data collected in several unpublished and independent studies reviewed by the department, no BMSB have been documented to survive the recommenced conditions for sulfuryl fluoride (Ormsby 2018, Walse 2015). During the 2018–19 season, 33,551 consignments were treated with sulfuryl fluoride. No new data has come to light to support a change to these conditions, and no issues relating to the treatment rates were identified. Therefore, conditions are recommended to remain the same for the 2019–20 season. Rates to achieve an effective sulfuryl fluoride fumigation for at-risk goods are:

- A dose of 24 g/m^3 or above, at 10°C or above, for a minimum of 12 hours (but less than 24 hours), with a minimum end point reading of 12 g/m^3
  or

- A dose of 24 g/m^3 or above, at 10°C or above, for 24 hours or longer, with a minimum end point reading of 8 g/m^3

Note: Dose increases to compensate for temperatures less than 10°C are NOT permitted.

The dose of a fumigant can also be referred to as the Concentration by Time Product (CT Product) normally expressed as gram hours per cubic metre. Many monitoring systems measure the dose as a CT value, and the department has also provided gulidlines for these systems.

Sulfuryl Fluoride – Using third-party system*
- Achieve a CT of 200 g-h/m^3 or more, at 10°c or above, for 12 hours or longer, with a minimum end point reading of 12 g/m^3
  or

- Achieve a CT of 200 g-h/m^3 or more, at 10°C or above, for 24 hours or longer, with a minimum end point reading of 8 g/m^3

Note: currently approved third party systems are:

Douglas Products FumiGuide

Ensystex II, Inc. Fumicalc

Methyl bromide fumigation
The methyl bromide rate recommended by the department is based on data in unpublished studies reviewed by the department, New Zealand’s experience with methyl bromide (Ormsby 2018) as well as the department's experience. During the 2018–19 season 10,367 consignments were treated with methyl bromide at the departments required rate. No BMSB have been documented to survive these recommended rates of methyl bromide. The overall recommended rates to treat BMSB with methyl bromide are:

- A dose of 24 g/m^3 or above, at 10°C or above, for a minimum of 12 hours (but less than 24 hours), with a minimum end point reading of 12 g/m^3
  or
- A dose of 24 g/m^3 or above, at 10°C or above, for 24 hours or longer, with a minimum end point reading of 8 g/m^3

Note: Dose increases to compensate for temperatures less than 10°C are NOT permitted.

Heat treatment
Heat treatment rates are based on a number of published reports (Aigner & Kuhar 2016; Ormsby 2018; Scaccini, Duso & Pozzebon 2019). During the 2018–19 season 36,822 consignments were treated with the department’s required heat treatment. No BMSB have been documented to survive the recommended heat treatment conditions, and all species of hitchhiking overwintering arthropods are expected to experience high mortality with these heat treatment rates.

For all types and sizes of goods:

- 56°C or higher at the coldest surface of the goods, for a minimum of 30 minutes

or an alternative option for individual goods weighing less than 3000 kg shipped as break bulk only:

- 60°C or higher at the coldest surface of the goods, for a minimum of 10 minutes

Note: Individual goods shipped as break bulk weighing less than 3000 kg and treated at 60°C for 10 minutes require evidence within shipping documentation that they are less than 3000 kg for these treatments to be accepted.

Time between treatment and loading
BMSB appears to infest goods at the point of manufacture or during long-term storage, rather than at ports just prior to loading; however, treated goods may potentially be re-infested prior to being loaded on to a ship.

During the period of infestation risk, goods treated at a port or in a nearby urban environment are unlikely to be quickly re-infested, as population densities of BMSB in these areas, where there is little vegetation to host large numbers of BMSB, are low relative to the number of possible overwintering sites.

In the 2018–19 season this window had to be extended to 120 hours to accommodate movement of goods at some European ports. To date, there have been no documented instances of BMSB re-infesting treated cargo within this time window, and no documented instances of BMSB infesting goods at a port. Frequent movement of goods between treatment and final loading are likely to reduce the likelihood of BMSB settling into suitable areas within goods. Nevertheless, it is considered ideal to minimise the time between treatment and loading.

For goods that can be secured from BMSB access after treatment, such as sealing inside a sound container, re-infestation is considered unlikely and no particular time window is considered necessary. Similarly, goods treated after winter has commenced (for example, from 1 December in the northern hemisphere) are very unlikely to become re-infested by BMSB based on the current understanding of its biology and behaviour, and no time window between treatment and loading is considered necessary.

Approved safeguarding arrangement
Safeguarding arrangements are an alternative to the mandatory pre-shipment treatment requirements and require adoption of a detailed pest risk management plan/system that can be implemented by manufacturers offshore (Department of Agriculture and Water Resources 2015b).

Safeguarding arrangements must be approved by the Department of Agriculture, and goods that arrive without an approved arrangement in place will require mandatory treatment onshore, or be re-exported. Guidance on applying for an approved arrangement is available on the department's website http://www.agriculture.gov.au/import/before/brown-marmorated-stink-bugs

5.3 Operational Arrangements to ensure effective application and verification of measures

Offshore treatment
Treatments using sulfuryl fluoride, methyl bromide or heat are effective for controlling BMSB when applied as specified below, and following the departments best practice methodologies (http://www.agriculture.gov.au/import/arrival/treatments/treatments-fumigants). The department has provided guidance fact sheets for BMSB treatments (http://www.agriculture.gov.au/import/before/brown-marmorated-stink-bugs). These treatments may be applied offshore when mandatory offshore management of BMSB is required, or onshore to manage BMSB infestations intercepted at the border.

In instances where large numbers of BMSB have been intercepted on particular pathways on numerous occasions, and management at the border is not practical, mandatory offshore treatments will be required. This became necessary for certain goods from the USA beginning in 2014–15, and goods from various European countries beginning in 2017–18 due to the presence of very large BMSB infestations that were not practical to manage at the border.

Australia and New Zealand jointly maintain an offshore Brown Marmorated Stink Bug Treatment Providers Scheme (http://www.agriculture.gov.au/import/before/brown-marmorated-stink-bugs). The Offshore Brown Marmorated Stink Bug Treatment Providers Scheme, as updated from time to time, aims to:

- Set out the process to determine suitability of the provider to be able to perform offshore BMSB treatments of goods to be imported into Australia.
- Effectively manage biosecurity risks of BMSB risk goods imported into Australia.
- Define the offshore BMSB treatment provider's (provider's) ongoing compliance requirements.
- Set out the ways in which Australia and New Zealand will cooperate, share information, and make decisions about offshore BMSB treatments.

The department will determine the provider's suitability for registration by assessing their application form, supplementary documentation, compliance history (if relevant) and results of any onsite audit (if conducted). An onsite compliance assessment may be conducted at the provider's expense to confirm that the provider's facilities and procedures, including all equipment and operating procedures, meet the requirements of the scheme.

On-site compliance assessments will include, but are not limited to, the assessment of the provider's:

- equipment and site
- operating procedures
- application of treatments
- cleanliness and hygiene practices
- records management and procedures
- staff understanding and management structure to support activities.

If the provider is deemed suitable, they will be required to sign a letter of agreement acknowledging the obligations under the scheme. Once the provider has signed and returned their letter of agreement, they will be added to the acceptable offshore BMSB treatment providers list on the department website, and be allocated an Entity Identifier (AEI). If the provider ceases to operate, they must notify the department in writing. The provider will be removed from the acceptable offshore BMSB treatment providers list.

To maintain scheme registration, the provider must ensure that:

- All BMSB treatments must comply with the scheme and the relevant treatment methodology.
- Accurate treatment certification must be issued for each treatment with the treatment provider AEI clearly recorded on all certification issued.
- Details of all BMSB treatments conducted for Australia-bound goods must be provided to the department.
- Accurate records and certification of all BMSB treatments and equipment calibration must be created and maintained.

The provider will receive a non-compliance notification if a consignment treated by the provider has not met the scheme's requirements and the 'acceptable' status of the provider may be suspended. Following the issue of a non-compliance notification, the department may refer any consignments treated by the provider for any action it considers reasonable. Where no further non-compliance is identified in the referred consignments, the provider will have its 'acceptable' status reinstated.

The provider may be suspended when:

- Live quarantine pests are detected that indicate the provider has not complied with the scheme and the provider is determined to be at fault.
- The provider fails to provide records requested by the department within 72 hours.
- Non-compliance is identified and the department loses confidence in the provider.
- During an on-site or desk-top compliance assessment, the provider cannot demonstrate compliance with the scheme.

If suspended, the provider must provide satisfactory evidence of corrective actions before being eligible for reinstatement. The department reserves the right to require an on-site compliance assessment to determine compliance. This will be conducted at the provider's expense. In response to a suspension, the department will take measures to manage the potential biosecurity risk of any goods treated by a suspended provider. The department reserves the right not to reinstate where the provider has not demonstrated that it meets the requirements under the scheme.

Verification inspections of landed cargo

In order to verify the pest free status of cargo and correct application of treatments, all goods will be subject to onshore intervention through random verification inspections. Break bulk goods will be directed for a full inspection at the wharf. Containerised goods will be directed for a 'seals intact and full unpack' supervised inspection at an approved arrangement site.

Where appropriate and safe to do so, inspection may include the use of aids, such as aerosol insecticides or thermal pyrethrum fog to agitate BMSB and other overwintering pests to facilitate detection. The department has trained detector dogs to detect BMSB, and where appropriate, these dogs may be used.

Where BMSB or other pests are intercepted, the goods will be directed for onshore treatment (if permitted) or export. The department reviews interception records, and may respond to changes in risk profiles of goods at the border with changes to policy settings.

5.4 Consideration of alternative measures

Consistent with the principle of equivalence detailed in ISPM 11: *Pest risk analysis for quarantine pests* (FAO 2013), the Department of Agriculture will consider any alternative measure proposed by any relevant stakeholders including manufacturers, shippers, exporters and importers, providing that it demonstrably manages the target pest (BMSB) to achieve the ALOP for Australia. Evaluation of such measures or treatments will require a technical submission that details the proposed measures and includes suitable information to support the claimed efficacy, for consideration by the department. Acceptance of any alternative measure will require prior approval by the Department of Agriculture.

5.5 Review of processes

5.5.1 Verification of risk management measures

Prior to or during the season of trade, representatives from the Department of Agriculture may visit areas that produce at-risk goods for export to Australia. The department may need to verify operational systems, including the implementation of risk management measures.

5.5.2 Review of policy

The Department of Agriculture reserves the right to review the import policy as deemed necessary if there is reason to believe that the pest or phytosanitary status in a country has changed.

Available information indicates that BMSB is expanding its range within Europe and into the southern hemisphere. In some countries, the population densities of BMSB are increasing and economic effects are being observed in some horticultural areas. As BMSB populations increase in size in these areas, the risk of BMSB becoming a significant hitchhiker pest on goods from these areas is likely to increase. In these circumstances, the Department of Agriculture will continue to monitor relevant pathways and to consider whether offshore risk management treatments need to be applied.

6 Conclusion

The findings of this final pest risk analysis for *Halyomorpha halys* are based on a comprehensive scientific analysis of relevant literature, data analysis and consultation with experts.

The department considers that the risk management measures recommended in this report will provide an appropriate level of protection for Australia against *H. halys* entering on goods from all countries with established *H. halys* populations.

Appendix A Categorisation of brown marmorated stink bug (*Halyomorpha halys*)

The steps in the initiation and categorisation process are considered sequentially, with the assessment terminating at 'Yes' for column 3 (except for pests that are present, but under official control and/or pests of regional concern) or the first 'No' for columns 4, 5 or 6.

Details of the method used in this risk analysis are given in Section 2: Method for pest risk analysis.

Pest	Distribution	Present within Australia	Potential to be on pathway	Potential for establishment and spread	Potential for economic consequences	Pest risk assessment required
Halyomorpha halys (Stål, 1855) [Pentatomidae] Brown marmorated stink bug (BMSB) Synonyms: *Dalpada brevis* *D. remota* *Pentatoma halys* *Poecilometis mistus* (Rider 2014)	Asia, North America, Europe. Chile (under official control) (see Section 3.1.2).	No records found.	Yes. *Halyomorpha halys* is known to infest goods arriving from countries with populations of *H. halys* (see Section 1.2.1).	Yes. *Halyomorpha halys* has established and spread outside its native range (see Section 3.1.2).	Yes. *Halyomorpha halys* is known to cause economic damage to a range of commercial fruits and vegetables (see Section 3.1.6).	Yes

Appendix B Host plants of BMSB

This list of host plants recorded for BMSB is drawn from four sources (Bergmann et al. 2015; Bergmann et al. 2016; Lee et al. 2013; USDA-APHIS-PPQ 2010). Many references in the literature state that BMSB feeds on over 300 plant species (Nielsen, Hamilton & Matadha 2008; Smith, Hesler & Loeb 2014), however, no single host list of that length has been found. Nevertheless, this list, complied from only four sources, names over 275 plant species. This list should not be considered a comprehensive review of the literature, and not every host on this list is of equal quality for BMSB survival, development and reproduction. Given its wide host range, BMSB is also likely to be able to feed and develop on other plants related to those listed here, potentially also with varying degrees of success.

Host species	Common name	Reference
Abelia × grandiflora	Glossy abelia	a, d
Abelmoschus esculentus	Okra	a
Acer × freemanii	Freeman maple	a
Acer × tegmentosum	Manchurian snakebark maple	a, d
Acer buergerianum	Trident maple	a
Acer campestre	Hedge maple	a, d
Acer circinatum	Vine maple	a
Acer griseum	Paperbark maple	a
Acer japonicum	Amur (Japanese downy) maple	a
Acer macrophyllum	Bigleaf maple	a
Acer negundo	Boxelder	a
Acer palmatum	Japanese maple	a
Acer pensylvanicum	Striped maple	a
Acer platanoides	Norway maple	a
Acer pseudoplatanus	na	d
Acer rubrum	Red maple	a
Acer saccharinum	Silver maple	a, d
Acer saccharum	Sugar maple	a
Actinidia deliciosa	Kiwifruit	c
Aesculus × carnea	Red horse-chestnut	a
Aesculus glabra	Ohio buckeye	a
Ailanthus altissima	Tree of heaven	a, c
Akebia spp.	Chocolate vine	c
Amaranthus caudatus	Love-lies-bleeding (amaranth)	a
Amelanchier laevis (syn. × grandiflora)	Allegheny (apple) serviceberry	a
Antirrhinum majus	Garden snapdragon	a
Arctium minus	Lesser burdock	a, c, d
Armoracia rusticana	Horseradish	a
Artemisia argyi	Argyi wormwood	c
Asimina triloba	American pawpaw	a

Host species	Common name	Reference
Asparagus officinalis	Asparagus	c
Baptisia australis	Blue wild indigo	a
Basella rubra	Ceylon spinach	c, d
Beta vulgaris	Beet	c, d
Beta vulgaris ssp. cicla	Swiss chard	a
Betula spp.	Birch	c, d
Betula nigra	River birch	a
Betula papyrifera	Paper birch	a
Betula pendula	European white birch	a
Brassia spp.	Orchid	c
Brassica juncea	Wild mustard	a
Brassica napus	Canola	c
Brassica oleracea	Cabbage, collards	a
Buddleja spp.	Butterflybush	a, d
Buddleja davidii	Butterflybush	d
Camellia oleifera	Oil-seed camellia	c
Camellia sinensis	Chinese tea	c, d
Cannabis sativa	Hemp	a
Capsicum annuum	Cayenne pepper	a, c, d
Caragana arborescens	Siberian peashrub	a, d
Carpinus betulus	European hornbeam	a
Carya ovata	Shagbark hickory	a, d
Carya illinoinensis	Pecan	a
Catalpa spp.	Catalpa	a, c
Cayratia japonica	Bushkiller	c
Celastrus orbiculatus	Oriental bittersweet	a, d
Celosia spp.	Cock's comb	a
Celosia argentea	Feather cockscomb	b, d
Celtis occidentalis	Common hackberry	a
Celtis koraiensis	Korean hackberry	a
Cephalanthus occidentalis	Common buttonbush	a
Cercidiphyllum japonicum	Katsura tree	a, b
Cercis canadensis	Eastern redbud	a
Cercis canadensis var. *texensis*	Texas redbud	a, d
Cercis occidentalis	Hackberry	d
Chaenomeles speciosa	Japanese flowering quince	c
Chamaecyparis obtusa	Hinoki cypress	c
Chenopodium berlandieri	Pitseed goosefoot	a
Chionanthus retusus	Chinese fringe tree	a
Chionanthus virginicus	White fringe tree	a
Cinnamomum camphora	Camphor tree	c

Host species	Common name	Reference
Citrus spp.	Orange, mandarin, yuzu	c, d
Cladrastis kentukea (syn. lutea)	Kentucky (American) yellowwood	a
Cleome spp.	Cleome	d
Clerodendrum trichotomum	Harlequin glorybower	c
Cornus × Stellar series	Dogwood	a
Cornus florida	Flowering dogwood	a
Cornus kousa	Kousa dogwood	a, d
Cornus macrophylla	(Large-leaf) dogwood	a
Cornus officinalis	Asiatic (Japanese cornel) dogwood	a
Cornus racemosa	Gray dogwood	a
Cornus sericea	Redosier dogwood	a, d
Corylus colurna	Filbert, hazelnut	a
Crataegus laevigata	Smooth (English) hawthorn	a
Crataegus monogyna	Oneseed hawthorn	a
Crataegus pinnatifida	Chinese hawthorn	c
Crataegus viridis	Green hawthorn	a
Cucumis sativus	Garden cucumber	a, c
Cucurbita pepo	Field pumpkin (summer squash)	a
Cupressus spp.	Cypress	d
Decaisnea fargesii	na	d
Dendranthema morifolium	Chrysanthemum	c
Diospyros spp.	Persimmon	c, d
Diospyros kaki	Japanese persimmon	a, d
Elaeagnus angustifolia	Russian olive	a, d
Elaeagnus umbellata	Autumn olive	a
Eriobotrya japonica	Loquat	c
Euonymus alatus	Winged euonymus	d
Euonymus japonicus	Japanese spindle	c
Evodia spp.	na	b
Ficus carica	Edible fig	a, c, d
Firmiana platanifolia	Chinese parasol tree	c
Forsythia suspensa	Weeping forsythia	a
Fraxinus americana	White (American) ash	a, d
Fraxinus chinensis	Chinese ash	c
Fraxinus pennsylvanica	Green ash	a
Ginkgo biloba	Maidenhair tree (ginkgo)	a
Gleditsia triacanthos var. *inermis*	Thornless common honeylocust	a, b
Glycine max	Soybean	a, c, d
Gossypium hirsutum	Upland cotton	c, d
Halesia tetraptera	Mountain (carolina) silverbell	a, b
Hamamelis japonica	Invasive witchhazel	a

Host species	Common name	Reference
Hamamelis virginiana	American witchhazel	a
Helianthus annuus	Sunflower	a, c, d
Heptacodium miconioides	Seven sons flower	a
Hibiscus moscheutos	Crimsoneyed rosemallow	a
Hibiscus rosa-sinensis	Chinese hibiscus	c, d
Hibiscus syriacus	Rose of sharon (hibiscus)	a
Humulus lupulus	Common hop	a
Humulus scandens (japonicus)	Japanese hops	c
Ilex aquifolium	English holly	a
Ilex opaca	American holly	d
Ilex verticillata	Winterberry holly	d
Impatiens balsamina	Rose balsam	c
Juglans nigra	Black walnut	a, d
Juniperus virginiana	Eastern red cedar	a
Koelreuteria paniculata	Goldenrain tree	a, d
Lagerstroemia indica	Crepe myrtle	a
Larix kaempferi (syn. leptolepis)	Japanese larch	a
Ligustrum japonicum	Japanese or wax-leaf privet	a
Ligustrum sinense	Chinese privet	a
Liquidambar styraciflua	Sweetgum	a
Liriodendron tulipifera	Tulip tree	a
Lonicera spp.	Honeysuckle	a
Lonicera tatarica	Tatarian honeysuckle	a, d
Lycium barbarum	Wolfberry	c
Lythrum salicaria	Purple loosestrife	a
Magnolia stellata	Star magnolia	a
Magnolia grandiflora	Southern magnolia	a, d
Mahonia aquifolium	Holly leaved barberry (oregon grape)	a
Malus × zumi	Crab apple	a
Malus baccata	Siberian crab apple	a, d
Malus domestica	Apple	a, c
Malus pumila (syn. domestica)	Paradise apple	a
Malus sargentii	Sargent’s crab apple	a
Manihot esculenta	Tapioca	c
Metasequoia glyptostroboides	Dawn redwood	a
Mimosa spp.	Sensitive plant (mimosa)	a
Morus spp.	Mulberry	c, d
Morus alba	White mulberry	a
Musineon divaricatum	Leafy wild parsley	a
Nicotiana alata	Jasmine tobacco	c
Nyssa sylvatica	Blackgum (tupelo)	a, b

Host species	Common name	Reference
Olea oleaster	Wild olive	c
Oxydendrum spp.	na	b
Panicum miliaceum	Common millet	c
Parrotia spp.	na	b
Paulownia tomentosa	Princess tree (paulownia)	a, c, d
Phalaenopsis spp.	Orchid, moth	a
Phaseolus spp.	Bean	a, c, d
Phaseolus lunatus	Lima bean	c, d
Phaseolus vulgaris	Kidney bean	c, d
Photinia (syn. Aronia) spp.	Chokeberry	a
Phytolacca americana	American pokeweed	a
Pistacia chinensis	Chinese pistache	a
Pisum sativum	Pea	c, d
Platanus occidentalis	American sycamore	a, d
Platycladus orientalis	Oriental arborvitae	c
Polygonum perfoliatum	Mile-a-minute weed	c
Populus tomentosa	Chinese white poplar	c
Prunus spp.	Cherry, plum	c
Prunus × incam	Flowering cherry	a
Prunus armeniaca	Apricot	a, c
Prunus avium	Sweet cherry	a
Prunus cerasifera	Cherry plum	a
Prunus domestica	Plum	d
Prunus grayana	Japanese bird cherry	c, d
Prunus incisa	Fuji cherry	a
Prunus laurocerasus	Cherry laurel	a
Prunus mume	Green plum	c
Prunus persica	Peach	a, c
Prunus pseudocerasus	Cambridge cherry	c, d
Prunus serotina	Black cherry	a, d
Prunus serrulata	Japanese flowering cherry	a
Prunus subhirtella	Winter-flowering (Higan) cherry	a
Pseudocydonia sinensis	Chinese-quince	a, b
Pueraria montana var. *lobata*	Kudzu	c
Punica granatum	Pomegranate	c
Pyracantha spp.	Firethorn	a, d
Pyracantha coccinea	Firethorn	d
Pyrus spp.	Pear	a, c
Pyrus calleryana	Callery (Bradford) pear	a
Pyrus fauriei	Korean sun pear	a, d
Pyrus pyrifolia	Chinese (Asian) pear	a

Host species	Common name	Reference
Quercus alba	White oak	a
Quercus coccinea	Scarlet oak	a
Quercus robur	English oak	a
Quercus rubra	Northern red oak	a
Rhamnus spp.	Buckthorn	d
Rhamnus cathartica	Common buckthorn	a
Rhodotypos scandens	Jetbead	d
Rhus spp.	Sumac	d
Rhus typhina	Staghorn sumac	c
Robinia pseudoacacia	Black locust	a, c
Rosa canina	Dog (native) rose	a
Rosa multiflora	Mulitflora rose	a
Rosa rugosa	Rugosa rose	a
Rubus spp.	Raspberry, blackberry	a, c
Rubus phoenicolasius	Wine raspberry (wineberry)	a, d
Salix spp.	Willow	a, d
Sambucus spp.	Elder	d
Sambucus racemosa	Red elderberry	c
Sassafras albidum	Sassafras	a
Secale cereale	Cereal rye	a
Setaria italica	Pearl millet	c
Sicyos angulatus	Bur cucumber	d
Solanum lycopersicum	Tomato	a, c, d
Solanum melongena	Eggplant	a, c
Solanum nigrum	Black nightshade	c
Sophora japonica	Japanese pagoda tree	a
Sophora japonica L. forma pendula	Weeping scholar tree	c
Sorbus spp.	Mountain ash	d
Sorbus airia	Winterbeam	a
Sorbus americana	American mountain ash	a
Sorghum bicolor	Sorghum	c
Spiraea spp.	Spirea	a, d
Stewartia koreana	Korean stewartia	a, d
Stewartia pseudocamellia	Japanese stewartia	a
Styrax japonicus	Japanese snowbell	a, b
Symphytum spp.	Comfrey	a, d
Syringa spp.	Lilac	c, d
Syringa pekinensis	Peking (Chinese) tree lilac	a
Taxus cuspidata	Japanese yew	c
Tetradium daniellii (syn. Euodia hupehensis)	Bee-bee tree (Korean euodia)	a
Tilia spp.	Basswood	d

Host species	Common name	Reference
Tilia americana	American basswood	a
Tilia cordata	Little leaf linden	a
Tilia tomentosa	Silver linden	a
Triticum aestivum	Wheat	c, d
Tropaeolum majus	Nasturtium	d
Tsuga canadensis	Eastern hemlock	a
Ulmus spp.	Elm	d
Ulmus americana	American elm	a
Ulmus parvifolia	Chinese elm	a
Ulmus pumila	Elm	c
Ulmus procera (syn. minor)	English (smooth leaf) elm	a
Vaccinium corymbosum	Highbush blueberry	a
Vibernum spp.	Viburnum	c, d
Viburnum × burkwoodii	Viburnum	a, d
Viburnum dilatatum	Linden arrowwood	a
Viburnum opulus var. *americanum*	Highbush cranberry	d
Viburnum prunifolium	Viburnum (blackhaw)	a
Viburnum setigerum	Tea viburnum	d
Vigna angularis	Azuki bean	c, d
Vigna sesquipedalis	Chinese long bean	c
Vigna unguiculata	Cowpea	c
Vitex negundo	Chinese chaste tree	c
Vitis riparia	Riverbank wild grape	a, d
Vitis vinifera	Wine grape	a, c
Weigela hortensis	Japanese weigela	c
Wisteria sinensis	Chinese wisteria	c
Zea mays	Corn (field and sweet corn)	a, c, d
Zelkova spp.	Japanese zelkova	c
Ziziphus jujube	Jujube	c
na	Chestnut	c
na	Pine	c
na	Arrowroot	c
na	Wax myrtle	c
na	Acacia	c
na	Alder	c
na	Cedar	c
na	Chinese milk vetch	c
na	Clover	c
na	Common mallow	c
na	Hairy vetch	c
na	Hollyhock	c

Host species	Common name	Reference
na	Strawberry	c
na	Tung	c

a Bergmann et al. (2015). **b** Bergmann et al. (2016). **c** Lee et al. (2013). **d** USDA-APHIS-PPQ (2010). **na** not available/ not provided.

Appendix C Summary of recommendations for cargo measures for the 2018–19 BMSB season

Summary

On 1 September 2018, the department implemented BMSB measures to include high risk goods which were manufactured or stored in eight European countries: France, Georgia, Germany, Greece, Hungary, Italy; Romania and Russia, as well as goods from the United States of America. Additionally, the department required enhanced surveillance, including in-transit surveillance and reporting, for other goods from these countries and goods from a range of countries known or considered likely to have BMSB populations. As described in Chapter 5 Pest Risk Management, enhanced surveillance is used to verify lower risk pathways achieve ALOP.

The conditions set out for the 2018–19 season predicted 97% of the total number of alive and dead intercepted BMSB based on type of goods (1,931 of 1,989 total BMSB) and on country of origin (1,925 of 1,989 total BMSB). No live BMSB were intercepted from countries not considered likely to have BMSB. These dead BMSB from non-BMSB countries were mostly found associated with breakbulk goods or in containers, and are considered likely to represent contamination from previous international shipments of at-risk goods not destined for Australia. All BMSB found in goods not predicted to be at risk for BMSB infestation were dead except for one live BMSB detected in a shipping container of egg white powder from Italy, and 27 live BMSB detected in a vintage computer in mail from the USA.

This appendix summarises the large body of work done prior to the commencement of the 2018–19 season in order to determine these conditions. In particular, at the time the department faced a significant and novel challenge in attempting to predict which goods might be at risk for BMSB infestation from newly invaded countries. This appendix describes the reasoning and methodology used to predict BMSB risk based on cargo type, which was used successfully in the 2018–19 season and has been used again for the 2019–20 season.

BMSB risk from Europe

BMSB has been present in Europe since at least 2004, and perhaps from as early as the late 1990's. At least 16 countries in Europe had recorded established populations of this insect by 2018, and it was recorded as a pest in several of these (Table 8). As BMSB is continuing to spread, and most countries in Europe have climates suitable for BMSB to some degree, it is predicted that nearly all countries in Europe will have eventually have established BMSB populations.

However, in mid-2018 not all countries in Europe reported BMSB as being present, and in some countries BMSB had only just been reported; in the latter, populations were likely to be small, and unlikely to present issues in cargo in the 2018–19 season. Additionally, the risks from overwintering BMSB in cargo is dependent not only on the population of BMSB in the exporting country, but also the types of goods and the volume of goods being exported.

Because of these factors, for the 2018–19 European BMSB season, a Europe-wide offshore treatment requirement was not justified; instead, countries of highest risk were targeted based on information of the BMSB populations and trade volumes, taken in context of previous experience with BMSB from the USA and Italy. All countries in Europe with BMSB populations, or those near countries with BMSB populations, were considered to have some risk of exporting infested cargo, and cargo pathways were monitored though the season to determine if onshore measures are sufficient, or if off-shore measures were required.

Previous experience of BMSB becoming a serious issue in cargo was with the countries of the USA and Italy; in both countries BMSB is a relatively recent invader. In the USA, BMSB was first reported in 2001, and pest reports began in 2008, with widespread pest reporting in 2010. Live BMSB interceptions from the USA began in 2007, and reached problematic levels in 2014. In Italy, BMSB was first reported in 2012 and first reports of pest issues began in 2014. Live BMSB interceptions at the border began in 2014 and reached problematic levels in 2017.

Based on the time-frames from these two countries, live BMSB in cargo from newly invaded countries may become a serious issue between 5–13 years from an initial report of the pest, and 3–4 years after the first reports of becoming a crop pest, and within 3–7 years of first being intercepted at the border. These numbers are subject to a range of modifying factors, including the suitability of the climate, the relative survey and reporting efforts, and the locations of goods suppliers.

Local climates will strongly influence population growth of BMSB; either hot and dry summers and/or very cold winters are thought to limit BMSB populations. Some climates allow BMSB populations to only persist or grow slowly. For example BMSB populations in Switzerland (Zurich) have grown slowly, and BMSB has taken a longer time to be recorded as a pest in Switzerland than in many other European countries. The single generation per year and slower rate of nymph maturation, leading to increased proportions of autumn mortality in the cooler climate, are likely to be key reasons for this slower population growth.

Table 8 provides an estimate of the areas that are considered suitable for development of pest-level populations of BMSB in European countries that had recorded BMSB as being present in mid-2018. The estimates of areas of climatic suitability for pest population levels of BMSB were made by interpretation of several published climate matching studies (Fraser, Kumar & Aguilar 2017; Haye et al. 2015; Kriticos et al. 2017; Zhu et al. 2012; Zhu et al. 2016).

A further consideration was that because goods are widely moved through Europe without quarantine controls, it is considered likely that in the next few years populations of BMSB will grow as rapidly in some European countries than as experienced by Italy. For this reason, earlier estimates of risk years are preferred over later ones. Finally, higher volumes of trade present greater risk, as there is both a greater chance that goods infested with BMSB will arrive, and a greater difficulty in securing and treating high volumes of cargo on-shore.

Based on the above considerations, eight European countries were considered to have some potential to present heightened BMSB risk in cargo in the 2018–19 season. These countries are France, Georgia, Germany, Greece, Hungary, Italy, Romania and Russia. All other European countries were considered less likely to present significant BMSB issues in cargo for the 2018–19 season, due to the various factors as detailed in Table 8. However, they are now considered likely to present issues in the 2019–20 season. The following provides a breakdown of risk assessments for the countries identified as at-risk in the 2018–19 season.

France – BMSB has been present since 2012; this is potentially sufficient for BMSB to reach pest levels, and there are large areas of the country that are considered suitable for BMSB pest level populations. BMSB has been recorded in goods originating from this country four times by Australia (wood, packaging and machinery). As increased volumes of cargo are imported from France, BMSB is considered likely to arrive in goods during the 2018–19 season.

Georgia – BMSB has been recorded as a serious pest in Georgia since 2016, and large areas of this country are suitable for development of pest populations of BMSB.

Germany – BMSB has been present since 2012; this is potentially sufficient time for BMSB to reach pest levels, and there are some areas of this country that are suitable for pest-level BMSB populations, in particular the southwest part of the country, e.g. the Rhine Valley. BMSB has been recorded in goods originating from this country three times by Australia (once on packaging and twice on machinery and parts). As increased volumes of cargo are imported from Germany, BMSB is considered likely to arrive in goods during the 2018–19 season.

Greece – BMSB has been present since 2011; this is potentially sufficient time for BMSB to reach pest levels. Parts of this country are suitable for pest populations of BMSB.

Hungary – BMSB has been recorded as a pest in Hungary since 2015, and large areas of this country are suitable for pest-level populations of BMSB. BMSB has been intercepted twice by Australia (on personal effects and machinery). As increased volumes of cargo are imported from Hungary, BMSB is considered likely to arrive in goods during the 2018–19 season.

Italy – Large numbers of BMSB were found in a wide range of goods from Italy in the 2017–18 season. There was no evidence that at-risk goods from Italy would present a lower risk for BMSB for the 2018–19 season than for the 2017–18 season, therefore all at-risk goods from Italy continued to have risk mitigation measures applied to them.

Romania – BMSB has been recorded in Romania in 2014, as pest in 2016, and more than half of the counties in this country reported BMSB as present in the summer of 2017. Severe pest issues were also reported in the greater Bucharest area. Large areas of Romania are considered likely to be suitable for development of pest populations of BMSB.

Russia – BMSB has been recorded as serious pest in the Sochi region of Russia since 2016.

Table 8 Summary of BMSB infestation risk factors for at-risk goods from European countries with known BMSB populations in 2018.

Country	Estimated area of country suitable for pest-level BMSB populations	Year of BMSB establishment	Year of first BMSB pest record	Month and Year of first BMSB incident at Australia's border	Trade volume*
Austria	Low	2015	-		Moderate
Croatia	High	2017	-		Small
France	High	2012	overwintering pest reports 2018	Nov 2014	Large
Georgia	High	2013	2016		Small
Germany	Moderate (High in specific localities e.g. Rhine valley)	2012	overwintering pest reports 2018	May 2016	Large
Greece	Moderate	2011	pest report 2018		Moderate
Hungary	High	2013	2015	Feb 2018	Moderate
Italy	High	2012	2014	Jan 2015	Large
Romania	High	2014	2016		Moderate
Russia	Moderate/low (high in the southwest area, e.g. Sochi)	2013	2016 (Sochi)		Small
Serbia	High	2015	-		Small
Slovakia	High/Moderate	2016	-		Moderate
Slovenia	High	2016	-		Moderate
Spain	Moderate (hot and dry climates may reduce populations)	2016	-		Large
Switzerland	Low	2008	2017		Moderate
Turkey	High	2017	-		Moderate

*Trade volume summaries determined as Large – average of ~4,000 or more unique consignment/supplier/tariff combinations arriving per month, Moderate – average of less than ~4000 and greater than 400 such arrivals per month, and Small – less than ~ 400 consignment/supplier/tariff combinations arriving per month.

Highlighted countries are those that have been assessed in text of Appendix C.

North America

United States of America – Large and increasing numbers of BMSB have been found in goods from the United States since the 2014–15 season, although offshore treatments have reduced the number of incidents of live arrivals. There was no evidence that the United States would present a lower risk for BMSB in at-risk goods for the 2018–19 season than for previous seasons, therefore all at-risk goods from the United States continued to have offshore risk mitigation measures applied to them.

Canada – BMSB is known to be established in Canada, but large pest populations have not been reported, and BMSB has not been intercepted on any goods through the 2017–18 season. Therefore, for the 2018–19 season, possible at-risk goods from Canada were recommended to be subject to increased surveillance arriving during the overwintering season.

Asia

BMSB is native to China, South Korea and Japan, and these countries therefore have a significantly different risk profile for this pest. Native stink bug populations are expected to fluctuate from year to year, with occasional outbreaks to high numbers when conditions are particularly favourable. Historically, BMSB interception rates from native regions have changed from year to year without a rapidly increasing trend, in contrast to records from invaded countries. There is no information to suggest that BMSB or other native stink bug populations are undergoing a permanent increase in population levels in their native range. The broad measures proposed for these countries are offshore management and surveillance of known higher risk pathways (e.g. explosives from China, used cars from Japan), and increased surveillance across possible at-risk goods arriving during the overwintering season.

Risk of BMSB in cargo due to types and volumes of cargo, and previous levels of infestation

Countries that send cargo known to be contaminated with other biosecurity risk material are also considered to pose risks of sending BMSB-infested cargo if and/or when the local BMSB populations reach high levels. The volumes of at-risk cargo from each country have a major impact on the risk management capacity at the Australian border. The volumes of trade and the levels of contamination were analysed for all European countries listed in Table 8 in mid-2018 to predict emerging BMSB risk.

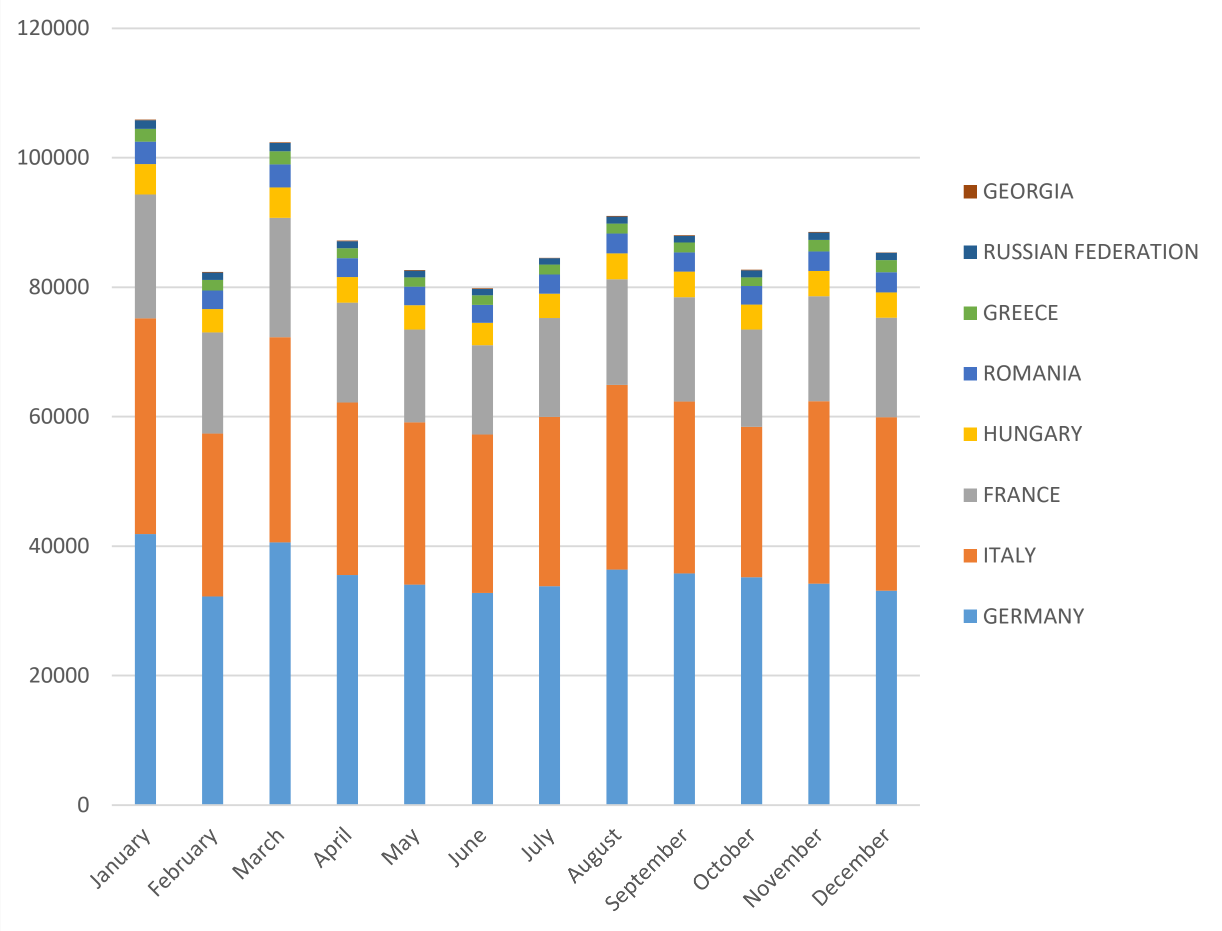
This analysis uses tariff codes to identify goods. Tariff codes are numeric codes developed for the Harmonized Commodity Description and Coding System (HS). The Harmonized System is an international nomenclature for the classification of products. It allows participating countries to classify traded goods on a common basis for customs purposes. Australia defines goods in accordance with this international system in the *Customs Tariff Act 1995*. Tariff codes in the *Customs Tariff Act 1995* are listed as eight digit codes comprising over 5,000 article/product descriptions that appear as headings and subheadings, arranged in 99 chapters. The eight digits can be broken down into parts. The first two digits identify the chapter the goods are classified in, e.g. Chapter 87 = Vehicles other than railway or tramway rolling-stock, and parts and accessories thereof. The next two digits identify groupings within that chapter, e.g. 8704 = Motor vehicles for the transport of goods. As all eight digits are added, more specifics of the goods are included, e.g. 8704.10.17 = Dumpers designed for off-highway use having a capacity not exceeding 30 tons. As all goods imported into Australia must be declared and are required to be classified by tariff code, this system provides a consistent way to define, group and analyse goods imported from all countries in the world.

Although many biosecurity pests are associated directly with plant and animal goods, trade in all goods carry the risk of allowing the entry and establishment of a wide range of biosecurity pests. The reasons goods become infested with biosecurity pests are diverse, and apply to most imported goods. Some pests such as the brown marmorated stink bug *Halyomorpha halys* are well known for entering into a wide range of goods such as air conditioners, electrode plates and even pharmaceutical samples when the seek out overwintering sites. This behaviour is shared with a wide range of other biosecurity pests intercepted at the Australian border that threaten not only horticulture but also environmental, animal and human health, such as *Harmonia axyridis* the harlequin ladybeetle, and and *Vespa* species*,* hornets. Many seeds can be associated with a range of goods as well, allowing for potential entry of weeds or pathogens. Not all such pests are seasonal, some such as black rice bugs (*Scotinophara spp*) and giant African snail (*Lissachatina fulica*) are tropical and can be sound at any time of year. Due to the way many goods are shipped, the nature of the goods themselves are often not a good indication of risk, for example, exotic frogs have found associated with a bulk import of corrosive chemicals, but the frogs were able to find shelter in the pallets and packing material around the bulk tanks.

Therefore, in order to predict emerging BMSB risk, any interceptions of any contaminating organisms, whether quarantine pests or not, was used to indicate a potential BMSB infestation. This approach covers not only live and dead arthropods, but also all other kinds of identifiable organisms, including other invertebrates, vertebrates and plants, the latter usually identified as contaminants due to presence of leaves and seeds. Use of this wide scope of interceptions is justified, as BMSB can infest a wide range of goods, based on whether it has access to the goods in question. BMSB has been found in co-infestations with other overwintering insects, and other risk material such as plant leaves. The presence of other animals or plant material is considered an indication that the goods in question were handled or stored in a way that could facilitate BMSB infestation.

Although there is some variation in total monthly trade volumes, there did not appear to be any significant seasonal trends for any European country considered (Figure 10).

Figure 10 Total volumes of cargo (unique counts of Integrated Cargo System entry number, tariff and supplier code) over five years (2013–2018) by month, for eight European countries considered likely to present BMSB risk.

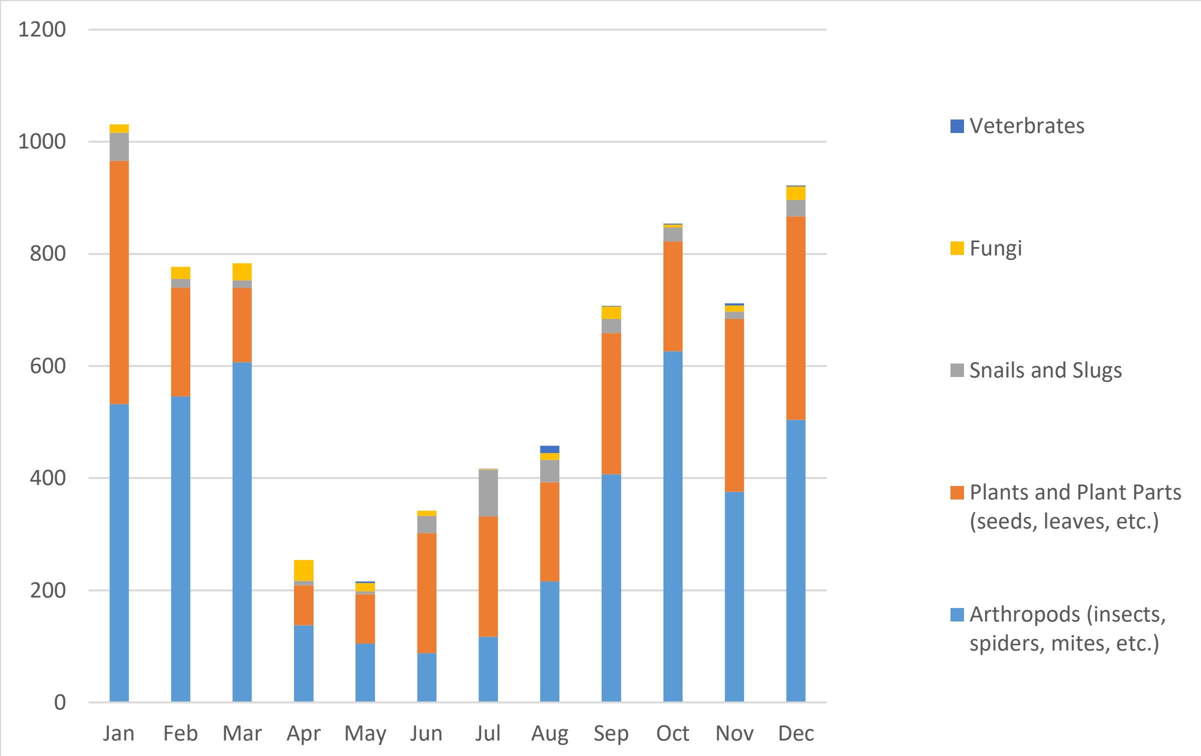


In contrast to the total trade volumes, the overall trend of biosecurity risk material in cargo from Europe was seasonal (Figure 11), following a similar seasonal pattern to BMSB contamination.

As the trade in fresh produce is itself seasonal, and the pests typically found in produce are not overwintering hitchhikers or likely to be indicative of BMSB risk, fresh produce (kiwi fruit, garlic and citrus) were excluded from the data reported in Figure 11. Fresh produce is imported from Italy, France and Spain, as kiwi fruit, citrus and garlic, and total inspection and contamination rates for these countries are influenced by these commodities, however, risk mitigation measures already in place for these goods also mitigate risk from BMSB.

Given that all countries considered have distinct temperate seasons, it is expected that the seasonal contamination of goods is likely do to the many temperate plant species which shed seeds and leaves in autumn, and many temperate arthropod species seek overwintering shelter at this time. Contamination driven by these factors is likely to be influenced mainly by the storage and handling of goods. Therefore, the overall seasonal pattern in risk material is considered to fit the same profile as the BMSB risk profile, and is an indication that contamination in general may be a good indicator for BMSB risk.

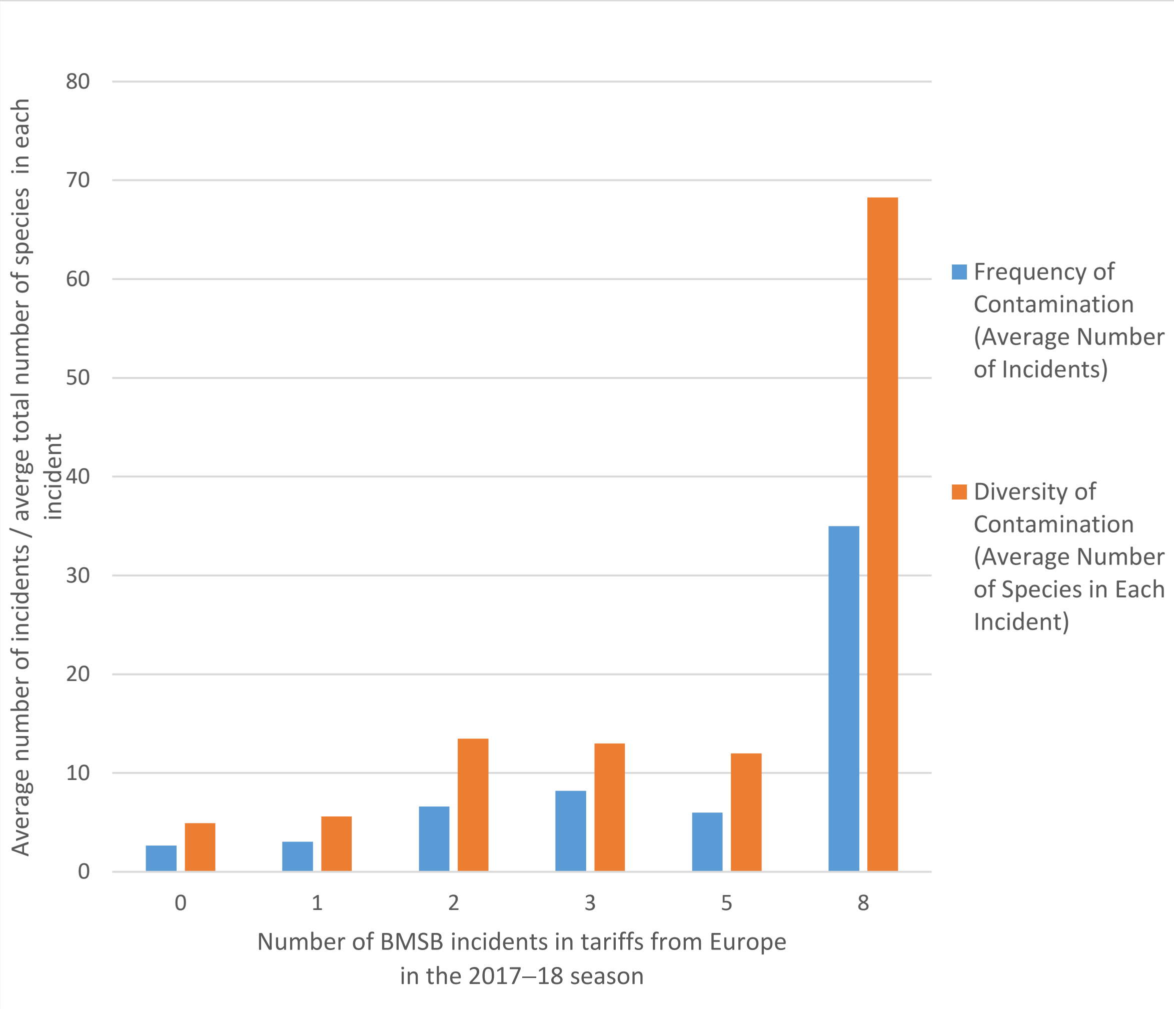
Figure 11 Counts and types of potential pests found in consignments from eight European countries from Jan 2013–April 2018, excluding fresh produce (kiwi fruit, garlic and citrus).



To further examine the assessment that overall contamination rates are indicative of BMSB risk, tariff codes of goods from Europe which were present in consignments infested with BMSB in the 2017–18 season were reviewed. This review confirmed that previous pest interception experience can serve as an indicator of the likelihood of BMSB infestation.

Overall the number and types of goods that are contaminated with potential biosecurity pests was diverse, this analysis has found that in the five year period anaysied, of the 5,229 unique tariff codes in 97 chapters imported, 1046 codes in 80 chapters were contaminated with potential biosecurity pests. However, in general, the more frequently a tariff code was found to have been associated with any biosecurity risk material, the more often it was associated with a BMSB infestation (Figure 12). Both the frequency of contamination (the average number of incidents for a given tariff code associated with at least one contaminating species), and the diversity of contamination (the average total number of different contaminating species in each incident) correlated to the number of BMSB incidents in that tariff code from Europe in the 2017–18 season.

Figure 12 The frequency of contamination and the diversity of contamination in goods (identified by tariff code) from Europe from 2013 to 2018, in comparison to the number of BMSB incidents from Europe recorded for that good's tariff code during the 2017–18 season.



Consistent with BMSB being a generalist hitchhiker, BMSB was found more frequently in goods which were found to be infested with any species of contaminant more frequently, or goods known to carry at least some contaminates and which were imported in higher volumes. These two metrics (infestation rates and import volumes) were used to generate lists of at-risk goods for the countries identified previously, which were considered likely to present a risk of BMSB infestation in the 2018–19 season. Based on practical considerations, and in order to prevent possible errors regarding goods declarations, at-risk goods requiring offshore treatment were identified on the basis of tariff chapter code (Table 9).

Some goods were determined to be at intermediate risk, where, due to lower sample numbers, there was insufficient information about contamination rates and associated goods storage and handling to give confidence that the ALOP for BMSB arrival will be achieved. These goods are termed 'target risk' and subject to enhanced surveillance onshore, but do not require off-shore treatment (Table 10).

Some goods were excluded from requirements for extra BMSB measures due to actions already taken at the border (for example, the pest risk mitigation measures already in place for fresh produce). In other cases the entire tariff chapter was not determined as requiring offshore treatment, but some goods within the chapter were targeted.

Table 9 Target high-risk goods, by tariff chapter code, requiring off-shore treatment by BMSB risk countries.

36 - Explosives; pyrotechnic products; matches; pyrophoric alloys; certain combustible preparations	74 - Copper and articles thereof	84 - Nuclear reactors, boilers, machinery and mechanical appliances; parts thereof
44 - Wood and articles of wood; wood charcoal	75 - Nickel and articles thereof	85 - Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles
45 - Cork and articles of cork	76 - Aluminium and articles thereof	86 - Railway or tramway locomotives, rolling-stock and parts thereof; railway or tramway track fixtures and fittings and parts thereof; mechanical (including electro-mechanical) traffic signalling equipment of all kinds
57 - Carpets and other textile floor coverings	78 - Lead and articles thereof	87 - Vehicles other than railway or tramway rolling-stock, and parts and accessories thereof
68 - Articles of stone, plaster, cement, asbestos, mica or similar materials	79 - Zinc and articles thereof	88 - Aircraft, spacecraft, and parts thereof
69 - Ceramic products – including sub chapters I and II	80 - Tin and articles thereof	89 - Ships, boats and floating structures
70 – Glass and glass ware	81 - Other base metals; cermets; articles thereof	93 - Arms and ammunition; parts and accessories thereof

72 - Iron and steel - including sub chapters I, II, III, IV	82 - Tools, implements, cutlery, spoons and forks, of base metal; parts thereof of base metal	
73 - Articles of iron or steel	83 - Miscellaneous articles of base metals	

Table 10 Target risk goods, subject to increased onshore inspection.

25 - Salt; sulphur; earths and stone; plastering materials, lime and cement	31 - Fertilisers	47 - Pulp of wood or of other fibrous cellulosic material; recovered (waste and scrap) paper or paperboard
26 - Ores, slag and ash	38 - Miscellaneous chemical products	48 - Paper and paperboard; articles of paper pulp, of paper or of paperboard
27 - Mineral fuels, mineral oils and products of their distillation; bituminous substances; mineral waxes	39 - Plastics and articles thereof – including sub chapters I and II	49 - Printed books, newspapers, pictures and other products of the printing industry; manuscripts, typescripts and plans
28 - Inorganic chemicals; organic or inorganic compounds of precious metals, of rare-earth metals, of radioactive elements or of isotopes - including sub chapters I, II, III, IV and V	40 - Rubber and articles thereof	56 - Wadding, felt and nonwovens; special yarns; twine, cordage, ropes and cables and articles thereof
29 - Organic chemicals - including sub chapters I, II, III, IV, V, VI, VII, VIII, IX, X, XII and X111	46 - Manufactures of straw, of esparto or of other plaiting materials; basket ware and wickerwork	

Appendix D Issues raised in stakeholder comments

This section summarises key stakeholder comments raised in consultation on the draft report, and the department's responses. Additional information on other issues commonly raised by stakeholders, which may be outside the scope of this technical report, is available on the department's website.

Issue 1: The seasonal window allows importation of goods without any BMSB treatments at certain times of year.

The draft risk analysis identified that at particular times of the year, BMSB has a very low likelihood of importation on goods from the northern hemisphere, based both on information about its biology, and previous interception records. The draft report proposed that during this time period, there is no justification in requiring additional measures such as offshore treatment for BMSB. Since the publication of the draft report, all further information which has been published, and interceptions which have been recorded, continue to support the conclusions of the draft report. Therefore, in this final report the department continues to consider that during the months of June to August the ALOP for BMSB is achieved without application of measures beyond those typically used for cargo.

Although there have not been any interceptions of BMSB recorded from the southern hemisphere, the months of January and February have been identified as ones during which the likelihood of importation of BMSB is extremely low for the reasons outlined in chapter 4, and therefore during these two months it is not expected that extra measures for BMSB will be required for at-risk cargo from countries in the southern hemisphere.

However, the department is continuing to monitor the global BMSB situation and trade pathways, and will alter conditions as necessary to ensure that the ALOP for BMSB is achieved. When BMSB is known or suspected to significantly change population levels in any country, or show previously unreported behaviour, the evidence will be reviewed and appropriate new measures will be applied, including potentially changing the seasonal window and the countries on the BMSB country list.

Similarly, the department monitors the pest free status of all imported goods from all countries at all times of the year. Any interceptions of BMSB on pathways not considered at-risk, including types of goods, country of origin or time of year, will trigger a review of the department's BMSB risk mitigation measures, and appropriate new measures will be applied, including potentially changing the seasonal window and the countries on the BMSB country list.

Issue 2: The assessed likelihood of BMSB establishment as Very Low for winter months in Australia.

The draft risk analysis considered the period during which BMSB would infest goods at the loading as being 1 September to 30 April in the northern hemisphere, which was also the time period for the department's offshore treatment requirements at that time. As the main countries presenting risk were in North America and Europe, and the cargo mainly affected was sea cargo, the use of loading date provided coverage into the month of May in Australia. However, as the number of countries with BMSB continues to grow, the final report now considers the start of the potential contamination season to be aligned with the date of loading, and the end of the season to be based on the date of arrival of goods in Australia. The risk period is still considered to begin on 1 September as the date of loading, but is now considered to end on 31 May for goods arriving in Australia; this better reflects both the risk period of BMSB importation and establishment. BMSB arriving as overwintering aggregations in goods from the northern hemisphere in the period of June to August are expected to be near the end of their overwintering period, and require immediate access to suitable food and climatic conditions in order to complete their lifecycle. The day length, temperature and host plant status in temperate Australia are all likely to be unsuitable for successful BMSB establishment at these times of year.

Issue 3: Data to support the proposed fumigation rates rely on personal communications or unpublished materials.

The department has worked with exporting countries and New Zealand to ensure that treatments for BMSB are consistent, effective, but not excessive. Data have been provided to the department to support the current treatment rates, but these data are not available for public release. The department and New Zealand MPI have agreed on the current treatment rates based on both that data and previous experience. In the 2018–19 season, the department required offshore and onshore treatment of at-risk goods for BMSB using approved heat (36,822 consignments treated), sulfuryl fluoride (33,551 consignments treated) and methyl bromide (10,367 consignments treated). During the 2018–19 season, there were a total of 284 interceptions of BMSB; of these, 224 interceptions consisted of only dead BMSB, totalling 1550 dead individuals. There is no evidence that BMSB have survived in goods that were correctly treated with the recommended treatments.

Appendix E Timeline of measures applied to manage BMSB risk

Season	Measures	Goods and Countries applied to
2014–15 (Emergency measures beginning in December 2014)	Methyl Bromide – 32g/m^3 for 24 hours at 21°C and above. Sulfuryl fluoride – 32 g/m^3 for a period of 24 hours at 21 °C and above; or 40 g/m^3 for a period of 24 hours at 16 °C and above; followed by a verification inspection Heat – 60 °C for 20 minutes in the coldest part of the goods. Heightened surveillance	Offshore and onshore treatments required for selected types of break bulk cargo from the USA. During the season, types of cargo extended.
2015–16	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. 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. Heat –50 °C or greater for at least 20 minutes in the coldest location in the goods. Heightened surveillance	Offshore and onshore treatments required for selected types of break bulk and containerised sea cargo shipped from the United States.
2016–17	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. 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	Offshore and onshore treatments required for selected types of break bulk and containerised sea cargo shipped from the United States.

	reading of 50% or more of the initial concentration and conducted at a temperature of 10 °C or higher. Heat –50 °C or greater for at least 20 minutes in the coldest location in the goods. Heightened surveillance	
2017–18	Methyl Bromide – A dose of 16g/m^3 or above, at 15 °C or above, for 12 hours or longer, with an end point reading of 50% or more of the initial concentration Sulfuryl fluoride – Treatment providers not using an approved third party program* • a dose of 24 g/m^3 or above, at 10 °C or above, for 12 hours or longer, with a minimum end point concentration of 12 g/m^3, or • a dose of 16 g/m^3 or above, at 10 °C or above, for 24 hours or longer, with a minimum end point concentration of 8 g/m^3. Treatment providers using an approved third party program* • Achieve a CT of 200g-h/m^3 or more, while conducting the treatment at 10°C or above, for 12 hours or longer, with a minimum end point concentration of 12 g/m^3, or • Achieve a CT of 200g-h/m^3 or more, while conducting the treatment at 10°C or above, for 24 hours or longer, with a minimum end point concentration of 8 g/m^3. *The approved third party programs are: • Douglas Products Fumiguide • Ensystex II, Inc Fumicalc. Heat – At 50 °C or higher for at least 20 minutes. The minimum temperature of the coldest part of the treated good should reach at least 50 °C for at least 20 minutes. Heightened surveillance including during season beginning heightened vessel surveillance for on all roll-on/roll-off (ro-ro) and general cargo vessels through	Offshore and onshore treatments required for selected types of break bulk and containerised sea cargo shipped from the United States and Italy. During the season, measures extended to cover all goods shipped from Italy

	additional pre-arrival reporting with a BMSB questionnaire and daily checks conducted by vessel masters.	
2018–19	Methyl Bromide – A dose of 16g/m^3 or above, at 15 °C or above, for 12 hours or longer, with an end point reading of 50% or more of the initial concentration Sulfuryl fluoride – Treatment providers not using an approved third party program* • a dose of 24 g/m^3 or above, at 10 °C or above, for 12 hours or longer, with a minimum end point concentration of 12 g/m^3, or • a dose of 16 g/m^3 or above, at 10 °C or above, for 24 hours or longer, with a minimum end point concentration of 8 g/m^3. Treatment providers using an approved third party program* • Achieve a CT of 200g-h/m^3 or more, while conducting the treatment at 10°C or above, for 12 hours or longer, with a minimum end point concentration of 12 g/m^3, or • Achieve a CT of 200g-h/m^3 or more, while conducting the treatment at 10°C or above, for 24 hours or longer, with a minimum end point concentration of 8 g/m^3. *The approved third party programs are: • Douglas Products Fumiguide • Ensystex II, Inc Fumicalc. Heat – At 50 °C or higher for at least 20 minutes. The minimum temperature of the coldest part of the treated good should reach at least 50 °C for at least 20 minutes. Heightened vessel surveillance on all roll-on/roll-off (ro-ro) and general cargo vessels through additional pre-arrival reporting with a BMSB questionnaire and daily checks conducted by vessel masters.	Offshore and onshore treatments required for a wide range of break bulk and containerised sea cargo shipped from France, Georgia, Germany, Greece, Hungary, Italy, Romania, Russia and the United States. Heightened vessel surveillance for all ships carrying cargo from all risk countries. Offshore Treatment provider's scheme required for goods treated offshore.

Glossary

Term or abbreviation	Definition
Appropriate level of protection (ALOP)	The level of protection deemed appropriate by the Member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory (WTO 1995).
Appropriate level of protection (ALOP) for Australia	The *Biosecurity Act 2015* defines the appropriate level of protection (or ALOP) for Australia as a high level of sanitary and phytosanitary protection aimed at reducing biosecurity risks to very low, but not to zero.
Area	An officially defined country, part of a country or all or parts of several countries (FAO 2015).
Australian territory	Australian territory as referenced in the *Biosecurity Act 2015* refers to Australia, Christmas Island and Cocos (Keeling) Islands.
Biosecurity	The prevention of the entry, establishment or spread of unwanted pests and infectious disease agents to protect human, animal or plant health or life, and the environment.
Biosecurity measures	The *Biosecurity Act 2015* defines biosecurity measures as measures to manage any of the following: biosecurity risk, the risk of contagion of a listed human disease, the risk of listed human diseases entering, emerging, establishing themselves or spreading in Australian territory, and biosecurity emergencies and human biosecurity emergencies.
Biosecurity risk	The *Biosecurity Act 2015* refers to biosecurity risk as the likelihood of a disease or pest entering, establishing or spreading in Australian territory, and the potential for the disease or pest causing harm to human, animal or plant health, the environment, economic or community activities.
Biosecurity risk analysis (BIRA)	The *Biosecurity Act 2015* defines a BIRA as an evaluation of the level of biosecurity risk associated with particular goods, or a particular class of goods, that may be imported, or proposed to be imported, into Australian territory, including, if necessary, the identification of conditions that must be met to manage the level of biosecurity risk associated with the goods, or the class of goods, to a level that achieves the ALOP for Australia. The risk analysis process is regulated under legislation.
Black light trap	A trap for nocturnal flying insects. A black light trap emits ultra violet light, which is not visible to humans but is visible and attractive to some species of insect. Insects attracted to this ultra violet light source are captured using various methods depending on the target species and specific goals of the study.
BMSB	The insect *Halyomorpha halys*, brown marmorated stink bug.
Break bulk cargo	Non-containerised cargo that must be loaded individually or cannot fit into a container. Typical break bulk cargo includes machinery, vehicles and timber.
Control (of a pest)	Suppression, containment or eradication of a pest population (FAO 2015).
Degree Days	A way of measuring insect growth or development in response to daily temperatures. Use of this method requires identifying the 'threshold temperature' – the minimum temperature at which development occurs for an insect species. One degree day results when the average temperature for a day is one degree over the threshold temperature. The simplest method used to estimate the number of degree-days for one day is called the averaging method: [(day maximum temp. + day minimum temp.)/2]- threshold temperature = degree days
Diapause	Period of suspended development/growth occurring in some insects, in which metabolism is decreased.
The department	The Australian Government Department of Agriculture.
Entry (of a pest)	Movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled (FAO 2015).

Term or abbreviation	Definition
Establishment (of a pest)	Perpetuation, for the foreseeable future, of a pest within an area after entry (FAO 2015).
Flight mill	A flight mill is a device that enables researchers to measure the speed and distance of flight of an insect. Insects are attached to a rotating arm on the mill and are allowed to fly. As the arm rotates the number of rotations and the amount of time to complete rotations are recorded, which allow the distance and speed of flight to be calculated.
Fumigation	A treatment for pest control that completely fills an area with gaseous pesticides to suffocate or poison the pests within.
Goods	The *Biosecurity Act 2015* defines goods as an animal, a plant (whether moveable or not), a sample or specimen of a disease agent, a pest, mail or any other article, substance or thing (including, but not limited to, any kind of moveable property).
Host	An organism that harbours a parasite, mutual partner, or commensal partner, typically providing nourishment and shelter.
Host range	Species capable, under natural conditions, of sustaining a specific pest or other organism (FAO 2015).
Incident	Interceptions of BMSB that are considered to be part of the same infestation. For example, an incident can involve as few as one BMSB found in one item, or hundreds of BMSB found in multiple pieces of machinery sent from the same supplier in the same shipment. Each of these two examples would be considered as one incident.
Infestation (of a commodity)	Presence in a commodity of a living pest of the plant or plant product concerned. Infestation includes infection (FAO 2015).
Inspection	Official visual examination of plants, plant products or other regulated articles to determine if pests are present or to determine compliance with phytosanitary regulations (FAO 2015).
Interception (of a pest)	The detection of a pest during inspection or testing of an imported consignment (FAO 2015).
International Plant Protection Convention (IPPC)	The International Plant Protection Convention provides an international framework for plant protection that includes developing International Standards for Phytosanitary Measures (ISPMs) for safeguarding plant resources.
International Standard for Phytosanitary Measures (ISPM)	An international standard adopted by the Conference of the Food and Agriculture Organization, the Interim Commission on Phytosanitary Measures or the Commission on Phytosanitary Measures, established under the IPPC (FAO 2015).
Introduction (of a pest)	The entry of a pest resulting in its establishment (FAO 2015).
Non-regulated risk analysis	Refers to the process for conducting a risk analysis that is not regulated under legislation (Biosecurity import risk analysis guidelines 2016).
Nymph	The immature form of some insect species that undergoes incomplete metamorphosis. It is not to be confused with larva, as its overall form is already that of the adult.
Pathogen	A biological agent that can cause disease to its host.
Pathway	Any means that allows the entry or spread of a pest (FAO 2015).
Pest	Any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products (FAO 2015).
Pest categorisation	The process for determining whether a pest has or has not the characteristics of a quarantine pest or those of a regulated non-quarantine pest (FAO 2015).
Pest risk analysis (PRA)	The process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it (FAO 2015).

Term or abbreviation	Definition
Pest risk assessment (for quarantine pests)	Evaluation of the probability of the introduction and spread of a pest and of the magnitude of the associated potential economic consequences (FAO 2015).
Pest risk assessment (for regulated non-quarantine pests)	Evaluation of the probability that a pest in plants for planting affects the intended use of those plants with an economically unacceptable impact (FAO 2015).
Pest risk management (for quarantine pests)	Evaluation and selection of options to reduce the risk of introduction and spread of a pest (FAO 2015).
Pest risk management (for regulated non-quarantine pests)	Evaluation and selection of options to reduce the risk that a pest in plants for planting causes an economically unacceptable impact on the intended use of those plants (FAO 2015).
Pest status (in an area)	Presence or absence, at the present time, of a pest in an area, including where appropriate its distribution, as officially determined using expert judgement on the basis of current and historical pest records and other information (FAO 2015).
Phytosanitary measure	Any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests (FAO 2015). The term 'risk management measure' has been used in the risk analysis as this term is used in the *Biosecurity Act 2015*.
Phytosanitary procedure	Any official method for implementing phytosanitary measures including the performance of inspections, tests, surveillance or treatments in connection with regulated pests (FAO 2015).
Phytosanitary regulation	Official rule to prevent the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests, including establishment of procedures for phytosanitary certification (FAO 2015).
Polyphagous	Feeding on a relatively large number of hosts from different plant family and/or genera.
PRA area	Area in relation to which a pest risk analysis is conducted (FAO 2015).
Quarantine	Official confinement of regulated articles for observation and research or for further inspection, testing or treatment (FAO 2015).
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 (FAO 2015).
Regulated article	Any plant, plant product, storage place, packaging, conveyance, container, soil and any other organism, object or material capable of harbouring or spreading pests, deemed to require phytosanitary measures, particularly where international transportation is involved (FAO 2015).
Regulated non-quarantine pest	A non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party (FAO 2015).
Regulated pest	A quarantine pest or a regulated non-quarantine pest (FAO 2015).
Restricted risk	Risk estimate with phytosanitary measure(s) applied.
Risk analysis	Refers to the technical or scientific process for assessing biosecurity risk and the development of risk management measures (Department of Agriculture and Water Resources 2016).
Spread (of a pest)	Expansion of the geographical distribution of a pest within an area (FAO 2015).
SPS Agreement	WTO Agreement on the Application of Sanitary and Phytosanitary Measures.
Stakeholders	Government agencies, individuals, community or industry groups or organizations, whether in Australia or overseas, including the proponent/applicant for a specific proposal, who have an interest in the policy issues.

Term or abbreviation	Definition
Surveillance	An official process which collects and records data on pest occurrence or absence by surveying, monitoring or other procedures (FAO 2015).
Tariff code	A standardized number for a particular product involved in global commerce to ensure uniformity of product classifications worldwide.
Treatment	Official procedure for the killing, inactivation or removal of pests, or for rendering pests infertile or for devitalisation (FAO 2015).
Unrestricted risk	Unrestricted risk estimates apply in the absence of risk mitigation measures.
Vector	An organism that does not cause disease itself, but which causes infection by conveying pathogens from one host to another.
Viable	Alive, able to germinate or capable of growth.

References

Abram, P, Hueppelsheuser, T, Acheampong, S, Clarke, P, Douglas, H & D. Gariepy, T 2017, 'Evidence of established brown marmorated stink bug populations in British Columbia, Canada', *Journal of the Entomological Society of British Columbia*, vol. 118, pp. 83-6.

Abram, P, Talamas, E, Acheampong, S, Mason, P & D. Gariepy, T 2019, 'First detection of the samurai wasp, *Trissolcus japonicus* (Ashmead) (Hymenoptera, Scelionidae), in Canada', *Journal of Hymenoptera Research*, vol. 68, pp. 29-36.

Acebes-Doria, AL, Leskey, TC & Bergh, JC 2016, 'Host plant effects on *Halyomorpha halys* (Hemiptera: Pentatomidae) nymphal development and survivorship', *Environmental Entomology*, vol. 45, no. 3, pp. 663-70.

Acebes-Doria, AL, Morrison, WR, 3rd, Short, BD, Rice, KB, Bush, HG, Kuhar, TP, Duthie, C & Leskey, TC 2018, 'Monitoring and biosurveillance tools for the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae)' *Insects*, vol. 9, no. 3, available at DOI 10.3390/insects9030082.

Aigner, JD, Jnr & Kuhar, TP 2014, 'Using citizen scientists to evaluate light traps for catching brown marmorated stink bugs in homes in Virginia' *Journal of Extension*, vol. 52, no. 4, pp. 4RIB5, available at www.joe.org/joe/2014august/rb5.php.

Aigner, JD & Kuhar, TP 2016, 'Lethal high temperature extremes of the brown marmorated stink bug (Hemiptera: Pentatomidae) and efficacy of commercial heat treatments for control in export shipping cargo', *Journal of Agricultural and Urban Entomology*, vol. 32, pp. 1-6.

Aigner, JD, Walgenbach, JF & Kuhar, TP 2015, 'Toxicities of neonicotinoid insecticides for systemic control of brown marmorated stink bug (Hemiptera: Pentatomidae) in fruiting vegetables', *Journal of Agricultural and Urban Entomology*, vol. 31, no. 1, pp. 70-80.

Andreadis, SS, Navrozidis, EI, Farmakis, A & Pisalidis, A 2018, 'First evidence of *Halyomorpha halys* (Hemiptera: Pentatomidae) infesting kiwi fruit (*Actinidia chinensis*) in Greece', *Journal of Entomological Science*, vol. 53, no. 3, pp. 402-5.

AQIS 1998, *Final import risk analysis of the importation of fruit of Fuji apple (Malus pumila Miller var. domestica Schneider) from Aomori prefecture in Japan*, Australian Quarantine and Inspection Service, Canberra, available at www.agriculture.gov.au/biosecurity/risk-analysis/plant/fujiapple-japan.

Baek, S, Hwang, A, Kim, H, Lee, H & Lee, J 2017, 'Temperature-dependent development and oviposition models of *Halyomorpha halys* (Hemiptera: Pentatomidae)', *Journal of Asia-Pacific Entomology*, available at DOI 10.1016/j.aspen.2017.02.009 [epub ahead of print], accessed 24 April 2017.

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 Entomology*, vol. 44, pp. 1011-21.

Bariselli, M, Bugiani, R & Maistrello, L 2016, 'Distribution and damage caused by *Halyomorpha halys* in Italy', *EPPO Bulletin*, vol. 46, no. 2, pp. 332-4.

Basnet, S, Kuhar, TP, Laub, CA & Pfeiffer, DG 2015, 'Seasonality and distribution pattern of brown marmorated stink bug (Hemiptera: Pentatomidae) in Virginia vineyards', *Journal of Economic Entomology*, vol. 108, pp. 1902-9.

Bayliss, KL, Saqib, M, Dell, B, Jones, MGK & Hardy, GE St J 2005, 'First record of '*Candidatus* Phytoplasma australiense' in *Paulownia* trees', *Australasian Plant Pathology*, vol. 34, pp. 123-4.

Beers, EH, Marshall, A, Hepler, J & Milnes, J 2019, 'Prospects for integrated pest management of brown marmorated stink bug in Washington tree fruits', *Outlooks on Pest Management*, vol. 30, pp. 25-32.

Bergh, C, Acebes-Doria, A, Leskey, T, Morrison, R, Short, B, Krawczyk, G, Walgenbach, J, Agnello, A, Jentsch, P, Hamilton, G, Nielsen, A, Blaauw, B, Walton, V, Wiman, N, Hewstrom, C, Shearer, P & Beers, B 2016, 'Integrated pest management for brown marmorated stink bug in orchard crops', available at www.stopbmsb.org/stopBMSB/assets/File/BMSB-in-Orchard-Crops.pdf (pdf 1.16 mb).

Bergh, JC & Leskey, TC 2014, 'Spring emergence patterns of overwintering brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), from manufactured shelters', *Working Group "Integrated Protection of Fruit Crops" Book of Abstracts of the Joint Meeting of the Sub-Groups "Pome fruit arthropods" and "Stone fruits" Vienna (Austria), 6-9 October 2014*, pp. 20-1.

Bergh, JC, Morrison, WR, III, Joseph, SV & Leskey, TC 2017, 'Characterizing spring emergence of adult *Halyomorpha halys* using experimental overwintering shelters and commercial pheromone traps', *Entomologia Experimentalis et Applicata*, vol. 162, no. 3, pp. 336-45.

Bergh, JC & Quinn, NF 2018, 'Can the dispersal behavior of *Halyomorpha halys* (Hemiptera: Pentatomidae) inform the use of insecticide-treated netting to mitigate homeowner issues from its fall invasion?', *Environmental Entomology*, vol. 47, no. 6, pp. 1501-8.

Bergmann, E, Bernhard, KM, Bernon, G, Bickerton, M, Gill, S, Gonzales, C, Hamilton, GC, Hedstrom, C, Kamminga, K & Koplinka-Loehr, C 2015, *Host plants of the brown marmorated stink bug in the US*, www.stopbmsb.org/where-is-bmsb/host-plants/.

Bergmann, EJ & Raupp, MJ 2014, 'Efficacies of common ready to use insecticides against *Halyomorpha halys* (Hemiptera: Pentatomidae)', *Florida Entomologist*, vol. 97, pp. 791-800.

Bergmann, EJ, Venugopal, PD, Martinson, HM, Raupp, MJ & Shrewsbury, PM 2016, 'Host plant use by the invasive *Halyomorpha halys* (Stål) on woody ornamental trees and shrubs' *PLoS ONE*, vol. 11, no. 2, pp. e0149975, available at DOI 10.1371/journal.pone.0149975.

Biosecurity Australia 2009, *Final import risk analysis report for fresh unshu mandarin fruit from Shizuoka prefecture in Japan*, Department of Agriculture, Fisheries and Forestry, Canberra, available at http://www.agriculture.gov.au/biosecurity/risk-analysis/plant/unshu-mandarin-from-japan (pdf 2 mb).

-- -- 2010, *Final import risk analysis report for fresh apple fruit from the People's Republic of China*, Biosecurity Australia, Department of Agriculture, Fisheries and Forestry, Canberra, available at http://www.agriculture.gov.au/biosecurity/risk-analysis/plant/apples-china (pdf 2.9 mb).

-- -- 2011a, *Final import risk analysis report for table grapes from the People's Republic of China*, Department of Agriculture, Fisheries and Forestry, Canberra, available at http://www.agriculture.gov.au/biosecurity/risk-analysis/plant/table-grapes-china (pdf 38 kb).

-- -- 2011b, *Final non-regulated risk analysis report for table grapes from the Republic of Korea*, Department of Agriculture, Fisheries and Forestry, Canberra, available at http://www.agriculture.gov.au/biosecurity/risk-analysis/plant/grapes-korea/baa2011-15-final-table-grapes-korea (pdf 2.55 mb).

Blaauw, BR, Polk, D & Nielsen, AL 2015, 'IPM-CPR for peaches: incorporating behaviorally-based methods to manage *Halyomorpha halys* and key pests in peach', *Pest Management Science*, vol. 71, pp. 1513-22.

BOM 2017, *Maps of average conditions*, Bureau of Meteorology, Australian Government, http://www.bom.gov.au/climate/averages/maps.shtml.

Bon, MC, Hoelmer, KA, Talamas, EJ, Buffington, ML, Guermache, F & Weber, DC 2017, 'Poster 3: Genetic diversity and origins of *Halyomorpha halys* in the U.S. and of its potential biocontrol agent unexpectedly recovered from the wild in the United States', *Proceedings of the 5th International Symposium on Biological Control of Arthropods*, CAB International, Wallingford, pp. 240-1.

Bosco, L, Moraglio, ST & Tavella, L 2018, '*Halyomorpha halys,* a serious threat for hazelnut in newly invaded areas', *Journal of Pest Science*, vol. 91, no. 2, pp. 661-70.

Cambridge, J, Payenski, A & Hamilton, GC 2015, 'The distribution of overwintering brown marmorated stink bugs (Hemiptera: Pentatomidae) in college dormitories', *Florida Entomologist*, vol. 98, no. 4, pp. 1257-9.

Cesari, M, Maistrello, L, Ganzerli, F, Dioli, P, Rebecchi, L & Guidetti, R 2014, 'A pest alien invasion in progress: potential pathways of origin of the brown marmorated stink bug *Halyomorpha halys* populations in Italy', *Journal of Pest Science*, vol. 88, pp. 1-7.

Cesari, M, Maistrello, L, Piemontese, L, Bonini, R, Dioli, P, Lee, W, Park, CG, Partsinevelos, GK, Rebecchi, L & Guidetti, R 2018, 'Genetic diversity of the brown marmorated stink bug *Halyomorpha halys* in the invaded territories of Europe and its patterns of diffusion in Italy', *Biological Invasions*, vol. 20, no. 4, pp. 1073-92.

Chambers, BD 2018, 'The influence of thermal and physical characteristics of buildings on overwintering brown marmorated stink bugs (*Halyomorpha halys*)', Doctor of Philosophy Dissertation, Virginia Polytechnic Institute and State University.

Chambers, BD, Kuhar, TP, Reichard, G, Leskey, TC & Pearce, AR 2019, 'Size restrictions on the passage of overwintering *Halyomorpha halys* (Hemiptera: Pentatomidae) through openings', *Journal of Economic Entomology*, vol. 112, no. 3, pp. 1343-7.

Choi, DS, Kim, KC & Lim, KC 2000, 'The status of spot damage and fruit piercing pests on Yuzu (*Citrus junos*) fruit' (in Korean), *Korean Journal of Applied Entomology*, vol. 39, no. 4, pp. 259-66.
Chouinard, G, Larose, M, Légaré, JP & Bourgeois, GB, M. 2018, 'Interceptions and captures of *Halyomorpha halys* (Hemiptera: Pentatomidae) in Quebec from 2008 to 2018', *Phytoprotection*, vol. 98, no. 1, pp. 46-50.

Cira, TM, Burkness, EC, Koch, RL & Hutchison, WD 2017, '*Halyomorpha halys* mortality and sublethal feeding effects following insecticide exposure' *Journal of Pest Science*, vol. 90, available at https://link.springer.com/article/10.1007/s10340-017-0871-y.

Cira, TM, Koch, RL, Burkness, EC, Hutchison, WD & Venette, RC 2018, 'Effects of diapause on *Halyomorpha halys* (Hemiptera: Pentatomidae) cold tolerance', *Environmental Entomology*, vol. 47, no. 4, pp. 997-1004.

Cira, TM, Venette, RC, Aigner, J, Kuhar, T, Mullins, DE, Gabbert, SE & Hutchison, WD 2016, 'Cold tolerance of *Halyomorpha halys* (Hemiptera: Pentatomidae) across geographic and temporal scales', *Environmental Entomology*, vol. 45, no. 2, pp. 484-91.

Cissel, WJ, Mason, CE, Whalen, J, Hough-Goldstein, J & Hooks, CR 2015, 'Effects of brown marmorated stink bug (Hemiptera: Pentatomidae) feeding injury on sweet corn yield and quality', *Journal of Economic Entomology*, vol. 108, pp. 1065-71.

Claerebout, S, Haye, T, Ólafsson, E, Pannier, É & Bultot, J 2019, 'Première occurrence de *Halyomorpha halys* (Stål, 1855) (Hemiptera: Heteroptera: Pentatomidae) pour la Belgique et actualisation de sa distribution en Europe' (First occurrence of *Halyomorpha halys* (Stål, 1855) (Hemiptera: Heteroptera: Pentatomidae) for Belgium and update of its distribution in Europe), *Bulletin de la Société royale belge d'Entomologie/Bulletin van de Koninklijke Belgische vereniging voor entomologie*, vol. 154, pp. 205-27.

Clarke, AR 1990, 'The control of *Nezara viridula* L. with introduced egg parasitoids in Australia. A review of a 'landmark' example of classical biological control', *Australian Journal of Agricultural Research*, vol. 41, no. 6, pp. 1127-46.

Connexion Journalist 2018, 'France infested with Asian stink bug insects', *The Connexion*, 18 October, available at https://www.connexionfrance.com/French-news/France-infestation-of-Asian-stink-bug-insects-getting-worse-this-autumn, accessed 25 July 2019.

DAFF 2004, *Persimmon fruit (Diospyros kaki L.) from Japan, Korea and Israel: final import policy*, Department of Agriculture, Fisheries and Forestry, Canberra, available at http://www.agriculture.gov.au/biosecurity/risk-analysis/plant/persimmons-japankoreaisreal.

Day, ER, McCoy, T, Miller, D, Kuhar, TP & Pfeiffer, DG 2011, 'Brown marmorated stink bug', Virginia Cooperative Extension, VirginiaTech and Virginia State University, available at www.louisacvmg.org/images/StinkBugs.pdf (pdf 2065 kb).

Department of Agriculture 2014, *Draft report for the non-regulated analysis of existing policy for fresh table grapes from Japan*, Department of Agriculture, Canberra, available at http://www.agriculture.gov.au/ba/reviews/current-plant/table-grapes-japan/ba2014-01-draft-ira-report-table-grapes-from-japan.

Department of Agriculture and Water Resources 2015a, *Guide to the identification of brown marmorated stink bug, Halyomorpha halys, and other similar bugs*, Australian Government Department of Agriculture and Water Resources, Canberra, available at www.agriculture.gov.au/publications.

-- -- 2015b, 'Safeguarding arrangements for the 2015-16 stink bug season: industry guide', Australian Government Department of Agriculture and Water Resources, Canberra, available at www.agriculture.gov.au/import/industry-advice/ian/15/68-2015.

-- -- 2016, *Biosecurity import risk analysis guidelines 2016: Managing biosecurity risks for imports into Australia*, Department of Agriculture and Water Resources, Canberra, Australia, available at http://www.agriculture.gov.au/SiteCollectionDocuments/bira-guidelines-2016.pdf (pdf 872.83 kb).

Eddy, D 2018, 'Brown marmorated stink bug officially deemed pest of California almonds', *Growing Produce*, available at https://www.growingproduce.com/nuts/brown-marmorated-stink-bug-officially-deemed-pest-california-almonds/.

Esenbekova, PA 2017, 'First record of *Halyomorpha halys* (Stal, 1855) (Heteroptera, Pentatomidae) from Kazakhstan' (in Russian), *Euroasian Entomological Journal*, vol. 16, no. 1, pp. 23-4.

FAO 2007, *International Standards for Phytosanitary Measures (ISPM) no. 2: Framework for pest risk analysis*, Food and Agriculture Organization of the United Nations, Rome, available at https://www.ippc.int/en/core-activities/standards-setting/ispms/.

-- -- 2013, *International Standards for Phytosanitary Measures (ISPM) no. 11: Pest risk analysis for quarantine pests*, Food and Agriculture Organization of the United Nations, Rome, available at https://www.ippc.int/en/core-activities/standards-setting/ispms/.

-- -- 2015, *International Standards for Phytosanitary Measures (ISPM) no. 5: Glossary of phytosanitary terms*, Food and Agriculture Organization of the United Nations, Rome, available at https://www.ippc.int/en/core-activities/standards-setting/ispms/.

Faúndez, EI & Rider, DA 2017, 'The brown marmorated stink bug *Halyomorpha halys* (Stål, 1855) (Heteroptera: Pentatomidae) in Chile', *Arquivos Entomolóxicos*, vol. 17, pp. 305-7.

Fengjie, C, Zhifang, Z, Ruiping, L & Xuechun, L 1997, 'Study on control and observation of the bionomics characteristics of *Halyomorpha picus* Fabricias' (in Japanese), *Journal of the Agricultural University of Hebei*, vol. 20, no. 2, pp. 12-7.

Fraser, D, Kumar, S & Aguilar, G 2017, 'Mapping the potential global range of the brown marmorated stink bug, *Halyomorpha halys*, with particular reference to New Zealand' *Climate*, vol. 5, no. 75, available at DOI 10.3390/cli5030075.

Fujiie, A 1985, 'Seasonal lifecycle of *Halyomorpha mista*' (in Japanese), *Bulletin of the Chiba Agricultural Experiment Station*, vol. 26, pp. 87-93.

Fukuoka, T, Yamakage, H & Niiyama, T 2002, 'Damage to vegetables by the brown marmorated stink bug' (in Japanese), *Annual Report of the Society of Plant Protection of North Japan*, vol. 53, pp. 229-31.

Funayama, K 1996, 'Sucking injury on apple fruit by the adult of brown marmorated stink bug *Halyomorpha mista* (Uhler)' (in Japanese), *Annual Report of the Society of Plant Protection of North Japan*, vol. 47, pp. 140-2.

-- -- 2012a, 'Control effect on the brown-marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), by combined spraying of pyrethroid and neonicotinoid insecticides in apple orchards in northern Japan', *Applied Entomology and Zoology*, vol. 47, pp. 75-8.

-- -- 2012b, 'Nutritional states of post-overwintering adults of the brown-marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae)', *Japanese Journal of Applied Entomology and Zoology*, vol. 56, pp. 12-5.

-- -- 2013, 'Effect of climate change on annual fluctuations in the population density of the brown marmorated stink bug (Hemiptera: Pentatomidae) in northern Japan', *Journal of Economic Entomology*, vol. 106, pp. 2141-3.

Gariépy, TD, Bruin, A, Haye, T, Milonas, P & Vétek, G 2015, 'Occurrence and genetic diversity of new populations of *Halyomorpha halys* in Europe', *Journal of Pest Science*, vol. 88, pp. 451-60.
Gariépy, TD, Fraser, H & Scott-Dupree, CD 2014, 'Brown marmorated stink bug (Hemiptera: Pentatomidae) in Canada: recent establishment, occurrence, and pest status in southern Ontario', *The Canadian Entomologist*, vol. 146, pp. 579-82.

Gariépy, TD, Haye, T, Fraser, H & Zhang, J 2013, 'Occurrence, genetic diversity, and potential pathways of entry of *Halyomorpha halys* in newly invaded areas of Canada and Switzerland', *Journal of Pest Science*, vol. 87, pp. 17-28.

Gariépy, TD, Haye, T & Zhang, J 2014, 'A molecular diagnostic tool for the preliminary assessment of host-parasitoid associations in biological control programmes for a new invasive pest', *Molecular Ecology*, vol. 23, pp. 3912-24.

Geoscience Australia 2017, *Geodesy & GPS, astonomical information*, Geoscience Australia, Australian Government, http://www.ga.gov.au/bin/geodesy/run/sunrisenset.

Güncan, A & Gümüs, E 2019, 'Brown marmorated stink bug, *Halyomorpha halys* (Ståhl, 1855) (Hemiptera: Heteroptera, Pentatomidae), a new and important pest in Turkey', *Entomological News*, vol. 128, no. 2, pp. 204-10.

Halbert, S & Hodges, GS 2011, 'The brown marmorated stink bug, *Halyomorpha halys* (Stål)', Department of Agriculture and Consumer Services Pest Alert, Florida, USA, available at www.freshfromflorida.com/content/download/23899/486244/halyomorpha-halys.pdf (pdf 752 kb).

Hamilton, GC 2009, 'Brown marmorated stink bug', *American Entomologist*, vol. 55, no. 1, pp. 19-20.

Hancock, TJ, Lee, DH, Bergh, JC, Morrison, R & Leskey, TC 2015, 'Utilizing citizen science to identify characteristics important to overwintering site selection for brown marmorated stink bug', paper presented at BMSB IPM Working Group Meeting, College Park, Maryland, USA, 9 June 2015.

Haye, T, Abdallah, S, Gariépy, T & Wyniger, D 2014, 'Phenology, life table analysis and temperature requirements of the invasive brown marmorated stink bug, *Halyomorpha halys*, in Europe', *Journal of Pest Science*, vol. 87, pp. 407-18.

Haye, T, Gariépy, T, Hoelmer, K, Rossi, JP, Streito, JC, Tassus, X & Desneux, N 2015, 'Range expansion of the invasive brown marmorated stinkbug, *Halyomorpha halys*: an increasing threat to field, fruit and vegetable crops worldwide', *Journal of Pest Science*, vol. 88, pp. 665-73.

Hedstrom, CS, Shearer, PW, Miller, JC & Walton, VM 2014, 'The effects of kernel feeding by *Halyomorpha halys* (Hemiptera: Pentatomidae) on commercial hazelnuts', *Journal of Economic Entomology*, vol. 107, pp. 1858-65.

Herrick, C 2016, 'Brown marmorated stink bug causes $37 million in losses to mid-Atlantic apple growers', *American/Western Fruit Grower*, Meister Media Worldwide, available at www.growingproduce.com/fruits/apples-pears/brown-marmorated-stink-bug-causes-37-million-in-losses-to-mid-atlantic-apple-growers/.

Hoebeke, ER & Carter, ME 2003, '*Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae): a polyphagous plant pest from Asia newly detected in North America', *Proceedings of the Entomological Society of Washington*, vol. 105, no. 1, pp. 225-37.

Hoffmann, WE 1931, ‘A pentatomid pest of growing beans in south China’, *Peking Natural History Bulletin*, vol. 5, no. 2, pp. 25-6.

Ingels, C 2014, ‘Update on brown marmorated stink bug characteristics, spread, and management’, *Tree and Vine Newsletter*, University of California, available at http://cesacramento.ucanr.edu.

Ingels, CA & Daane, KM 2018, ‘Phenology of brown marmorated stink bug in a California urban landscape’, *Journal of Economic Entomology*, vol. 111, no. 2, pp. 780-6.

Inkley, DB 2012, ‘Characteristics of home invasion by the brown marmorated stink bug (Hemiptera: Pentatomidae)’, *Journal of Entomological Science*, vol. 47, no. 2, pp. 125-30.

Joseph, SV, Stallings, JW, Leskey, TC, Krawczyk, G, Polk, D, Butler, B & Bergh, JC 2014, ‘Spatial distribution of brown marmorated stink bug (Hemiptera: Pentatomidae) injury at harvest in mid-Atlantic apple orchards’, *Journal of Economic Entomology*, vol. 107, pp. 1839-48.

Kamminga, K, Herbert, DA, Toews, MD, Malone, S & Kuhar, T 2014, ‘*Halyomorpha halys* (Hemiptera: Pentatomidae) feeding injury on cotton bolls’, *The Journal of Cotton Science*, vol. 18, pp. 68-74.

Katayama, E, Fukuda, T & Nozawa, H 1993, ‘Light trap monitoring of the fruit tree stink bugs and their ovarian development’ (in Japanese), *Tochigi Agricultural Research Report*, vol. 40, pp. 59-74.

Kawada, H & Kitamura, C 1983, ‘The reproductive behaviour of the brown marmorated stink bug, *Halyomorpha mista* Uhler (Heteroptera: Pentatomidae) I. Observation of mating behaviour and multiple copulation’, *Applied Entomology & Zoology*, vol. 18, no. 2, pp. 234-42.

Kenyon, LJ, Meulia, T & Sabree, ZL 2015, ‘Habitat visualization and genomic analysis of "*Candidatus Pantoea carbekii*," the primary symbiont of the brown marmorated stink bug’, *Genome Biology and Evolution*, vol. 7, pp. 620-35.

Kim, JH & Park, CG 2015, ‘Effects of persimmon tannin on survival and reproduction of *Halyomorpha halys* (Hemiptera: Pentatomidae)’, *Entomological Research*, vol. 45, pp. 71-6.

Kim, SU, Jang, YS & Kim, DS 2015, ‘Feeding effects of *Halyomorpha halys* (Hemiptera: Pentatomidae) on fruit drop and decay rate in mandarin citrus orchards’, *Korean Journal of Applied Entomology*, vol. 54, no. 2, pp. 121-5.

Kobayashi, T & Kimura, S 1969, ‘Studies on the biology and control of house-entering stink bugs. I. The actual state of the hibernation of stink bugs in houses’ (in Japanese), *Bulletin of the Tohoku Agricultural Experiment Station*, vol. 37, pp. 123-38.

Kriticos, DJ, Kean, JM, Phillips, CB, Senay, SD, Acosta, H & Haye, T 2017, ‘The potential global distribution of the brown marmorated stink bug, *Halyomorpha halys*, a critical threat to plant biosecurity’, *Journal of Pest Science*, available at DOI 10.1007/s10340-017-0869-5 [epub ahead of print], accessed 22 May 2017.

Kuhar, TP & Kamminga, K 2017, ‘Review of the chemical control research on *Halyomorpha halys* in the USA’, *Journal of Pest Science*, available at DOI 10.1007/s10340-017-0859-7 [epub ahead of print], accessed 26 April 2017.

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*, vol. May 2012, available at DOI 10.1094/PHP-2012-0523-01-BR.

Lara, J, Pickett, C, Ingels, C, Haviland, DR, Grafton-Cardwell, E, Doll, D, Bethke, J, Faber, J, Dara, SK & Hoddle, M 2016, 'Biological control program is being developed for brown marmorated stink bug', *California Agriculture*, vol. 70, no. 1, pp. 15-23.

Lara, JR, Kamiyama, M, Hernandez, G, Lewis, M & Hoddle, MS 2018, 'Laboratory assessment of feeding injury and preference of brown marmorated stink bug, *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), for *Actinidia chinensis* var. *deliciosa* 'Hayward' (Zespri® Green) and *Actinidia chinensis* var. *chinensis* 'Zesy002' (Zespri® SunGold)' *New Zealand Entomologist*, vol. 41, available at DOI 10.1080/00779962.2018.1438758.

Le, C, Min, D & Xiang'ge, D 2008, 'The occurrence rule of the brown marmorated stink bug *Halyomorpha halys* and its control strategies in the suburb of Beijing' (in Chinese), *Northern Horticulture*, vol. 11, pp. 168-9.

Lee, DH 2015, 'Current status of research progress on the biology and management of *Halyomorpha halys* (Hemiptera: Pentatomidae) as an invasive species', *Applied Entomology and Zoology*, vol. 50, pp. 277-90.

Lee, DH, Cullum, JP, Anderson, JL, Daugherty, JL, Beckett, LM & Leskey, TC 2014, 'Characterization of overwintering sites of the invasive brown marmorated stink bug in natural landscapes using human surveyors and detector canines' *PLoS ONE*, vol. 9, no. 4, pp. e91575, available at DOI 10.1371/journal.pone.0091575.

Lee, DH & Leskey, TC 2015, 'Flight behavior of foraging and overwintering brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae)', *Bulletin of Entomological Research*, vol. 105, pp. 566-73.

Lee, DH, Nielsen, AL & Leskey, TC 2014, 'Dispersal capacity and behavior of nymphal stages of *Halyomorpha halys* (Hemiptera: Pentatomidae) evaluated under laboratory and field conditions', *Journal of Insect Behavior*, vol. 27, pp. 639-51.

Lee, DH, 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*, vol. 42, no. 4, pp. 627-41.

Lee, DH, Wright, SE & Leskey, TC 2013, 'Impact of insecticide residue exposure on the invasive pest, *Halyomorpha halys* (Hemiptera: Pentatomidae): analysis of adult mobility', *Journal of Economic Entomology*, vol. 106, pp. 150-8.

Leskey, TC 2017, 'Monitoring and management tools for the brown marmorated stink bug', paper presented at Heteroptera Workshop, 2017 International Heteroptera Symposium and Workshop, Seaside, California, USA, 18-20 April 2017.

Leskey, TC, Agnello, A, Bergh, JC, Dively, GP, Hamilton, GC, Jentsch, P, Khrimian, A, Krawczyk, G, Kuhar, TP, Lee, DH, Morrison, WR, III, Polk, DF, Rodriguez-Saona, C, Shearer, PW, Short, BD, Shrewsbury, PM, Walgenbach, JF, Weber, DC, Welty, C, Whalen, J, Wiman, N & Zaman, F 2015, 'Attraction of the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) to traps baited with semiochemical stimuli across the United States', *Environmental Entomology*, vol. 44, pp. 746-56.

Leskey, TC, Hamilton, GC, Nielsen, AL, Polk, DF, Rodriguez-Saona, C, Bergh, JC, Herbert, DA, Kuhar, TP, Pfeiffer, DG, Dively, GP, Hooks, CRR, Raupp, MJ, Shrewsbury, PM, Krawczyk, G, Shearer, PW, Whalen, J, Koplinka-Loehr, C, Myers, EW, Inkley, D, Hoelmer, KA, Lee, DH & Wright, SE 2012a, 'Pest status of the brown marmorated stink bug, *Halyomorpha halys* in the USA', *Outlooks on Pest Management*, vol. 23, pp. 218-26.

Leskey, TC, Lee, DH, Short, BD & Wright, SE 2012b, 'Impact of insecticides on the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae): analysis of insecticide lethality', *Journal of Economic Entomology*, vol. 105, pp. 1726-35.

Leskey, TC & Nielsen, AL 2018, 'Impact of the invasive brown marmorated stink bug in North America and Europe: history, biology, ecology, and management', *Annual Review of Entomology*, vol. 63, pp. 599-618.

Leskey, TC, Short, BD, Butler, BR & Wright, SE 2012c, '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*, vol. 2012, pp. 1-14.

Leskey, TC, Short, BD & Lee, DH 2014, 'Efficacy of insecticide residues on adult *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) mortality and injury in apple and peach orchards', *Pest Management Science*, vol. 70, pp. 1097-104.

Li, X, Yin, XY, Ma, L, Liu, YH, Fu, J & Liu, XF 2007, '*Halyomorpha halys* behaviours and their application for control' (in Chinese), *Journal of Northwest A&F University*, vol. 35, no. 10, pp. 139-45.

Lowenstein, DM & Walton, VM 2018, '*Halyomorpha halys* (Hemiptera: Pentatomidae) winter survival, feeding activity, and reproduction rates based on episodic cold shock and winter temperature regimes', *Journal of Economic Entomology*, vol. 111, no. 3, pp. 1210-8.

Mainali, BP, Kim, HJ, Yoon, YN, Oh, IS & Bae, SD 2014, 'Evaluation of apple and orange fruits as food sources for the development of *Halyomorpha halys* (Hemiptera: Pentatomidae)', *Korean Journal of Applied Entomology*, vol. 53, pp. 473-7.

Maistrello, L, Bariselli, M & Mazzoli, GL 2014, 'Citizen science and early detection: the example of first occurrences of the brown marmorated stink bug *Halyomorpha halys* in Italy', paper presented at EFSA/EPPO workshop: data collection and information sharing in plant health, Parma, Italy, 1-3 April 2014.

Maistrello, L, Costi, E, Caruso, S, Vaccari, G, Bortolotti, P, Nannini, R, Casoli, L, Montermini, A, Bariselli, M, Cesari, M & Guidetti, R 2014, 'Update on pest status of brown marmorated stink bug in Italy', paper presented at BMSB IPM Working Group Meeting, AHS AREC, Winchester, Virginia, USA, 4 December 2014.

Martinson, HM, Venugopal, PD, Bergmann, EJ, Shrewsbury, PM & Raupp, MJ 2015, 'Fruit availability influences the seasonal abundance of invasive stink bugs in ornamental tree nurseries', *Journal of Pest Science*, vol. 88, pp. 461-8.

Mathews, CR & Hallack, MH 2012, 'Brown marmorated stink bug host-use in organic vegetables with trap crop', paper presented at BMSB IPM Working Group Meeting, Winchester, Virginia, USA, 27 November 2012.

Medal, J, Smith, T, Fox, A, Santa Cruz, A, Poplin, A & Hodges, A 2012, 'Rearing the brown marmorated stink bug *Halyomorpha halys* (Heteroptera: Pentatomidae)', *Florida Entomologist*, vol. 95, no. 3, pp. 800-2.

Medal, J, Smith, T & Santa Cruz, A 2013, ‘Biology of the brown marmorated stink bug *Halyomorpha halys* (Heteroptera: Pentatomidae) in the laboratory’, *Florida Entomologist*, vol. 96, no. 3, pp. 1209-12.

Mertz, TL, Jacobs, SB, Craig, TJ & Ishmael, FT 2012, ‘The brown marmorated stinkbug as a new aeroallergen’, *Journal of Allergy and Clinical Immunology*, vol. 130, pp. 999-1001.

Mohekar, P, Osborne, J & Tomasino, E 2018, ‘Effects of fining agents, reverse osmosis and wine age on brown marmorated stink bug (*Halyomorpha halys*) taint in wine’ *Beverages*, vol. 4, no. 17, available at DOI 10.3390/beverages4010017.

Moraglio, ST, Bosco, L & Tavella, L 2018, ‘*Halyomorpha halys* invasion: a new issue for hazelnut crop in northwestern Italy and Western Georgia?’, *Acta Horticulturae*, vol. 1226, pp. 379-84.
Moriya, S, Shiga, M & Mabuchi, M 1987, ‘Analysis of light trap records in four major species of fruit-piercing stink bugs, with special reference to body size variation’ (in Japanese), *Bulletin of the Fruit Tree Research Station Series A*, vol. 14, pp. 79-94.

Morrison, WR, III, Acebes-Doria, A, Ogburn, E, Kuhar, TP, Walgenbach, JF, Bergh, JC, Nottingham, L, Dimeglio, A, Hipkins, P & Leskey, TC 2017a, ‘Behavioral response of the brown marmorated stink bug (Hemiptera: Pentatomidae) to semiochemicals deployed inside and outside anthropogenic structures during the overwintering period’, *Journal of Economic Entomology*, available at DOI 10.1093/jee/tox097 [epub ahead of print], accessed 24 April 2017.

Morrison, WR, III, Bryant, AN, Poling, B, Quinn, NF & Leskey, TC 2017b, ‘Predation of *Halyomorpha halys* (Hemiptera: Pentatomidae) from web-building spiders associated with anthropogenic dwellings’, *Journal of Insect Behavior*, vol. 30, no. 1, pp. 70-85.

Morrison, WR, Mathews, CR & Leskey, TC 2016, ‘Frequency, efficiency, and physical characteristics of predation by generalist predators of brown marmorated stink bug (Hemiptera: Pentatomidae) eggs’, *Biological Control*, vol. 97, pp. 120-30.

Morrison, WRI, Blaauw, BR, Nielsen, AL, Talamas, E & Leskey, TC 2018, ‘Predation and parasitism by native and exotic natural enemies of *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) eggs augmented with semiochemicals and differing host stimuli’, *Biological Control*, vol. 121, pp. 140-50.

Mueller, G, Landau Luescher, I & Schmidt, M 2011, ‘New data on the incidence of household arthropod pests and new invasive pests in Zurich (Switzerland)’, *Proceedings of the Seventh International Conference on Urban Pests*, Instituto Biológico, Brazil, pp. 99-104.

Murvanidze, M, Krawczyk, G, Inasaridze, N, Dekanoidze, L, Samsonadze, N, Macharashvili, M, Khutsishvili, S & Shengelaia, S 2018, ‘Preliminary data on the biology of brown marmorated stink bug *Halyomorpha halys* (Hemiptera, Pentatomidae) in Georgia’, *Turkish Journal of Zoology*, vol. 42, pp. 617-24.

Musolin, DL, Konjević, A, Karpun, NN, Protsenko, VY, Ayba, LY & Saulich, AK 2018, ‘Invasive brown marmorated stink bug *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae) in Russia, Abkhazia, and Serbia: history of invasion, range expansion, early stages of establishment, and first records of damage to local crops’, *Arthropod-Plant Interactions*, vol. 12, no. 4, pp. 517-29.

New Zealand Environmental Protection Authority 2018, *APP203336: an application to seek pre-approval to release Trissolcus japonicus (the samurai wasp) as a biocontrol agent for brown marmorated stink bug should it arrive in New Zealand* (pdf 2649 kb).

Nielsen, A 2013, 'BMSB spray schedule table', available at http://plant-pest-advisory.rutgers.edu/bmsb-insecticide-options-revised/bmsb-spray-schedule-table-3/.

Nielsen, AL, Dively, G, Pote, JM, Zinati, G & Mathews, C 2016, 'Identifying a potential trap crop for a novel insect pest, *Halyomorpha halys* (Hemiptera: Pentatomidae), in organic farms', *Environmental Entomology*, vol. 45, no. 2, pp. 472-8.

Nielsen, AL, Fleischer, S & Chen, S 2016, 'Coupling developmental physiology, photoperiod, and temperature to model phenology and dynamics of an invasive Heteropteran, *Halyomorpha halys*' *Frontiers in Physiology*, vol. 7, no. 165, available at DOI 10.3389/fphys.2016.00165.

Nielsen, AL & Hamilton, GC 2009a, 'Life history of the invasive species *Halyomorpha halys* (Hemiptera: Pentatomidae) in northeastern United States', *Annals of the Entomological Society of America*, vol. 102, no. 4, pp. 608-16.

-- -- 2009b, 'Seasonal occurrence and impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) in tree fruit', *Journal of Economic Entomology*, vol. 102, pp. 1133-40.

Nielsen, AL, Hamilton, GC & Matadha, D 2008, 'Developmental rate estimation and life table analysis for *Halyomorpha halys* (Hemiptera: Pentatomidae)', *Environmental Entomology*, vol. 37, no. 2, pp. 348-55.

Nielsen, AL, Holmstrom, K, Hamilton, GC, Cambridge, J & Ingerson-Mahar, J 2013, 'Use of black light traps to monitor the abundance, spread, and flight behavior of *Halyomorpha halys* (Hemiptera: Pentatomidae)', *Journal of Economic Entomology*, vol. 106, pp. 1495-502.

Nielsen, AL, Shearer, PW & Hamilton, GC 2008, 'Toxicity of insecticides to *Halyomorpha halys* (Hemiptera: Pentatomidae) using glass-vial bioassays', *Journal of Economic Entomology*, vol. 101, no. 4, pp. 1439-42.

Niva, CC & Takeda, M 2003, 'Effects of photoperiod, temperature and melatonin on nymphal development, polyphenism and reproduction in *Halyomorpha halys* (Heteroptera: Pentatomidae)', *Zoological Science*, vol. 20, pp. 963-70.

NZ MPI 2014, 'Brown marmorated stink bug', New Zealand Ministry for Primary Industries, available at www.mpi.govt.nz/document-vault/3587 (pdf 428 kb).

Ohira, Y 2003, 'Outbreak of the stink bug attacking fruit trees in 2002' (in Japanese), *Plant Protection*, vol. 57, no. 4, pp. 164-8.

Ormsby, M 2018, *Technical review-proposed treatments for BMSB (Halyomorpha halys (Stål); Pentatomidae)*, New Zealand Ministry of Primary Industries.

Owens, DR, Herbert, DA, Dively, GP, Reisig, DD & Kuhar, TP 2013, 'Does feeding by *Halyomorpha halys* (Hemiptera: Pentatomidae) reduce soybean seed quality and yield?', *Journal of Economic Entomology*, vol. 106, pp. 1317-23.

Peiffer, M & Felton, GW 2014, 'Insights into the saliva of the brown marmorated stink bug *Halyomorpha halys* (Hemiptera: Pentatomidae)' *PLoS ONE*, vol. 9, no. 2, pp. e88483, available at DOI 10.1371/journal.pone.0088483.

Penca, C & Hodges, A 2018, 'First report of brown marmorated stink bug (Hemiptera: Pentatomidae) reproduction and localized establishment in Florida', *Florida Entomologist*, vol. 101, no. 4, pp. 708-11.

Peverieri, GS, Talamas, E, Claude Bon, M, Marianelli, L, Bernardinelli, I, Malossini, G, Benvenuto, L, Roversi, P & Hoelmer, K 2018, 'Two Asian egg parasitoids of *Halyomorpha halys* (Stål) (Hemiptera, Pentatomidae) emerge in northern Italy: *Trissolcus mitsukurii* (Ashmead) and *Trissolcus japonicus* (Ashmead) (Hymenoptera, Scelionidae)', *Journal of Hymenoptera Research*, vol. 67, pp. 37-53.

Pezzini, DT, Nystrom Santacruz, EC & Koch, RL 2018, 'Predation and parasitism of *Halyomorpha halys* (Hemiptera: Pentatomidae) eggs in Minnesota', *Environmental Entomology*, vol. 47, pp. 812-21.

Pizzinat, A, Pansa, MG, Bardella, S, Vittone, G & Tavella, L 2015, 'Indagini sulla nuova cimice esotica *Halyomorpha halys* e valutazione dell'efficacia di metodi per il monitoraggio' (in Italian), *Ricerca applicata in frutticoltura. Sintesi dei risultati 2014.*, vol. 88, pp. 86-93.

Poplin, AV 2013, 'A Florida perspective on host preference, early detection, and identification of the brown marmorated stink bug, *Halyomorpha halys* (Stål)', MSc thesis, University of Florida.
Qin, W 1990, 'Occurrence rule and control techniques of *Halyomorpha picus*' (in Japanese), *Plant Protection*, vol. 16, no. 6, pp. 22-3.

Quarles, W 2014, 'IPM for the brown marmorated stink bug', *The IPM Practitioner*, vol. 34, no. 3-4, pp. 1-8.

Rice, KB, Bergh, CJ, Bergmann, EJ, Biddinger, DJ, Dieckhoff, C, Dively, GP, Fraser, H, Gariépy, T, Hamilton, G, Haye, T, Herbert, A, Hoelmer, K, Hooks, CR, Jones, AC, Krawczyk, G, Kuhar, T, Martinson, H, Mitchell, WC, Nielsen, AL, Pfeiffer, DG, Raupp, MJ, Rodriguez-Saona, C, Shearer, P, Shrewsbury, P, Venugopal, P, Whalen, J, Wiman, NG, Leskey, TC & Tooker, JF 2014, 'Biology, ecology, and management of brown marmorated stink bug (Hemiptera: Pentatomidae)', *Journal of Integrated Pest Management*, vol. 5, pp. 1-13.

Rice, KB, Troyer, RR, Watrous, KM, Tooker, JF & Fleischer, SJ 2017, 'Landscape factors influencing stink bug injury in mid-Atlantic tomato fields', *Journal of Economic Entomology*, available at DOI 10.1093/jee/tow252 [epub ahead of print], accessed 24 April 2017.

Rider, DA 2014, *Halyomorpha halys Stål, 1855*, North Dakota State University, USA, www.ndsu.edu/pubweb/~rider/Pentatomoidea/Species_Cappaeini/Halyomorpha_halys.htm.

Rider, DA, Zheng, LY & Kerzhner, IM 2002, 'Checklist and nomenclatural notes on the Chinese Pentatomidae (Heteroptera). II. Pentatominae', *Zoosystematica Rossica*, vol. 11, no. 1, pp. 135-53.

Rijal, J & Duncan, R 2017, 'First report of an established brown marmorated stink bug (Hemiptera: Pentatomidae) population in California agricultural crops', *Journal of Entomological Science*, vol. 52, no. 4, pp. 450-4.

Rijal, J & Gyawaly, S 2018, 'Characterizing brown marmorated stink bug injury in almond, a new host crop in California', *Insects*, vol. 9, no. 4, p. 126.

Roca-Cusachs, M, Fernandez, D, Goula, M & Escudero-Colomar, LA 2018, 'New records of the invasive alien plant pest *Halyomorpha halys* (Stål, 1855) in the Iberian Peninsula (Heteroptera: Pentatomidae)', *Butlletí de la Institució Catalana d'Història Natural*, vol. 82, pp. 73-7.

Rodriguez-Saona, C, Vincent, C & Isaacs, R 2019, 'Blueberry IPM: past successes and future challenges', *Annual Review of Entomology*, vol. 64, pp. 95-114.

Russell, D 2012, ‘Agricultural interdiction station inspection’, available at http://freshfromflorida.s3.amazonaws.com/pdf_caps2013w-agricultural-interdiction-stations-2012.pdf (pdf 1601 kb).

SAG 2017, ‘Resolution 1761: Declara control obligatorio de la plaga *Halyomorpha halys* (Stål)’, Servicio Agricola y Ganadero, Ministry of Agriculture, Chile, available at http://www.sag.cl/ambitos-de-accion/halyomorpha-halys/1438/normativas.

Sargent, C, Martinson, HM & Raupp, MJ 2014, ‘Traps and trap placement may affect location of brown marmorated stink bug (Hemiptera: Pentatomidae) and increase injury to tomato fruits in home gardens’, *Environmental Entomology*, vol. 43, pp. 432-8.

Sauer, C 2012, ‘Die Marmorierte Baumwanze tritt neu im Deutschschweizer Gemüsebau auf’ (in German), *Extension Gemüsebau, Forschungsanstalt Agroscope Changins-Wädenswil, Gemüsebau Info*, vol. 28, no. 12, pp. 4-5.

Scaccini, D, Duso, C & Pozzebon, A 2019, ‘Lethal effects of high temperatures on brown marmorated stink bug adults before and after overwintering’ *Insects*, vol. 10, pp. 355, available at DOI 10.3390/insects10100355.

Scaccini, D, Tirello, P, Mingardo, A, Zanin, D, Duso, C & Pozzebon, A 2018, ‘Effect of high and low temperatures on the mortality of brown marmorated stink bug, *Halyomorpha halys* (Heteroptera: Pentatomidae)’, paper presented at XI European Congress of Entomology, Naples, 2-6 July 2018.

Skillman, VP 2017, ‘Nutrient profile and nursery feeding damage of *Halyomorpha halys* (Hempitera: Pentatomidae)’, MSc thesis, Oregon State University.

Smith, JR, Hesler, SP & Loeb, GM 2014, ‘Potential impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) on grape production in the Finger Lakes region of New York’, *Journal of Entomological Science*, vol. 49, no. 3, pp. 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*, vol. 44, pp. 1581-9.

Stahl, JM, Babendreier, D, Marazzi, C, Caruso, S, Costi, E, Maistrello, L & Haye, T 2019, ‘Can *Anastatus bifasciatus* be used for augmentative biological control of the brown marmorated stink bug in fruit orchards?’ *Insects*, vol. 10, no. 108, available at DOI 10.3390/insects10040108.
StopBMSB.org 2016, ‘State-by-state’, available at www.stopbmsb.org/where-is-bmsb/state-by-state/.

Talamas, EJ, Herlihy, MV, Dieckhoff, C, Hoelmer, KA, Buffington, M, Bon, M & Weber, DC 2015, ‘*Trissolcus japonicus* (Ashmead) (Hymenoptera, Scelionidae) emerges in North America’, *Journal of Hymenoptera Research*, vol. 43, pp. 119-28.

Tang, ML, Zhang, PP, Zhang, LY, Li, MH & Wu, LF 2012, ‘A potential bioenergy tree: *Pistacia chinensis* Bunge’, *Energy Procedia*, vol. 16, pp. 737-46.

Tavberidze, V 2018, ‘Denying the stink bug - a success story’, *Georgia Today*, available at http://georgiatoday.ge/news/11706/Denying-the-Stink-Bug-%E2%80%93-A-Success-Story.
Taylor, CM, Coffey, PL, DeLay, BD & Dively, GP 2014, ‘The importance of gut symbionts in the development of the brown marmorated stink bug, *Halyomorpha halys* (Stål)’ *PLoS ONE*, vol. 9, no. 3, pp. e90312, available at DOI 10.1371/journal.pone.0090312.

Tebbe, C, Breckheimer, B, Racca, P, Schorn, C, Kleinhenz, B & Nauen, R 2016, 'Incidence and spread of knockdown resistance (kdr) in German Colorado potato beetle (*Leptinotarsa decemlineata* Say) populations', *EPPO Bulletin*, vol. 46, no. 1, pp. 129-38.

Tomasino, E, Wieman, N, Osborne, J, Hedstrom, C & Walton, V 2013, 'Impact of brown marmorated stinkbug on pinot noir wine quality', *Technical Abstracts, 64th ASEV National Conference, Monterey, California, USA, 24-28 June 2013*, pp. 76-7.

Tooker, J 2013, 'Brown marmorated stink bug as a pest of corn and soybeans', Department of Entomology, Pennsylvania State University, USA, available at http://ento.psu.edu/extension/factsheets/brown-marmorated-stink-bug-as-a-pest-of-corn-and-soybeans.

Toyama, M, Ihara, F & Yaginuma, K 2006, 'Formation of aggregations in adults of the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae): The role of antennae in short-range locations', *Applied Entomology and Zoology*, vol. 41, pp. 309-15.

-- -- 2010, 'Photo-response of the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae), and its role in the hiding behavior', *Applied Entomology and Zoology*, vol. 46, pp. 37-40.

USDA-APHIS-PPQ 2010, *Qualitative analysis of the pest risk potential of the brown marmorated stink bug (BMSB), Halyomorpha halys (Stål), in the United States*, Plant Protection and Quarantine, Animal and Plant Health Inspection Service, United States Department of Agriculture, North Carolina, USA.

USDA-NASS 2016, *National Agricultural Statistics Service*, United States Department of Agriculture, https://www.nass.usda.gov.

Vandervoet, TF, Bellamy, DE, Anderson, D & MacLellan, R 2019, 'Trapping for early detection of the brown marmorated stink bug, *Halyomorpha halys*, in New Zealand', *New Zealand Plant Protection*, vol. 72, pp. 36-43.

Vaughn, C 2019, 'Stink bugs bugging you? Asian species spotted on Eastern Shore', *Delmarva Now*, available at https://www.delmarvanow.com/story/news/2019/05/16/stink-bugs-bugging-you-asian-species-spotted-eastern-shore/3662664002/.

Venugopal, PD, Dively, GP, Herbert, A, Malone, S, Whalen, J & Lamp, WO 2016, 'Contrasting role of temperature in structuring regional patterns in invasive and native pestilential stink bugs' *PLoS ONE*, vol. 11, no. 2, pp. 0150649, available at DOI 10.6084/m9.figshare10.1371/journal.pone.0150649.

Venugopal, PD, Dively, GP & Lamp, WO 2015, 'Spatiotemporal dynamics of the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) in and between adjacent corn and soybean fields', *Journal of Economic Entomology*, vol. 108, pp. 2231-341.

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*, vol. 44, pp. 474-9.

Vetek, G, Papp, V, Haltrich, A & Redei, D 2014, 'First record of the brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Heteroptera: Pentatomidae), in Hungary, with description of the genitalia of both sexes', *Zootaxa*, vol. 3780, pp. 194-200.

Walgenbach, J 2015, 'Distribution, pest status, and research programs for the brown marmorated stink bug in the southeastern US', paper presented at BMSB IPM Working Group Meeting, AHS AREC, Winchester, Virginia, USA, 2 December 2015.

Wallner, AM, Hamilton, GC, Nielsen, AL, Hahn, N, Green, EJ & Rodriguez-Saona, CR 2014, 'Landscape factors facilitating the invasive dynamics and distribution of the brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), after arrival in the United States' *PLoS ONE*, vol. 9, no. 5, pp. e95691, available at DOI 10.1371/journal.pone.0095691.

Wang, Y & Wang, Y 1988, 'Studies on the pear bug *Halyomorpha picus* Fabricius' (in Chinese), *Acta Agriculturae Boreali - Sinica*, vol. 3, no. 4, pp. 96-101.

Watanabe, K 1996, 'Characteristic of damages of *Lygocoris (Apolygus) lucorum* (Meyer-Dür) (Heteroptera: Miridae) and *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae) on cherry' (in Japanese), *Annual Report of the Society of Plant Protection of North Japan*, vol. 47, pp. 143-4.

Watanabe, M 1979, 'Ecology and extermination of *Halyomorpha halys*. 4. The relationship between day length and ovarian development', *Annual Report of the Toyama Institute of Health* vol. 3, pp. 33-7.

-- -- 1980, 'Study of the life cycle of the brown marmorated stink bug, *Halyomorpha mista* by observing ovary development' (in Japanese), *Insectarium*, vol. 17, pp. 168-73.

Watanabe, M, Arakawa, R, Shinagawa, Y & Okazawa, T 1994, 'Fluctuation in brown marmorated stinkbug's winter migrations into human dwellings' (in Japanese), *Animal Health*, vol. 45, no. 1, pp. 25-31.

Weber, DC, Morrison, WR, Khrimian, A, Rice, KB, Leskey, TC, Rodriguez-Saona, C, Nielsen, AL & Blaauw, BR 2017, 'Chemical ecology of *Halyomorpha halys*: discoveries and applications', *Journal of Pest Science*, available at DOI 10.1007/s10340-017-0876-6 [epub ahead of print], accessed 22 May 2017.

Wermelinger, B, Wyniger, D & Forster, B 2008, 'First records of an invasive bug in Europe: *Halyomorpha halys* Stål (Heteroptera: Pentatomidae), a new pest on woody ornamentals and fruit trees?', *Mitteilungen der Schweizerischen Entomologischen Gesellschaft: Bulletin de la Société Entomologique Suisse*, vol. 81, pp. 1-8.

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*, vol. 108, pp. 1156-63.

Wiman, NG, Walton, VM, Shearer, PW & Rondon, SI 2014a, 'Electronically monitored labial dabbing and stylet 'probing' behaviors of brown marmorated stink bug, *Halyomorpha halys*, in simulated environments' *PLoS ONE*, vol. 9, no. 12, pp. e113514, available at DOI 10.1371/journal.pone.0113514.

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

WTO 1995, *Agreement on the application of sanitary and phytosanitary measures*, World Trade Organization, Geneva, available at https://www.wto.org/english/docs_e/legal_e/15-sps.pdf (pdf 90.58 kb).

Wyniger, D & Kment, P 2010, ‘Key for the separation of *Halyomorpha halys* (Stål) from similar-appearing pentatomids (Insecta: Heteroptera: Pentatomidae) occurring in Central Europe, with new Swiss records’, *Mitteilungen der Schweizerischen Entomologischen Gesellschaft: Bulletin de la Société Entomologique Suisse*, vol. 83, no. 3-4, pp. 261-70.

Xu, J, Fonseca, DM, Hamilton, GC, Hoelmer, KA & Nielsen, AL 2014, ‘Tracing the origin of US brown marmorated stink bugs, *Halyomorpha halys*’, *Biological Invasions*, vol. 16, pp. 153-66.
Yanagi, T & Hagihara, Y 1980, ‘Ecology of the brown marmorated stink bug’ (in Japanese), *Plant Protection*, vol. 34, no. 7, pp. 315-26.

Yu, GY & Zhang, JM 2007, ‘The brown-marmorated stink bug, *Halyomorpha halys* (Heteroptera: Pentatomidae) in P. R. China’, *International Workshop on Biological Control of Invasive Species of Forests, 20-25 September 2007*, pp. 58-62.

Zhang, CT, Li, DL, Su, HF & Xu, GL 1993, ‘Study on the biological characteristics of *Halyomorpha picus* and *Erthesina fullo*’ (in Chinese), *Forest Research*, vol. 6, no. 3, pp. 271-5.

Zhang, J, Zhang, F, Gariepy, T, Mason, P, Gillespie, D, Talamas, E & Haye, T 2017, ‘Seasonal parasitism and host specificity of *Trissolcus japonicus* in northern China’, *Journal of Pest Science*, available at DOI 10.1007/s10340-017-0863-y [epub ahead of print], accessed 24 April 2017.

Zhang, JM, Wang, H, Zhao, LX, Zhang, F & Yu, GY 2007, ‘Damage to an organic apple orchard by the brown marmorated stink bug, *Halyomorpha halys* and its control strategy’ (in Chinese), *Chinese Bulletin of Entomology*, vol. 44, pp. 898-901.

Zhu, G, Bu, W, Gao, Y & Liu, G 2012, ‘Potential geographic distribution of brown marmorated stink bug invasion (*Halyomorpha halys*)’ *PLoS ONE*, vol. 7, no. 2, pp. e31246, available at DOI 10.1371/journal.pone.0031246.

Zhu, GP, Ye, Z, Du, J, Zhang, DL, Zhen, YH, Zheng, CG, Zhao, L, Li, M & Bu, WJ 2016, ‘Range wide molecular data and niche modeling revealed the Pleistocene history of a global invader (*Halyomorpha halys*)’ *Scientific Reports*, vol. 6:23192, available at DOI 10.1038/srep23192.

Zimmermann, O, Reißig, A, Trautmann, M & Haye, T 2018, ‘The unnoticed invasion of a pest with high harmful potential in fruit and vegetable production: the brown marmorated stink bug *Halyomorpha halys* in Germany’, *Eco-fruit: Proceedings of the 18th International Conference on Organic Fruit-Growing, 19-21 February 2018*, University of Hohenheim, Germany, pp. 249-50.

Zobel, ES, Hooks, CR & Dively, GP 2016, ‘Seasonal abundance, host suitability, and feeding injury of the brown marmorated stink bug, *Halyomorpha halys* (Heteroptera: Pentatomidae), in selected vegetables’, *Journal of Economic Entomology*, available at DOI 10.1093/jee/tow055 [epub ahead of print], accessed 11 April 2016.