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Ministry for Primary Industries
Manatū Ahu Matua

Pest risk assessment: *Halyomorpha halys* (Brown marmorated stink bug)

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14 October 2019

Approved for general release

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Version information

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1.0	Peer-reviewed and current at date of release	14/10/2019

New Zealand is a member of the World Trade Organisation and a signatory to the Agreement on the Application of Sanitary and Phytosanitary Measures ("The Agreement"). Under the Agreement, countries must base their measures on an International Standard or an assessment of the biological risks to plant, animal or human health.

This document provides a scientific analysis of the risks associated with *Halyomorpha halys* on multiple pathways. It assesses the likelihood of entry, exposure, establishment and spread of *Halyomorpha halys* in relation to all likely pathways and assesses the potential impacts of those organisms should they enter and establish in New Zealand. The document has been internally and externally peer reviewed and is now released publically. Any significant new science information received that may alter the level of assessed risk will be included in a review, and an updated version released.

Contributors to this risk assessment

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Executive summary

Purpose

This document updates the previous BMSB risk analysis. The document assesses the biosecurity risks associated with *Halyomorpha halys* entering New Zealand via all likely entry pathways. The results of this work will be used to determine how effective the existing risk management measures for *H. halys* are. The analysis also considers current and developing surveillance and monitoring options, and risk management options.

Background

Halyomorpha halys is a sap sucking insect native to China, Japan, Korea and Taiwan that has become invasive in North America, Europe and Chile. Commonly known as the brown marmorated stink bug (BMSB), it causes significant feeding damage to a wide array of economically important crop species. In addition, BMSB is a vector of *Paulownia witches broom phytoplasma*. The bug is also known to over winter en-masse in man-made structures, where it becomes a nuisance pest at high abundance.

Risk assessment findings

Halyomorpha halys is not present in New Zealand. This analysis examines the risk of *H. halys* entering New Zealand as a hitchhiker on inanimate pathways, such as containers and their contents, and new and used vehicles, machinery and equipment. The analysis also examines the risk of entry of *H. halys* adults, nymphs and eggs associated with nursery stock, fresh produce, and cut flowers and foliage, as well as on the passenger and personal effects pathways.

Likelihoods of entry and exposure are assessed separately for each pathway. The highest likelihood of entry and exposure was considered to be on inanimate pathways and associated with passenger personal effects from the Northern Hemisphere. The life stage considered to be most likely to enter New Zealand is overwintering adults from the Northern Hemisphere. Based on current standards, the likelihood of entry and exposure of *H. halys* from the Northern Hemisphere associated with nursery stock and fresh produce is considered very low and considered negligible in association with cut flowers and foliage. The likelihood of entry from the Southern Hemisphere is considered very low to low, based on *H. halys* current population size and limited distribution in Chile. Should *H. halys* spread within Chile or elsewhere in the Southern Hemisphere, all pathways will need to be re-assessed.

The likelihood of establishment and spread is considered independently of entry. Aggregations of *H. halys* from the Northern Hemisphere are considered to have a high likelihood of establishing in New Zealand and aggregations from the Southern Hemisphere are considered to have a moderate likelihood of establishment based on a combination of the insect's biological requirements, environmental conditions and host availability. The likelihood of spread of an established population is considered high.

The economic consequences of *H. halys* establishing in New Zealand are considered to be moderate to high and the socio-cultural impacts of establishment are considered moderate. The potential environmental impacts are considered very low with high uncertainty and the potential health impacts are considered negligible.

This document also discusses current and developing surveillance options including the detection of volatile organic compounds, environmental DNA and aggregation pheromones. The analysis also summarises the available literature on chemical and temperature based management options.

1 Risk analysis of *Halyomorpha halys* (Stål), 1855 (brown marmorated stink bug)

1.1 Introduction

Scientific name: *Halyomorpha halys* (Stål), 1855 (Hemiptera: Pentatomidae)
Other relevant scientific names: *Halyomorpha mista, H. brevis, H. remota* a full list of synonyms is presented in section 1.4
Common name: Brown marmorated stink bug

Halyomorpha halys (brown marmorated stink bug (BMSB)) is native to China, Taiwan, Korea and Japan (Lee et al, 2013) and has been accidentally introduced into the USA, Europe, Canada and Chile. There are also published reports of BMSB in India and Nigeria, but these are unverified.

Halyomorpha halys is damaging to a wide variety of economically significant agricultural, arable and horticultural species and has become a social pest in some areas of its introduced range. The aggregation and overwintering behaviour of BMSB is conducive with long distance (international) dispersal as a hitchhiker on inanimate pathways.

1.2 Purpose

This document updates the previous BMSB risk analysis (MPI, 2012). The document assesses the biosecurity risks associated with *Halyomorpha halys* entering New Zealand via all likely entry pathways. The results of this work will be used to determine how effective the existing risk management measures for *H. halys* are. The analysis also considers current and developing surveillance and monitoring options, and risk management options.

1.3 Scope

The risk of *Halyomorpha halys* entering, establishing and causing unwanted impacts in New Zealand is examined in this assessment. The assessment is undertaken for all likely entry pathways including inanimates (e.g. containers, vehicles, machinery and equipment), nursery stock, fresh produce, cut flowers and foliage, passengers and their personal effects. Likely pathways were identified with the aid of the previous *H. halys* risk assessment (MPI 2012), records of *H. halys* intercepted on commodities at the New Zealand border or post border and published records of introductions and interceptions in North America and Europe.

The analysis complies with the Biosecurity New Zealand Risk Analysis Procedures (MAF 2006).

Deciding on specific biosecurity surveillance and risk management options is outside the scope of this analysis. However, current and developing surveillance options relating to specific pathways are discussed in section 6, and potential risk management options are discussed in section 7

1.4 Taxonomic issues

There are 37 species recognised in the genus *Halyomorpha* (Rider, 2005). The native distribution of these species is Africa (16 spp.), India (8 spp.) and Asia (13 spp.) (Hoebeke and Carter, 2003).

Josifov and Kerzher ((1978) in Rider, (2014)) determined that there is only one *Halyomorpha* species occurring in Eastern China, Taiwan, Japan and Korea and this should be referred to as *H.*

halys (Rider et al, 2002; Hoebeke and Carter 2003; Rider 2014). However, the name *H. mista* has been used in Japan until very recently and is possibly still in use (Rider et al, 2002).

The systematics of *H. halys* has been revised several times since its initial description in 1855. These revisions are detailed in Hoebeke and Carter (2003), Rider, (2014) and Hamilton et al, (2018). Of particular note is that *H. halys* was once considered a junior synonym of *H. picus* - an identical looking species occurring in India. They are now considered to be two distinct species, based largely on differences in male reproductive anatomy. It has been suggested that recent reports of *H. halys* from India (Shanthakumar et al, 2010; Karun and Sridhar, 2013; Tembe et al, 2014) are the result of misidentification of *H. picus* (Cianferoni, 2018).

Synonyms:

- *Pentatoma halys* Stål, 1855:182.
- *Poecilometis mistus* Uhler, 1860: 223. (syn. by Josifov & Kerzhner, 1978)
- *Cappaea halys* Stål, Annales de la Société entomologique de France, 1865(4) 5:170
- *Dalpada brevis* Walker, 1867: 226-227. (syn. by Josifov & Kerzhner, 1978)
- *Dalpada remota* Walker, 1867: 227. (syn. by Josifov & Kerzhner, 1978)
- *Halyomorpha picus* (Fabricius) 1794
- *Halyomorpha timorensis*; Signoret, Bulletin de la Société entomologique de France1881 (5): 46
- *Halyomorpha brevis*: Hasegawa, Japan Plant Protection Association, Tokyo 167, 171, 175, 176, 267
- *Halyomorpha mista* (Uhler)

2 Hazard identification

2.1 Description

Halyomorpha halys is a sap sucking Hemipteran insect in the family Pentatomidae. Commonly known as the brown marmorated stink bug (BMSB), it causes significant feeding damage to a wide array of economically important crop species. In addition, BMSB is a vector of Paulownia witches broom phytoplasma (Jin et al, 1981; Nagano et al, 1997; Sun et al, 1999; Wermelinger et al, 2008). The bug is also known to over winter *en-masse* in man-made structures, where it becomes a nuisance pest at high abundance (Inkley et al, 2012).

2.2 Commodity association

The previous MPI pest risk analysis of BMSB (MPI, 2012) and the Australian Draft PRA for BMSB (DAWR, 2017) concluded that the highest risk commodities are inanimates (e.g. vehicles, machinery and equipment, personal effects and containerised goods) imported from infested Northern Hemisphere countries during the BMSB overwintering period. This overwintering period falls between September and April. Based on available interception data (MPI, 2019), these remain the most likely pathways for aggregations of BMSB to arrive in New Zealand from the Northern Hemisphere.

Nursery Stock, Fresh Produce and Cut Flowers and Foliage have the potential to carry egg masses and/or individual adults or nymphs, but are not likely to carry aggregations for two reasons; firstly they are generally harvested at a time prior to the aggregation period and secondly they lack the architecture for large groups of BMSB to shelter in.

Halyomorpha halys has been reported to infest more than 300 hosts in 75 families (Appendix Table A1.). This infestation can broadly be divided into two categories: feeding hosts and nesting hosts, although the division may not be exclusive and is often poorly defined (Oda et al, 1980; Lee et al, 2013; Maistrello et al, 2016). Egg masses and first instar nymphs are more likely to be associated with species described as nesting hosts than feeding hosts. Furthermore, as host preference changes between life stages (Bergmann et al, 2016), it is likely that some life stages may be more prevalent on certain species.

Eggs are typically deposited on the underside of host tree leaves situated higher in the canopy (Leskey and Nielsen, 2018). This preference for higher oviposition sites may reduce the likelihood of entry of BMSB eggs on nursery stock or cut foliage.

First instar nymphs are sedentary and remain associated with their natal egg mass after hatching in order to uptake gut symbionts from the egg chorion (Taylor et al, 2014). The likelihood of entry of first instar nymphs on nursery stock or cut foliage is therefore considered the same as for BMSB eggs.

Second instar nymphs are more mobile and third to fifth instar nymphs walk to other hosts, travelling 3- 4.5 metres per hour depending on temperature (Lee et al, 2014).

Nymphs are unable to fly and feed on stems and vegetative plant parts as well as fruit (Acebes-Doria, 2016). In a study performed in ornamental plant nurseries, Martinson et al, (2015) report that highest abundances of both BMSB adults and nymphs are found on plants bearing mature fruit. However fruit maturation cannot be viewed as the only factor driving abundance, as other factors such as environmental temperatures at various life stage have also been demonstrated to play a role (Kiritani 2006; Funayama 2012).

Adult BMSB and nymphs have been reported to feed on a wide variety of commercially significant host species including, but not limited, to *Pyrus* spp. (pear) *Malus* spp. (apple), *Prunus* spp. (stonefruit), *Actinidia* spp. (kiwifruit), *Vitis* spp. (grape) and *Phaseolus* spp. (bean) (Leskey and Nielsen 2018).

A report from the USA (Ingles, 2017), describes the presence of BMSB throughout the vines in some California vineyards. In the afternoon, when temperatures are high, the bugs shelter from the heat in the middle of grape clusters. Once in the grape clusters, BMSB were difficult to detect. Nymphs were particularly hard to see in the clusters (Ingels, 2017).

Feeding injury is caused when the bug inserts its stylet into the fruiting body of the host. Damage may take the form of deformation, sunken areas, flesh dicolouration or sponginess (Haye et al, 2014). Feeding on flower buds may result in abortion of fruit and feeding on nuts may result in empty shells (Hedstrom et al, 2014). Evidence of BMSB feeding should be visible during pre-export sorting and quarantine inspection. It is unlikely that damaged fruit would be exported, but fruit showing such damage may indicate the presence of BMSB adults or nymphs in the consignment.

Plant associations

Halyomorpha halys is highly polyphagous, being associated with 75 plant families (Appendix Table A1). A large propotion of the reported hosts come from two familes - Rosaceae and Fabaceae. Other families containing ten or more species that are known to be hosts of BMSB include and Oleaceae, Aceraceae and Malvaceae. Commercially significant genera to New Zealand that are damaged by BMSB include: *Acer, Actinidia, Asparagus, Beta, Brassica, Cannabis, Capsicum, Citrus, Fragaria, Glycine, Helianthus, Juglans, Malus, Olea, Phaseolus, Pinus, Prunus, Pyrus, Rubus, Solanum, Sorghum, Vitis* and *Zea.*

2.3 Potential for establishment and impact

Establishment

Environmental conditions and host plant availability in many regions of New Zealand are suitable for brown marmorated stink bug to establish.

Climate matching (Phillips unpublished) with the known native and invaded distribution of *H. halys* indicates a 70-90% similarity with New Zealand's climate. Climate is therefore unlikely to be a barrier to BMSB establishment in at least some parts of New Zealand (Figure 1).

Halyomorpha halys has been recorded in association with more than 300 host species spanning 75 families (Table A1). Many of these host species, including but not limited to *Prunus* spp, *Pyrus* spp. *Malus* spp. *Actinidia* spp, *Phaseolus* spp. *Glyine max* and *Phaseolus vulgaris* are cultivated across New Zealand.

Impact

Economic impact

Halyomorpha halys is a significant economic and social pest in other regions.

Halyomorpha halys adults and late instar nymphs severely damage the fruiting bodies and vegetative structures of commercially significant plants when they feed. Early season feeding results in discoloured and deformed fruit that is often unmarketable (Leskey and Nielsen 2018).

The brown marmorated stink bug is difficult to manage on commercial crops (Kuhar and Kamminga 2017). A number of insecticides, including pyrethroids and neonicotinoids have proven ineffective against BMSB (Leskey et al, 2012) and others require frequent high dose applications to manage the bug. In addition to the high cost of such pesticide applications, they have resulted in increases in secondary pest abundance and unsaleability of fruit due to elevated pesticide residues. Some growers have had to resort to the use of high cost exclusion netting solutions (Pansa et al, 2018).

In addition to the physical damage it inflicts, *H. halys* is a vector of the Paulownia witches' broom phytoplasma (PaWB) (Jin et al, 1981; Nagano et al, 1997; Sun et al, 1999; Wermelinger et al, 2008) and the yeast *Eremothecium coryli*, which is a causal agent of fruit rot (Rice et al, 2014).

***Halyomorpha halys* is a social pest at high abundance**.

In autumn *H. halys* may enter homes and other human made structures to shelter from cold conditions outside (Leskey et al, 2012). The likelihood of infestation of buildings increases with proximity to host plants (Maistrello et al, 2016). In parts of the USA, numbers in excess of 26, 000 individuals have been recorded in a single house (Leskey et al, 2012).

When disturbed, *H. halys* emits a pungent and unpleasant odour (Leskey et al, 2012) and at high abundance can stain floors and walls with its frass (Leskey et al, 2012).

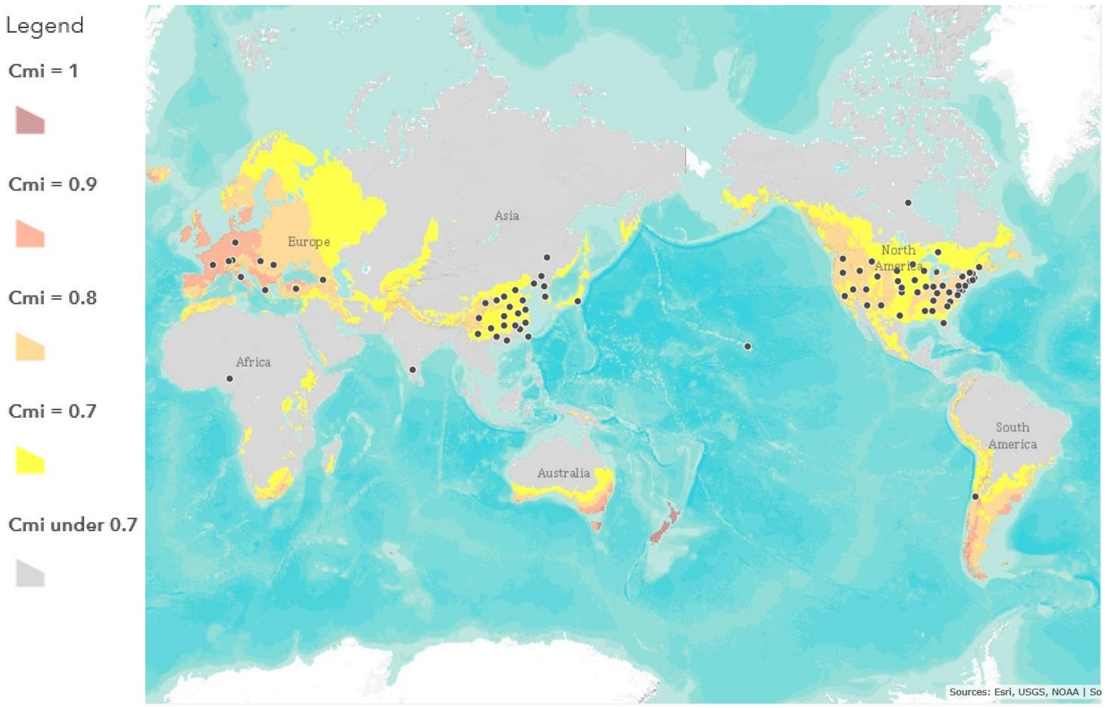

Figure 1. The known distribution of *Halyomorpha halys* plotted against a New Zealand climate matching model (Philips unpublished) where grey = <70% similarity, yellow =70% similarity, peach =80%, salmon pink =90% and mauve 100%). Note the map does not distinguish between occasional records and widespread established populations.

2.4 Hazard identification conclusion

Given that *Halyomorpha halys*

- Has been intercepted multiple times as a hitchhiker on goods from multiple countries in both its native and invaded range;
- has spread rapidly though the USA, Canada and Europe and is now present in Chile;
- is not recorded from NZ;
- can potentially establish in New Zealand;
- can potentially cause unwanted impacts including damage to multiple fruit and crop species leading to significant financial losses
- can be a nuisance pest in dwellings particularly those near host vegetation

Halyomorpha halys is considered a hazard in this risk analysis

3 General geographic distribution

Halyomorpha halys (brown marmorated stink bug (BMSB)) is native to China, Taiwan, Korea and Japan (Lee et al, 2013) and has been accidentally introduced into the USA, Europe, Canada and Chile. There are also published reports of BMSB in India and Nigeria, but these are unverified.

The native and introduced range of *H. halys* falls between 35° and 45° latitude in the Northern hemisphere. Its solitary detection in the Southern hemisphere is at a comparable latitude (-33.4°S).

The USDA StopBMSB website uses a four category classification to describe the level of BMSB infestation in each state. These categories are:

- BMSB detected/intercepted: BMSB detected or intercepted, but no evidence of established populations.
- Nuisance problems only: signifies reproducing populations exist in the state. Generally early stage infestations, usually confined to residential areas.
- Agricultural and nuisance problems: recurring populations at or below economically damaging levels on agricultural crops, and in residential areas
- Severe agricultural and nuisance problems: severe economic damage to susceptible commodities in the absence of control measures, widespread infestations of homes and businesses in the fall/winter.

Based on the the most current information available, the distribution of BMSB in its invaded range has been categorised according to the USDA criteria and is presented in Table 1.

Table 1. Known distribution of *Halyomorpha halys* with indicative abundance based on the USDA StopBMSB.org categories.

Country	Equivalent USDA Category	Notes	References
Albania	BMSB detected/intercepted	A single adult from Berat and an unconfirmed nymph in Vlora presented on inaturalist and reported by Lara Maistrello	https://www.inaturalist.org/taxa/81923-Halyomorpha-halys Maistrello, (2019)
Austria	BMSB detected/intercepted	Multiple adults found in Vienna and a single adult found in Vorarlberg	Rabitsch, (2015)
Belgium	BMSB detected/intercepted	Two adults discovered – one male in Soignies	Claerebout et al, 2019

Country	Equivalent USDA Category	Notes	References
		and a second of unknown sex in Saint-Nicolas (Province of East Flanders)	
Bulgaria	BMSB detected/intercepted	3 nymphs and one Adult collected in Sofia	Simov, (2016)
Canada	BMSB detected/intercepted	British Columbia, Prince Edward Island, Quebec	Fogain and Graff, (2011) CBC News (2017) www.stopbmsb.org (2018)
	Nuisance problems only	Ontario	
Chile	Nuisance problem Only	Confined to Santiago	Faundez and Rider, (2017)
China (inc. Taiwan)	Native Range	Distibuted in 22 provinces see figure 2	Zhang et al, (2007), EPPO (2019), (Lee et al, (2013))
Croatia	BMSB detected/intercepted	Six adults (two female, four male) found in Rijeka in Western Croatia between January and May, 2017 A single adult from Split, Hrvatska presented on inaturalist	Sapina and Jelaska, (2018) https://www.inaturalist.org/taxa/81923-Halyomorpha-halys
Czech Republic	BMSB detected/intercepted	No further details	Maistrello, (2019)
France Corsica Island	Nuisance problems only BMSB detected/intercepted	Present, restricted distribution: An established population has been reported in Strasbourg and Paris Specimen detected in Porto Vecchio Found on the green area around the port	Callot and Brua, (2103); Garrouste et al, (2014); Maistrello et al, (2018 and pers com)
Georgia	Severe agricultural and nuisance problems	Established in Khobi Municipality of Samegrelo–Verkhnyaya Svanetiya Territory in Western Georgia causing severe losses within 1 year of discovery	Gapon, (2016) www.jam-news.net (2018)
Germany	Nuisance problems only	Breeding populations established in Southern Germany	Haye and Zimmerman, (2017)
Greece	Agricultural and nuisance problems	Adults reported causing nuisance to resident is Central Athens. Found infesting kiwifruit in Northern Greece	Milonas and Partsinevelos, (2014); Andreadis et al, (2018)

Country	Equivalent USDA Category	Notes	References
Guam	Detected/intercepted	Single specimen only	Moore, (2014)
Hungary	Severe agricultural and nuisance problems	Established - Widespread Budapest, Péterimajor	Vetek et al, (2014)
Iceland	BMSB detected/intercepted	Intercepted only	Cianferoni et al, (2018)
India	Uncertain	Status uncertain. It has been suggested that reports of *H. halys* are the result of misidentification of the native Indian species *H. picus*. The two may only be differentiated by dissection of the male genitalia (Cianferoni 2018).	Shanthakumar et al, (2010); Karun and Sridhar (2013) Tembe et al, (2014)
Italy	Severe agricultural and nuisance problems	Established – Widespread through Northern Italy Emilia-Romagna, Piedmont, Lombardy, Veneto and Friuli First report in Sardinia September 2016 Increasing cases in all regions from Central and Southern Italy, as well as in Sicily	Maistrello et al, (2014) Maistrello et al, (2016) Bariselli et al, (2016) Dioli et al, (2016) Maistrello et al (2018)
Liechtenstein	Nuisance problems only	First found in 2004, but not identified until 2009. Present in Balzers.	Arnold, (2009) Haye, (2013)
Japan	Native Range	Native range	Lee et al, (2013)
Kazakhstan	BMSB detected/intercepted	Nymphs and new adults found in Almaty region	Esenbekova, (2017)
Korea North	Native Range	Native Range	Kim, (2010) in Hamilton et al,(2018)
Korea South	Native Range	Native range	Lee et al, (2013)
Macedonia	BMSB detected/intercepted	BMSB detected in Central Macedonia – no further details	Cianferoni et al, (2018)
Malta	BMSB detected/intercepted	One male *H. halys* found in traps near Freeport in Birżebbu. Many European transhipments occur in this region which is surrounded by agricultural fields	Tassini and Mifsud, (2019)
Myanmar	Native Range	Native Range	Li, (1985) in Yu and Zhang,

Country	Equivalent USDA Category	Notes	References
		Yu and Zhang (2007) and Hamilton et al, (2018 include Myanmar and Vietnam in BMSB's native range. This was based on citations of publications from China (Li, (1985); Wang and Liu (2005)), not reports directly from Vietnam or Myanmar. I have not come across any primary sources that suggest it is present in these countries.	(2007); Wang and Liu, (2005) in Hamilton et al, (2018)
Nigeria	Uncertain. Agricultural and nuisance problems	Status uncertain reported in Ado Ekiti, Southwestern Nigeria at high abundance damaging amaranth flower heads	Borisade et al, (2017)
Norway	BMSB detected/intercepted	Aggregation of 25 adults detected in imported tiles	Kvamme, (2018)
Poland	BMSB detected/intercepted	A single adult from Dobczyce presented on inaturalist and reported by Lara Maistrello	https://www.inaturalist.org/taxa/81923-Halyomorpha-halys Maistrello, (2019)
Romania	Nuisance problems only	Adults and nymphs found in botanic gardens of Bucharest and in other urban green areas	Macavei et al, (2015)
Russian Federation	Nuisance problems only	Limited distribution (Sochi and Abkhazia) first observed in or before 2013 and began causing nuisance to residents in 2016.	Gapon, (2016)
Serbia	BMSB detected/intercepted	Adults and Nymphs found in Belgrade	Seat, (2015)
Spain	Nuisance problems only	A single 4th instar nymph detected in Catalonia Population in Iberian peninsula	Dioli et al, (2016); Roca-Cusachs et al, (2108)
Slovakia	BMSB detected/intercepted	Single 5th instar nymph detected	Hemala and Kment, (2017)
Slovenia	Nuisance problems only	NPPO of Slovenia declared *H. halys* Present at low prevalence in July 2017 occurring in Western Slovenia. Adults	NPPO of Slovenia in EPPO, 2018

Country	Equivalent USDA Category	Notes	References
		detected at NZ border on Sports goods ex Slovenia in 2017	
Sweden	BMSB detected/intercepted	Detected – no further info	Cianferoni et al, (2018)
Switzerland	Agricultural and nuisance problems	Present – Wide distribution Basel-Stadt, Schaffhausen, St. Gallen, Zurich	EPPO (2013) Wyniger & Kment, (2010) Haye & Wyniger, (2013)
Turkey	Nuisance problems only	Specimens collected from Istanbul and Kemalpaşa District of Artvin Province	Cerci and Kocak, (2017)
Ukraine	BMSB detected/intercepted	A single adult from Odesa and a single adult from Simferopol presented on inaturalist and reported by Lara Maistrello	https://www.inaturalist.org/taxa/81923-Halyomorpha-halys Maistrello, (2019)
United Kingdom	BMSB detected/intercepted	Intercepted only - Six interceptions to date. All were adults with likely pathways	Malumphy, (2014), Malumphy and Eyre, (2015) Yale, (2018)
United States of America	BMSB detected/intercepted	Arizona, Arkansas, Colorado, Florida, Hawaii, Idaho, Kansas, Nebraska, Nevada, New Mexico, Massachusetts, Mississippi, North Dakota, Texas	www.stopBMSB.org (2018)
	Nuisance problems only	Illinois, Iowa, Maine, Minnesota, Missouri, New Hampshire, Rhode Island, Vermont, Wisconsin	
	Agricultural and nuisance problems	Alabama, California, Connecticut, Georgia, Indiana, Kentucky, Michigan, Ohio, Oregon, South Carolina, Utah, Washington	
	Severe agricultural and nuisance problems	North Carolina, Delaware, Maryland, New Jersey, New York, Pennsylvania, Tennessee, Virginia, West Virginia	

Country	Equivalent USDA Category	Notes	References
Vietnam	Native Range	Native Range Yu and Zhang (2007) and Hamilton et al, (2018 include Vietnam in BMSB's native range. This was based on citations of publications from China (Li, (1985); Wang and Liu (2005)), not reports directly from Vietnam or Myanmar. I have not come across any primary sources that suggest it is present in these countries.	Li, (1985) in Yu and Zhang, (2007); Wang and Liu, (2005) in Hamilton et al, 2018

Figure 2. Known distribution of BMSB in China (large red dots) based on information in Zhang et al, (2007) and EPPO (2019). Map: Wikipedia

4 Biology – Literature Review

4.1 Phenology

Halyomorpha halys is hemimetabolous. After hatching, *H. halys* passes through five larval instars before the final moult to adulthood. Life cycle timing of BMSB is broadly similar throughout the Northern Hemisphere and it is bivoltine in the USA (Nielsen et al. 2016, 2017). The bug overwinters between November and April, emerges from its recovery sites and moves to host plants between April and June, reproduces between May and August and moves to its overwintering sites between September and November (Nielsen et al 2016; Nielsen et al 2017; Costi et al, 2017). An estimated Southern Hemisphere lifecycle is presented in Table 2.

Number of generations produced per year

Halyomorpha halys typically produces one to two generations per year in most of its native and invaded range (Lee et al, 2013; Haye et al, 2014; Costi et al, 2017). Up to six generations per year have been reported in Southern China (Hoffman, 1931), however there do not appear to be any recent reports confirming that this is the case and the veracity of this has been disputed as a result. The number of generations produced is an artefact of development rates, which are in turn closely linked to temperature and daylength (Haye et al, 2014; Musolin et al, 2019; Nielsen et al. 2017).

Table 2. Estimated BMSB life cycle in the Southern Hemisphere.

Season	WINTER		SPRING			SUMMER			AUTUMN			
Phenology	Overwintering				Emerge and move to feeding sites	Reproductive period			Aggregation		Overwintering	
Northern Hemisphere	January	February	March	April	May	June	July	August	September	October	November	December
Southern Hemisphere	July	August	September	October	November	December	January	February	March	April	May	June

4.2 General Description of life stages

Eggs.

Halyomorpha halys eggs are approximately 1.6 mm long and 1.3 mm wide, white and elliptical with fine superficial reticulation and minute spines. Eggs are laid in regular clusters of between 20 and 30 (Hoebeke and Carter, 2003) (Figure 1).

Eggs are typically laid on the underside of leaves at heights greater than two metres above the ground. While instances have been reported of eggs being laid on structural and reproductive plant parts (Leskey, 2012), this is not common.

Each of the insect's paired ovaries comprises 7 ovarioles. Each of these ovarioles is capable of producing two fully formed eggs at the same time, with the result that an average of 28 eggs are laid per cluster (Watanabe et al, 1978). A single female may lay between 260 and 420 eggs in her lifetime (Leskey and Nielsen, 2018).

In the Northern Hemisphere, eggs are generally laid between May and September. Detections of BMSB eggs in Santiago, Chile are sparse. Two egg masses have been observed, the first on the 29th of January the second on the 7th of February 2018 (SAG unpublished). As overwintered females emerge in late October in Chile (SAG unpublished) and as BMSB typically take approximately two weeks to mature (Nielsen et al, 2008), eggs are likely produced from mid-November onwards. As nymphs were observed until mid- April in Santiago (SAG unpublished), it is assumed eggs are produced until early April.

Parthenogenesis has been reported in *H. halys.* Fengjie and Zhifang (1997) isolated 30 newly moulted adult females and fed them on a diet of peach and pear. Of these isolated females, 53% produced eggs without mating and of the unfertilised eggs 12.47% hatched into nymphs. It is not mentioned whether these nymphs completed their development into adults. However, in conducting life-table analysis, Nielsen et al, (2008) evaluated reproductive output of unmated female BMSB. While eggs were produced, no nymphs hatched out of these unfertilized eggs. The veracity of parthogenetic reproduction is therefore highly uncertain.

Egg development

There is some disagreement about the lower temperature threshold for egg development. In Japan the threshold has been identified as 11°C (Fujiie 1985), 11.7 °C (Kono et al, 1979 in Kiritani 2007), 11.9°C (Uchida 1986 in Kiritani 2007), 12.1°C (Kita, 1979 in Kiritani, 2007), 12.9°C (Watanabe, 1980) and 13.8°C (Yanagi and Hagihara, 1980). In Europe, Haye et al, (2014) found that eggs can develop at temperatures between 15°C and 33°C and that development does not occur above 35°C. In the USA, Nielsen, (2008) reported that while eggs developed and hatched at 15 °C, there was 100% mortality of first instar nymphs at this temperature and the minimum temperature for egg incubation was modeled at 13.94˚C.

Egg development times are temperature dependent. Eggs can take between 22 and 26 days to hatch at 15°C and 2-4 days at 30°C (Haye et al, 2014).

Figure 3. Left. Newly laid *Halyomorpha halys* egg cluster on the underside of a host leaf. (Photo: https://bugguide.net/node/view/968037 and Right close up of BMSB eggs showing reticulated pattern and spines (Photo Susan Ellis, Bugwood.org)

Nymphs

Halyomorpha halys passes through five nymphal stages. All nymphs are flightless and range in size from 2.4 to 12 mm in length (Figure 4). A full morphological description of each instar is given by Hoebeke and Carter (2003)

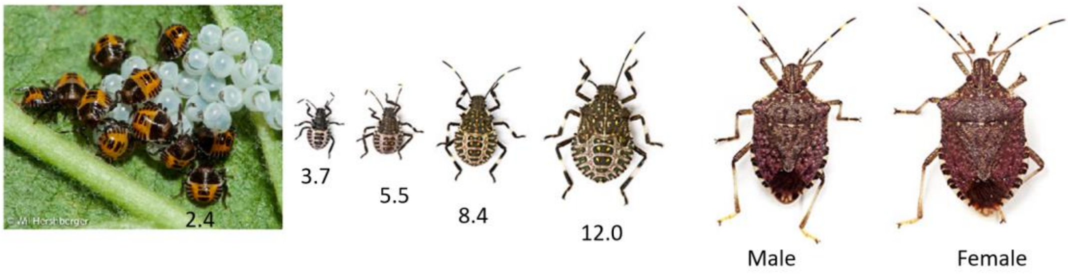

Figure 4. Left to right *Halyomorpha halys* first to fifth instar nymphs with average lengths (in mm), and adult male and female to scale. All Photos by W. Herschberger and taken from www.stopbmsb.org

First instar nymphs are sedentary. These nymphs remain associated with their natal egg mass after hatching in order to uptake gut symbionts from the egg chorion (Taylor et al, 2014). These gut symbionts have been demonstrated to reduce nymphal development time and increase survivorship (Taylor, 2014).

By contrast, the second to fifth instar nymphs are highly mobile, and are able to move between 2 and 4 metres per hour vertically or horizontally to feed or seek shelter from the sun. The distance travelled by these instars increases with temperature. (Lee et al, 2014).

Halyomorpha halys nymphs do not form over wintering aggregations, but are attracted by the aggregation pheromone emited by adult BMSB prior to overwintering (Weber et al. 2017). It has also been observed that BMSB nymphs aggregate in large numbers on feeding substrates. However, given that they are easily disturbed and highly mobile, they are unlikely to remain associated with substrates such as Fresh Produce or Nursery Stock that are subjected to regular handling.

Nymphal development

Nymphal development typically requires a mixed diet of vegetative and reproductive plant material from multiple hosts (Acebes- Doria et al, 2016). However, a combination of peach (*Prunus persica*) fruit and foliage has been demonstrated to be an effective single host diet for nymphal development. Host suitability has also been found to be to be seasonal and associated with the development of reproductive structures (Nielsen and Hamilton 2009); for example, nymphal survival is greater on tree of heaven (*Ailanthus altissima*) later in the season than earlier (Acebes-Doria et al, 2016).

Nielsen et al 2008 demonstrated that the minimum temperature threshold for development of nymphal BMSB in the USA is 14.14°C and that the optimum temperature for development is 27°C. Nielsen also reported high levels of mortality at and above 30°C. These threshold temperatures are lower than those reported by Haye *et al*, (2014) in a study of European BMSB, which found the minimum temperature threshold for nymphal development is 20°C and that development is not completed at temperatures >35°C. Haye et al (2014) report that development from first instar to fifth instar moult to adult took between 65.81 days (at 20°C) and 29.97 days at (30°C). The optimum temperature for development is 30°C (Haye et al, 2014) (Table 5). Based on these lab studies, development times appear to be consistent in Europe and the USA (Table 6). How accurately these studies these studies reflect development in the field is uncertain. Fengjie and Zhifang (1997) reported comparable development rates from BMSB nymphs in China, which took an average of 49.15 days to develop to adult moult. However, in the paper the temperature is not reported or whether the nymphs were kept at controlled or fluctuating temperatures.

Table 5. Development times in days (± standard error) for each nymphal stage of European *H. halys* at three temperatures as presented in Haye et al, (2014) compared to development times of nymphs reported from China.

	Temperature controlled			Unknown temperature (Fengjie and Zhifang 1997)
Instar	**20°C**	**25°C**	**30°C**	
1st	**9.06 ± 0.11**	**5.17 ± 0.05**	**3.94 ± 0.03**	**5.85**
2nd	**14.40 ± 0.26**	**7.29 ± 0.10**	**5.50 ± 0.09**	**12.69**
3rd	**11.00 ± 0.16**	**6.58 ± 0.20**	**5.09 ± 0.15**	**9.76**
4th	**12.54 ± 0.28**	**6.89 ± 0.13**	**6.16 ± 0.13**	**10.39**
5th	**18.81 ± 0.34**	**10.58 ± 0.22**	**9.28 ± 0.27**	**10.46**
Total	**65.81**	**36.51**	**29.97**	**49.15**

Development rates from egg to adult are temperature dependent and development times appear to be consistent among *H. halys*' European and USA distribution. Under lab conditions in the USA, Nielsen et al, (2008) report development from egg to adult occurred in an average 121.5 days at a constant 17°C, however survival rates were low (2%). Survival increased to 62% at 20°C. Haye et al, (2014) reports similar results from Europe under fluctuating ambient temperatures. No eggs developed to adult hood at 15°C and the optimum temperature for development from egg to adult appears to be 30°C (Haye et al, 2014) (Table 6).

Table 6. Development rates from egg to adult at three temperatures in Switzerland and the USA (Haye *et al*. 2014; Nielsen et al. 2008)

Temperature	**20°C**	**25°C**	**30°C**	**Country**
Development period (days)	76.7	41.9	33.6	Switzerland
	81.2	44.92	33.4	USA

Adult active and dormant phases

The adult BMSB exhibits two behavioural phases – an active phase and a dormant phase. For the purposes of risk estimation, these two phases should be assessed separately.

The active phase commences after the fifth instar moult. During the active phase BMSB reach sexual maturity, disperse, feed and mate. In populations where two generations are produced per year, the first generation generally has no dormant phase. However, Costi et al (2017) report that adults which emerged in the second half of August in Switzerland and Italy under short photoperiodic (<15:9 day/night) went straight to diapause indicating this is not always the case.

For the overwintering generation, the active phase is punctuated by a dormant phase, which includes an aggregation period, followed by a period of quiescence. Adult BMSB are sexually immature at the point of aggregation, having entered a state of reproductive diapause (Nielsen et al. 2017). This diapause is not broken until re-emergence after which the active phase is resumed.

Hosts.

Active BMSB feed and oviposit on a broad variety of hosts (Appendix Table A 1). To date, more than 300 hundred host species in 75 families have been reported for BMSB (Bergmann *et al,* 2016; Funayama 2004; Lee *et al*, 2013; Maistrello *et al*, 2016; Musolin *et al*, 2017; Wermelinger *et al,* 2008; Yu and Zhang 2007; www.stopbmsb.org, 2018; Eppo 2018; CABI, 2018). A large proportion of these records come from two families - Rosaceae (48 species) and Fabaceae (24 species). Other families with ten or more species known to be hosts of BMSB include and Oleaceae, Aceraceae and Malvaceae.

Not all species recorded as hosts are capable of supporting all life stages of the bug. Of 254 species examined, Bergmann *et al,* (2016) found 88 woody ornamental tree and shrub taxa in the USA that support all life stages of *H. halys* and a further 123 that are hosts to at least one, but not all, life stages. The greatest abundance of BMSB were found on species in the families Leguminosae [now Fabaceae] and Sapindaceae. Significantly more BMSB were found on angiosperms than on gymnosperms.

Overwintering

For this summary the following terms and definitions will be used, which are in line with those used in Diniz et al, (2017) and Saulich and Musolin (2012).

- **Aggregation** – an accumulation of individual bugs in a single space
- **Overwintering** – a period of dormancy in response to unfavourable environmental conditions that encompasses reduced metabolic rates (quiescence) and arrested reproductive development (diapause).
- **Diapause** – a period of suspended development. In BMSB, this is a suspension of reproductive development characterised by arrested ovary development, supressed oogenesis and an absence of oviposition in females and suppressed sexual activity and pheromone production in males.
- **Quiescence** – a period of reduced metabolic activity induced by environmental stimuli.
- **Reactivation** – the recommencement of normal metabolic or developmental function.
- **Diapause termination** – the recommencement of reproductive development

Halyomorpha halys adults overwinter in aggregations in both its native and invaded ranges. Broadly, Northern Hemisphere BMSB populations begin moving to overwintering sites in September, increase this activity in October and are all are in a state of dormancy by the end of November. This dormancy continues until late April, when the bugs begin to re-emerge from their overwintering sites. However, there is considerable variation in the timing of the onset of these events at different latitudes and locations. For example aggregation behaviour has been reported in late August in China (Zhang et al, 1993) and adult BMSB have been trapped after overwintering as early as February in California and Florida, USA (Ingels and Daane, 2018; Penca and Hodges, 2018).

Aggregation

Aggregation of BMSB adults is facilitated by a combination of an aggregation pheromone and tactile cues including antennal contact and vibrations. To some degree aggregations are maintained by low temperature, which reduces movement.

In Shimoniikawa Japan, BMSB begin to congregate at aggregation sites in late September when daily lows in temperature are <15°C. Peak numbers occur in mid-late October when lows are <10°C and movement ends in late November, when the highest temperatures of the day are <15°C (Watanabe et al, 1994 (a)). However, Toyama et al, (2006) presented evidence that aggregation is not induced by temperature, but rather a combination of tactile and olfactory cues. These olfactory cues include an aggregation pheromone secreted by males (Weber et al, 2014). A reduction in temperature serves to reduce activity and maintain the aggregation (Toyama et al, 2006).

Diapause induction

As with most Pentatomid bugs, the dominant environmental cue for *H. halys* entry into reproductive diapause is daylength (Saulich and Musolin, 2012). The precise environmental cues for triggering diapause are not well understood and appear to involve the interaction of multiple environmental factors. Under experimental conditions, BMSB raised under long day (16L: 8D) conditions did not enter diapause, whereas those raised under short day (12L: 12D) conditions did (Niva and Tekada, 2003). Exposure to day lengths greater than 13 hours during the later nymphal instars predisposes bugs to enter the diapause state (Niva and Tekada, 2003, Cira et al, 2018, Musolin et al, 2019), which may subsequently be triggered by photoperiods of 11h:13h (L:D) (Sibayan, 2018). In bivoltine populations it is the second generation that enters diapause and overwinters (Costi et al, 2017).

Quiescence

Halyomorpha halys is typically inactive during the overwintering period. Li et al, (2007), report that BMSB cease all movement at temperatures below 9°C and enter a quiescent state.

However, overwintering bugs are still capable of movement in response to external stimuli. Increases in temperature have been associated with increased movement in overwintering adult BMSB (Toyama et al, 2006; Hamilton, 2009; Inkley, 2012; Nixon, 2018). Activity has also been observed in response to exposure to synthetic pyrethroids (MPI, 2018) and when nutritional reserves become low (Funayama, 2012; Costi et al, 2017).

Synthetic pyrethroids have an initial irritant effect on BMSB, inducing uncoordinated irregular movement within 10 minutes of exposure (Lee et al, 2013). This excitation decreases significantly within 1.5 hrs of exposure to pyrethroid residues as insects became incapacitated (Lee et al, 2013). Treatment of imported vehicles by fogging with pyrethroid based insecticides has resulted in increased finds of BMSB that would otherwise have been missed by visual inspection alone. As this fogging has occurred while bugs have been overwintering, it is fair to assume that the irritant effect of the pyrethroids stimulates BMSB to exit their quiescent state to move away from the source of irritation.

Funayama (2012) suggests depletion of overwintering reserves may drive bugs out of their quiescent state to find food. Costi et al, (2017) reported that the first cohort to exit overwintering experienced higher mortality than subsequent cohorts and suggested the increased mortality may be due to a combination of depleted nutritional reserves and lack of available food resources.

The results of dissections of active BMSB intercepted on goods and vessels entering New Zealand during the overwintering risk period have shown them to be reproductively inactive (MPI, 2018; Nixon et al, 2019). Nielsen et al, (2017) developed a scale of reproductive function ranging from one (undeveloped oocytes or one immature oocyte per ovariole) to five (post-vitellogenic females, ovaries distended, oocytes degenerating). To date, all the overwitnering BMSB intercepted have been found to be in class one or two (>1 immature oocyte per ovariole) when examined. This suggests that while temperature increases, or other stimuli, experienced on board ship or entering the Southern hemisphere spring/summer may stimulate activity, the bug remains in a state of reproductive diapause.

Overwintering mortality

Overwintering mortality among diapausing adults is highly variable with reports from Europe ranging between 39% (Haye et al, 2014) and 89% (Costi et al, 2017). This variation may be attributable in some part to uni vs. bivoltine phenology and resultant differences in accumulated body mass prior to overwintering.

Post overwintering adults have been demonstrated to have depleted nutritional reserves (estimated by live body weight (mg)/ pronotum width (mm)) compared to pre-overwintering adults (Funayama, 2012). Foraging for food has been demonstrated to be a priorty for BMSB on emergence from overwintering (Haye, 2017). Adults that have not accumulated sufficient nutritional reserves tend to emerge from diapause earlier. They are prone to higher mortality rates, potentially because there are insufficient food resources available in early spring to replenish their depleted reserves (Funayama, 2012). As second generation adults have a shorter available period to acrue resources for overwintering, aggregations arriving in New Zealand from bivoltine populations (e.g. Northern Italy, Southern Switzerland, China, Southern Japan and the United States) may have higher mortality than those arriving from univoltine populations.

Rates of overwintering mortality are also dependent on temperature. Kiritani, (2006) reported a 13.5% increase in overwintering survival for every 1°C increase in temperature above 4°C during the winter months (January and February). Presumably, this increase in survivorship would only occur up to 10°C as BMSB are likely to become active at this temperature; Funayama (2012) demonstrated that early emergence is associated with increased mortality.

In an experimental simulation of shipping conditions. Nixon et al, (2018) found that mortality was 89.5 ± 4.0% in BMSB prematurely "awoken" by increased temperatures matching those likely to be experienced on a voyage from the USA to New Zealand.

Cold reactivation

Cold reactivation has been demonstrated to be of primary significance for most insect species in the temperate zone and developmental activity is usually resumed after exposure to temperatures from 0-10°C (Saulich and Musolin, 2012).

Taylor et al, (2017) present experimental evidence that diapause termination in *H. halys* follows a period of at least seven weeks exposure to cold temperatures. Diapausing females were found to be unable to consistently produce viable eggs unless they had been stored for a minimum of seven weeks at a temperature of 9°C. Taylor et al, (2017) state this is consistent with unpublished field data by Nielsen. This coincides with the threshold temperature below which BMSB become inactive, as reported in Li et al, (2007), and may indicate immature adult females require a period of overwintering prior to receiving the photoperiodic cues to proceed to sexual maturity. However, the photoperiod that the BMSB were reared under is not mentioned by Taylor et al, (2017). This creates uncertainty whether the failure of BMSB subjected to shorter periods of cold storage to produce viable eggs is due to a deficiency in exposure to suitable temperatures or photoperiod.

Leskey et al, (2012) subjected overwintering adult BMSB collected from human made overwintering sites to 16:8 DN, 25 ± °C temperature and 70 ± 10% humidity conditions for ≥ two weeks to return them to an actively foraging state for insecticide trials. It is not known how long the BMSB had been overwintering or whether the treatment resulted in them becoming reproductively active or just broke their quiescence.

Photoperiodic reactivation

Daylength is considered to be the dominant environmental cue driving termination of diapause in *H. halys* (Nielsen et al, 2016). Watanabe (1980) described a limited window, between late April and mid- August, in central Japan when photoperiods were suitable for ovarian development. There is some variation in the reported critical daylength necessary for diapause termination in *H. halys*. The critical daylength has been reported to lie between 14.8 and 15.5 hours in Nagano, Japan (Yanagi and Hagihara, 1980), between 13.5 and 14 hours in Toyama Japan (Watanabe, 1979) and 13 hours in Italy (Costi et al, 2017). However, the recent discovery of gravid females in an established BMSB population in Florida, USA in mid-February, when the daylength is below 11.5 hours, (Penca and Hodges, 2018), may indicate that cues directing diapause in *H. halys* may either be less rigid than previously considered, that requirements vary dependent on the population of origin, or that diapause is not obligatory and in some regions there is no reproductive diapause. Either way, this suggests that the expansion of this species into lower latitudes cannot be entirely discounted.

Post-overwintering ovarian development

As overwintering BMSB are sexually immature, there is a lag time between diapause termination and oviposition during which the female's ovaries develop. The duration of this period is dictated by environmental factors including temperature and food availability.

After diapause termination, ovarian development may also be limited by temperature. Watanabe (1980) demonstrated that a minimum temperature of 16.3°C is necessary for ovarian development in post-diapause BMSB. Ovarian development is typically completed within two weeks (Watanabe et al, 1978).

Exit from overwintering in Italian populations begins when maximum temperatures exceed 14°C and daylength is approximately 13 hrs (Costi et al, 2017); this is comparable to overwintering exit conditions reported from Japan (Costi et al, 2017). First egg masses were laid 35.8 days later when temperatures were 21.4°C and daylength was approximately 15hrs. This suggests that ovarian development begins when daylengths are ≥14hrs (Costi et al, 2017).

Effect of nutritional status on ovarian development

Ovarian development may also be suppressed if insufficient nutrients are available (Oda et al, 1981). *Halyomorpha halys* must generally feed on multiple hosts to oviposit. Bugs fed on single host diets of pear (Fujiie, 1985) and green bean (Watanabe 1979) under experimental conditions did not produce eggs. However, some hosts such as soybean appear to provide all the nutritional requirements for egg production (Watanabe, 1979).

Biotic and abiotic factors affecting dispersal and flight ability

Foraging BMSB have been reported to fly an average of 2.7km, with about 13% of the population capable of flying >5km (Lee and Leskey, 2015). Experimental results have demonstrated that BMSB may fly as far as 75km or 117km in a single flight (Wiman et al, 2015; Lee and Leskey, 2015).

Flight capacity is variable between male and female BMSB. Typically females are able to fly further than males. This asymmetry may be attributable to the differing male and female roles in aggregation (Wiman et al, 2015).

In bivoltine populations overwintered adults do not fly as far as summer generation adults when foraging. Preflight weight was found to be negatively correlated with flight speed and distance and positively correlated with frequency. Overwintered adults lose a large proportion of their pre-flight weight during diapause, which may account for this asymmetry (Wiman et al, 2015).

Temperature, irradiance and wind speed are the key abiotic factors affecting flight. Increasing temperatures (up to 30°C) increase the proportion of individuals that fly (Table 2.). Conversely, decreasing wind speed increases the likelihood that BMSB will fly. When conditions are still, 83% of individuals will make a flight. At wind speeds ≥0.75m/s fewer than 10% will fly. Flight typically occurs in the opposite direction to the sun, particularly before noon (Lee and Leskey, 2015).

Table 7. Proportion of BMSB individuals undertaking dispersal flights increases with increasing temperature (Lee and Leskey, 2015).

Temperature range (°C)	10-15	15-20	20-25	25-30
Proportion of individuals undertaking flight (%)	3	61	84	87

Mating communication

Long range mating communication in *H. halys* is mediated by aggregation pheromones emmited by males (Khrimian et al, 2014). The two main compounds in the pheromone are (1S,4S)-4-((R)-4-((S)-3,3-dimethyloxiran-2-yl)butan-2-yl)-1-methylcyclohex-2-enol and (1R,4S)-4-((R)-4-((S)-3,3-dimethyloxiran-2-yl)butan-2-yl)-1-methylcyclohex-2-enol (Khrimian et al, 2014), or, using terpene nomenclature (3S,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol and (3R,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol (Weber et al, 2014). These compounds, in combination with a synthetic isolate of the aggregation pheromone of the brown-winged green bug *Plautia stali* Methyl (E,E,Z)-2,4,6-decatrienoate (MDT), have been shown to be more effective as BMSB lures than any of the compounds individually (Weber et al, 2014).

Short range (i.e. between multiple BMSB on a single plant) communication is mediated by vibrational signals (Polajnar et al, 2016; Mazzoni et al, 2017). Males emit a vibrational call that females respond to with their own call and this in turn stimulates male searching behaviour. Simulations of these calls have been tested as a potential lure for BMSB in orchards (Mazzoni et al, 2017).

5 Risk assessment

This assessment considers the risk of BMSB entering, finding suitable habitat and establishing in New Zealand and the likely economic, environmental and social impacts if this were to occur. For the purposes of this assessment, likelihood is divided into five Categories: Negligible, Low, Moderate and High. These categories are defined as follows:

- Negligible- Not worth considering; insignificant
- Very Low - Close to insignificant
- Low – Less than average, coming below the normal level
- Moderate – Around the normal or average level
- High – Extending above the normal or average level

5.1 Entry assessment

Interceptions

Organisms intercepted on imported goods at the border or post border are sometimes identified and recorded, usually during the biosecurity clearance process or as part of a monitoring survey. These records are extremely valuable because they demonstrate an actual rather than a theoretical association with a pathway for both live and dead organisms.

However there are significant limitations to their use, and both relative and absolute numbers of interception records are largely meaningless. Some of the reasons interception data cannot be used quantitatively are:

- Not every organism on a pathway is detected. The level of detection of contaminants was tested on four pathways into the USA by Work et al. (2005). They estimated that even rigorous quarantine inspections probably only find 19-50% of associated species, depending on the pathway. These results were limited to insect species, probably due to the difficulty involved in detecting pathogens and other very small non-insect arthropods (such as mites) by visual examination. Work et al. (2005) also found that, although interception rates were highest in refrigerated maritime cargo (which includes fresh produce) the detection rate was poor on this pathway compared to the other cargo pathways. Detection rates are likely to vary greatly depending on the nature of the commodity and the biological characteristics of the taxon involved e.g. cryptic behaviour and body size. The sampling protocols used are also influential (e.g. Venette et al. 2002; Barron 2006).

- Not every organism detected is recorded or identified.
- The same interception may be recorded in multiple locations and duplications can occur.
- Search effort and the levels of identification done can vary (for example many interception records come from surveys).
- The level and reliability of identifications can vary.
- The viability or life stage of an organism may not be recorded, or may be inaccurately recorded.

Additionally, entry pathways have different levels of quarantine inspection, identification and recording, and interceptions recorded during surveys reflect only that season or set of import conditions. Many interceptions are not identified to species level and post border interceptions generally rely on public reporting (Toy and Newfield, 2010). For the reasons detailed above, absence of interceptions cannot be taken as evidence of absence on the pathway. Similarly, as the levels of inspection may vary between pathways, a high frequency of detections on one pathway may not necessarily reflect a higher level of contamination.

Between 14th of November, 2005 and the 9th of May, 2018 there were 592 BMSB interception events at the New Zealand Border and 33 post border. Of these interceptions, the three main source countries were Italy (260), the USA (149) and Japan (96). With the exception of one dead nymph in a sea container from Italy, all BMSB intercepted were adults.

The type and format of interception data recorded for BMSB was revised in late 2017. While the overall quality of data improved significantly, the revision makes reliable comparison of the two data sets difficult. For this reason, BMSB detection data is summarised below in two blocks 2005-2017 and 2017-2018.

From 2005 to 2017 there were 309 interception/detection events recorded (280 pre-arrival or at the border, and 29 post border). Of the 29 post border detections, 20 involved BMSB that were alive, 2 involved a mixture of live and dead BMSB and the remaining 7 were of dead stink bugs.

The reported countries of origin for the border detections were: China (8), Hong Kong (1), Hungary (2), Italy (110), Japan (27), Korea (4), Malaysia (2), Papua New Guinea (1), Slovenia (1), Switzerland (2), Taiwan (1), United Kingdom (2) Unknown (16), USA (103).

These border interception events detected a total of 1244 individual BMSB adults, of which 153 were recorded as alive, 1077 as dead and 14 were recorded as a mixture of dead and alive. It should be noted that at this time no distinction was recorded between freshly dead (post treatment) and long dead insects, making it difficult to estimate how many BMSB arrive at the border alive. The number of individual bugs on goods from the reported country of origin and recorded life state are presented in the Table 8.

Table 8. Between 2005 and 2017 1244 individual BMSB adults were intercepted at the New Zealand border from various countries of origin. Of these 1244 bugs, 1077 were recorded as dead and 153 alive. Mixed refers to records where the total number of BMSB detected was not divided into living and dead.

Country of Origin	Alive	Dead	Mixed
China	5	48	0
Hong Kong	0	1	0
Hungary	2	2	0
Italy	50	504	5
Japan	2	42	0
Korea (South)	2	7	0
Malaysia*	1	3	0
Papua New Guinea*	0	1	0
Slovenia	0	30	0
Switzerland	1	1	0
Taiwan	0	1	0
United Kingdom*	1	1	0
Unknown	4	44	0
USA	85	392	9

N.B. Countries marked * are not known to have established populations of BMSB.

As might be expected from a hitchhiker species, there was no biological association with the fomites the BMSB were detected on. The interceptions were on a wide variety of commodities including vehicles, machinery, containers, vessels and tiles.

During a 2017 visit to Italy, MPI staff observed that many of the manufacturing or dispatch sites of goods that had had BMSB associated with them were in close proximity to woodland and/or agricultural land growing known BMSB host species. Many of the goods were stored outside prior to dispatch and it is likely that such storage significantly increased the likelihood of infestation. Maistrello et al, (2016) report that heavy infestations of overwintering BMSB were most commonly observed in buildings close to host vegetation.

Between 2017 and 2018 there were a further 316 detections/interception events (of which 4 were post border and the remaining 312 at the border). Forty of the 312 border detections contained one or more live stink bugs. Typically, fewer than three live bugs were found at one time, but larger aggregations of 15, 24 and 27 live BMSB were found on goods from Italy. Nine detections contained a mixture of dead and living bugs. The number of bugs in these detections ranged from 2 to 139. The largest numbers were on goods from Japan (including detections of 94 and 139 bugs) and Italy (74 bugs). All were associated with containerised goods, vehicles or machinery. However, it is uncertain from the available data what ratio of live or dead bugs was present or whether the dead insects arrived alive and died as a result of treatment or if they were long dead. The remainder of the detections were of dead BMSB.
The number of individual bugs on goods from the reported country of origin and recorded life state are presented in the Table 9.

Between 2005 and 2018, live BMSBs have been intercepted in all months except May, July and August. However, the greater number of interceptions have occurred in November, December and January with the greatest number occurring in December across all years (MPI 2019).

Table 9. Between September 2017 and May 2018 a further 2616 individual BMSB adults were intercepted at the New Zealand border from various countries of origin. Of these 108 were alive, 2118 were recorded as dead and 390 as a mixture of both live and dead.

Country of Lading	Alive	Dead	Both
China	4	9	2
Hungary	0	1	
Indonesia		1	
Italy	81	762	83
Japan	1	1023	288
Korea (South)	4	5	
Netherlands		1	
UK	1	2	
Unknown	4	143	17
USA	13	171	

Predicting risk countries using distribution and interception data

Detections of BMSB from newly invaded Northern Hemisphere countries appear to begin at the New Zealand border one year after the bug has been reported as established. While precise change in distribution data is sparse and this detection rate is clearly dependent on import volumes and existing measures, the authors' observations suggest that countries pose a potential risk as soon as an established BMSB population is detected and that this risk increases concomitantly with increase in distribution and abundance in that country.

Interception records indicate that *Halyomorpha halys* was first detected on goods from the USA at the New Zealand border in January 2013 and it has been intercepted yearly since (MPI, 2019). The USDA has been reporting BMSB distribution on the StopBMSB website since May 2012. The USDA reports pest status in individual states in USA based on establishment and abundance is divided into five categories: No record, Intercepted or detected, Nuisance only, Nuisance and Agricultural problems and Severe Agricultural problems (StopBMSB 2019). As MPI BMSB interception data on cargo from the USA is not state specific, it is only possible to make predictions for the USA at the country level.

To estimate the relationship between interceptions and pest category, the USDA BMSB impact categories for each state were converted from descriptive to numerical categories as follows: O = No record, 1 = Intercepted or detected, 2= Nuisance only, 3= Nuisance and Agricultural problems and 4= Severe Agricultural problems and Mean BMSB impact across all states were then calculated for each year. When this data was plotted against interceptions of BSMB from the USA, a moderate increase in interceptions was observed when the bug fell into the nuisance pest category. This suggests that the potential for BMSB interceptions on goods from the bug's invaded range will begin to increase as soon as it has become established in urban or industrial areas. However, it should be noted that the slope of the curve was likely reduced by the application of and adherence to measures on the import pathways (MPI, 2018).

BMSB interceptions at New Zealand border appear to increase exponentially with BMSB population growth. Based on available interception data (MPI, 2018), the first confirmed interceptions of BMSB at the New Zealand border from European countries occurred in November 2014. The bug is recorded as being alive on arrival. There were 125 subsequent interceptions of BMSB from Europe between December 2014 and November 2017. Of these 125 interceptions, 118 were on cargo that originated from Italy: one in 2014, 22 between November 2015 and March 2016, 93 between October 2016 and June 2017 and one (dead) in November 2017 (on tiles). These interceptions reflect the exponential BMSB population growth rate in Italy as presented in Maistrello et al., (2018).

The greatest number of interceptions of BMSB entering New Zealand on goods from Italy has been reported from December and January of each year. To ensure this peak did not coincide with a similar increase in the number of consignments, a simple linear regression was calculated between the number of consignments received from Italy between 2014 and 2018 on pathways that BMSB is known to have been associated with per month. No significant relationship between month and the number of consignments was found ($F (1\ 51) = 3.06$, $p = 0.09$ with an R^2 of 0.04). Given the timing of aggregation and onset of overwintering, and that the journey from Italy to New Zealand takes approximately six weeks, the peak in interceptions in December and January reflects associations with inanimates during the peak of aggregation period and initial onset of overwintering. This pattern is consistent with interception counts among cargo from other Northern hemisphere countries where BMSB is prevalent.

5.2 Pathway assessment

Inanimates (containers and their contents, vehicles, machinery and tyres)

The previous BMSB Pest Risk assessment (MPI, 2012) and the Australian Draft PRA for BMSB (DAWR, 2017) concluded that the highest risk pathways for BMSB to enter New Zealand is inanimates (containers and their contents, vehicles, machinery and equipment) imported during the bug's overwintering period from countries where BMSB is present. In the Northern Hemisphere, this overwintering period falls between September and April. These remain high volume import pathways and, based on available interception data (MPI, 2019), remain the pathways on which adult BMSB singles and aggregations are intercepted.

Halyomorpha halys is not known to lay its eggs on inanimate objects. The BMSB typically lays its eggs on the underside of leaves high in the canopy and very occasionally on fruit.

Though *H. halys* nymphs (second to fifth instar) are highly mobile (Lee et al, 2014), they cannot fly. They typically move from one host species to another in search of food. Nymphs may aggregate in large numbers on feeding substrates, but are not known to aggregate on inanimate objects. However, 2nd - 5th instar nymphs have been demonstrated to respond to aggregation pheromone (Harris et al 2015; Weber et al 2017), so the possibility that some late-emerging nymphs may be associated with overwintering adults cannot be altogether discounted. The likelihood they would remain associated with containers, machinery or vehicles is Low to very low.

In the Northern hemisphere, adult BMSB are likely to be active between late April and early October (Lee et al, 2013; Haye et al, 2014; Maistrello et al, 2016; Costi et al, 2017; Leskey and Nielsen, 2018). In Chile, they are likely to be active between late-October and mid-March (SAG unpublished). During this active period, BMSB feed and reproduce. Individuals may become trapped in machinery, vehicles or containers, but the likelihood this would happen to large numbers of bugs is negligible as they would be actively dispersing in search of food and mates rather than aggregating in a single area.

One or more mated females could become trapped in a vehicle or machinery. The likelihood for survival of a trapped, mated BMSB is uncertain. Nixon et al, (2018) report 89.5% mortality rate in overwintering BMSB subjected to simulated temperatures in a container on a voyage from the USA to New Zealand. Prior to overwintering BMSB accumulate nutritional reserves to carry them through the winter months (Funayama, 2012). It is unclear whether a mated female would have sufficient reserves to last the duration of a voyage, or whether she would oviposit during the voyage or on arrival. The likelihood should be considered very low to low that either instance could occur, and as such should not be discounted.

In some parts of the the Northern Hemisphere (China), BMSB has been reported to begin aggregation as early as the last week in August (Zhang et al, 1993) and overwinter until late April. However, other reports have reported emergence occurring as late as June (Costi et al, 2017; Bergh et al. 2017).

In Chile, aggregation appears to begin in mid-March, though nymphs have been observed foraging as late as the third week in April (SAG unpublished). The bug will remain quiescent over winter from the beginning of June until mid-to-late October. During this overwintering period, there is a high likelihood that BMSB will become associated with containers, vehicles and machinery, particularly those situated close to host plant material.

Vessel hold temperatures are typically greater than 10-15°C (Grier and Chan, 1970; Weiskircher, 2008), which is reported to be the temperature necessary to bring overwintering BMSB out of their quiescent state (Lee et al, 2013). Activity during the overwintering period depletes the nutritional reserves stored in the insect's fat bodies more rapidly than remaining quiescent (Funayama, 2012; Costi et al, 2017). There is a high likelihood that emerging BMSB would be unable to find suitable food or water on a vessel to replenish depleted reserves and this has been suggested to be a cause of the high mortality rates (89.5%) observed under experimental conditions simulating vessel temperatures (Nixon et al, 2018).

Similarly, under simulated temperature conditions (without light) of a ship originating from Baltimore, MD USA to Auckland, NZ, overwintering female survivroship was low. However, of the surviving females, 60% produced eggs. Surviving females took an average of 14-21 days to reproduce (Nielsen unpublished).

BMSB entering New Zealand from Chile would be coming from one winter environment to another. There is a high likelihood that the bugs' overwintering dormancy would have been be punctuated by a period of activity enroute induced by vessel temperatures There is also a high likelihood that temperatures on arrival would result in the resumption of their quiescent state. Activity during overwintering depletes stored nutritional reserves. Survival of BMSB with depleted nutritional reserves has been demonstrated to be lower than those with sufficient reserves (Funayama, 2012). There is a high level of uncertainty whether BMSB coming from Chile would retain sufficient resources to survive re-entering quiescence. Because of this uncertainty, the likelihood that they would survive until the end of winter in New Zealand is estimated to fall in the range of very low to low.

Given that:

- BMSB is not commonly known to lay eggs on inanimate objects;
- BMSB nymphs do not form overwintering aggregations and are highly mobile;
- BMSB adults are highly mobile and will be seeking hosts and mates between late-April and early September in the Northern Hemisphere and between late-October and early-March in the Southern Hemisphere;
- In the Northern Hemisphere, BMSB adults are likely to start overwintering aggrgations from September and overwinter from late November until April. In the Southern Hemisphere (Chile) BMSB is likely to start overwintering aggregations from late-March and overwinter until mid to late-October;
- In the Northern Hemisphere, BMSB is widespread through North America, Europe and Asia. In Chile, BMSB is only known to occur in urban Santiago and are currently at low abundance;

the risk of entry on inanimate pathways is estimated as per the entry assessment table EA1 below.

Table EA1. The risk of BMSB entry on inanimate pathways

Between April and September, the Likelihood of BMSB:	Eggs	Being associated with Inanimates (containers and their contents, vehicles, machinery and tyres) from the	Northern Hemisphere	is considered	**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		**Negligible**	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult singles active		Northern Hemisphere		Negligible	**Very Low**	**Low**	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult Aggregations		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	**Low**	Moderate	High
Between September and April, the Likelihood of BMSB:	Eggs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		Negligible	**Very Low**	**Low**	Moderate	High
			Southern Hemisphere		**Negligible**	**Very Low**	Low	Moderate	High
	Adult singles active		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern		Negligible	Very	**Low**	Moderate	High

			Hemisphere			Low			
	Adult Aggregation		Northern Hemisphere		Negligible	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High

N.B. The likelihood of overwintering BMSB entering from the Southern Hemisphere is considered very low because of the bug's current restricted distribution and limited abundance. Should BMSB distribution and abundance increase in Chile or elsewhere in the Southern Hemisphere, the risk should be re-assessed.

Nursery Stock

Nursery Stock may refer to whole plants, cuttings (dormant or non–dormant), bulbs and tubers and tissue culture (MPI IHS 155.02.06, 2019). Of these, BMSB is only likely to be associated with whole plants. Whole plants is a comparatively low volume pathway and there have been no reports of BMSB interceptions on this pathway between 2005 and 2018 (MPI, 2019).

Whole plants must be treated for insects and mites as part of Basic entry conditions (MPI, 2019). The approved treatments include fumigation with methyl bromide, or spray/dip treatment with any two of the following active chemicals: carbaryl, tebufenozide, imidacloprid, thiacloprid, acephate, chlorpyrifos, dimethoate, pirimiphos-methyl, deltamethrin, fenvalerate or spinosad.

In addition to these treatments, all Nursery Stock, unless specified in schedules of special entry conditions must undergo a period of post entry quarantine, typically not less than three months.

All BMSB life stages have the potential to be associated with whole, Nursery Stock plants. For adults, this will only be the case during their active phase when they are feeding and seeking mates. In the Northern Hemisphere, this active period falls between late April and early September (Lee et al, 2013; Haye et al, 2014; Maistrello et al, 2016; Costi et al, 2017; Leskey and Nielsen 2018). In Chile, BMSB has been reported to be active between late-October and mid-March (SAG unpublished).

Entry of eggs and nymphs:
Halyomorpha halys eggs are creamy green-white in colour, and are laid in regular clusters of between 20 and 30 on the underside of leaves in the upper canopy of host species (Hoebeke and Carter, 2003). Instances have been reported of eggs being laid on structural and reproductive plant parts (Leskey, 2012), but this is not common. These clusters are easily visible to the naked eye.

Insecticide dose rates required for effective control of the egg stages of insects may be significantly higher than those required for effective control of nymphs or adults. The required dose for sulfuryl fluoride needed to effectively control eggs may be 29 times greater than that required for adults (Ormsby, 2018). There is limited information available that is specific to the treatment of BMSB eggs, however Kuhar and Kamminga (2017) report that while the insecticides novaluron and diflubenzuron effectively controlled *H. halys* nymphs, they had little effect on adults or eggs.

First instar nymphs are sedentary remaining associated with their natal egg mass (Taylor 2014). First instar nymphs are more likely to be associated with leaves higher (>2m) on a plant. The nymphs are approximately 2.4 mm in length, orange with black markings and are easily visible to the naked eye (Figure 5.). Depending on height and species, there is a low to moderate likelihood first instar nymphs will be associated with leaves of nursery stock.

Second to fifth instar nymphs are highly mobile but flightless. They are easily disturbed and can move 2-4 m per hour depending on temperature (Lee et al, 2014). The likelihood of nymphs remaining associated with Nursery Stock plants subjected to normal production procedures is negligible.

Entry of adults

Adult BMSB is highly mobile, strong fliers and are easily disturbed. The likelihood that adult BMSB would remain associated with Nursery Stock plants subjected to normal production procedures is considered negligible.

Figure 5. Brown marmorated stink bug eggs and first instar nymphs on the underside of a leaf.

Given that:

- BMSB is only likely to be associated with Nursery Stock in the period between spring and autumn
- There have been no reported interceptions of BMSB on Nursery Stock at the New Zealand border.
- BMSB are only likely to be associated with Nursery Stock imported as whole plants
- Whole plants is a comparatively low volume pathway compared to other forms of Nursery Stock
- All whole plant Nursery stock is subject to fumigation or chemical spraying and most is subject to a minimum of three months post entry quarantine
- Eggs and first instar nymphs are most likely to be on the underside of leaves situated >2m above ground level
- Eggs may be resistant to many insecticide treatments effective on nymphs and adults
- Adult and second to fifth instar BMSB nymphs are highly mobile, easily disturbed and will not remain associated with whole plants subjected to routine pre –export handling
- All stages of BMSB are easily visible to the naked eye

the risk of entry on Nursery Stock is estimated as per the Entry assessment table EA2 below

Table EA2. The risk of BMSB entry on Nursery Stock

Between April and September, the Likelihood of BMSB:	Eggs	Being associated with Nursery Stock from the	Northern Hemisphere	is considered	Negligible	Very Low	**Low**	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult singles active		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult Aggregations		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
Between September and April, the Likelihood of BMSB:	Eggs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult singles active		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult Aggregation		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High

N.B.
The likelihood of BMSB egg masses entering from the Northern Hemisphere is considered low because of uncertainty around insecticide efficacy in treating BMSB egg masses.
The likelihood of BMSB egg masses entering from the Southern Hemisphere is considered negligible because of the bug's current restricted distribution and limited abundance. Should BMSB distribution and abundance increase in Chile or elsewhere in the Southern Hemisphere, the risk should be re-assessed.

Fresh Produce

The Import Health Standard (IHS) for Fresh Produce (Standard 152.02) manages imports by country rather than commodity.

Of the countries where BMSB is known to be present only the following have IHSs for the import of Fresh Produce into New Zealand: Chile, China, Italy, Japan, Korea, Spain, Taiwan, and USA. A list of commodities imported from each of these countries is presented in Table 10.

Table 10. Species with IHSs for import as Fresh Produce from countries where *Halyomorpha halys* is known to be established.

Country	Host species	
	Reported as BMSB host	Not reported as BMSB host
Chile	*Malus sylvestris* *Prunus domestica* *Vitis vinifera*	
China	*P.sp* nr *communis* *P.pyrifolia*, *Vitis vinifera*	*Allium sativum* *Pyrus bretschneideri*
Italy	*Actinidia deliciosa* *Vitis vinifera*	
Japan	*Citrus reticulata*, *Malus* x *domestica*	*Allium cepa*
Korea	*Pyrus pyrifolia*, *Vitis vinifera*	*Vitis labrusca*, *Vitis labruscana*
Spain	*Citrus sinensis*	
Taiwan		*Mangifera indica* *Litchi chinensis*
United States of America	*Actinidia deliciosa*, *Asparagus officianalis* *Citrus reticulata* *Citrus sinensis* *Fragaria* sp. *Malus* x *domestica* *Pisum sativum* *Prunus armeniaca* *Prunus avium* *Prunus domestica* *Prunus persica* *Punica granatum* *Pyrus communis* *Vitis vinifera*	*Allium cepa* *Allium sativum* *Carica papaya* *Citrus aurantifolia* *Citrus limon* *Citrus paradise* *Citrus paradise* x *C. reticulata* *Citrus maxima* *Mangifera indica* *Phoenix dactylifera*

Since 2005, there have been three interceptions/detections of BMSB on the Fresh Produce pathway. All of these detections have been on kiwifruit from Italy. A total of five BMSB were found, of which one was recorded as alive.

Different commodities are subject to different export production systems (postharvest and packing activities); these systems are assessed by the import risk analysis and the consequent import health standard for specific country and commodity combinations. Post-harvest export production systems typically include steps such as washing, brushing and visual inspection, although this can vary depending on the commodity. Furthermore the architecture of different commodities can determine the procedures used, for example oranges are much easier to wash and inspect than grapes; therefore, grapes may require additional treatments to comply with the relevant import health standard.

Eggs

Egg masses have been observed on fruit (grapes) (Leskey, 2011) but this is not commonplace. There is a high likelihood that the export production systems would remove any eggs that may be present on most fresh produce. However there is some uncertainty whether this would be the case for grapes.

Nymphs

Second to fifth instar nymphs are highly mobile but flightless. They are easily disturbed and can move 2-4 m per hour depending on temperature (Lee et al, 2014). The likelihood that nymphs would remain associated with Fresh Produce subjected to normal production procedures is very low.

Adults

Adult BMSB are highly mobile, strong flyers and are easily disturbed. The likelihood that adult BMSB would remain associated with Fresh Produce subjected to normal production procedures is very low. However, adult BMSB have been found associated with Fresh Produce from Italy, suggesting the likelihood is non negligible.

Any adult BMSB associated with Fresh produce are more than likely to be individuals rather than aggregations because the timing of fruit harvest coincides with the bug's active foraging rather than overwintering stage.

A recent report from California, suggested that BMSB shelter from high temperatures in California by crawling into the centre of grape clusters and that nymphs in particular were very difficult to see in grape clusters (Ingles 2017).

Table grapes are imported from the USA between mid-June and late December (Quancargo, 2018). This includes a period between early September and late December, when temperature and daylength in New Zealand is increasing and the probability of BMSB establishment is higher. However, establishment would still be reliant on multiple individuals arriving together, surviving and remaining in proximity. There is a very low likelihood that sufficient numbers of BMSB to form a founder population would be associated with a single cluster of grapes or that multiple infested clusters of grapes would remain in proximity.

Table grapes from California are subject to either SO_2/CO_2 (1:6%) fumigation at a minimum of 16 ºC or above for 30 minutes AND methyl bromide fumigation at 40 g/m3 for 2 hours at 15.5°C and above

OR

SO2/CO2 (1:6%) fumigation at a minimum of 16 ºC or above for 30 minutes AND The core temperature of the fruit to be held continuously at -0.5ºC (± 0.7 ºC) for 6 days before or during transit to New Zealand. OR The core temperature of the fruit to be held continuously at 0.9°C (± 0.7 ºC) for 12 days before or during transit to New Zealand.

A number of insecticides are known to be ineffective against BMSB. However, there is no available literature on the efficacy of SO_2/CO_2 in the treatment of BMSB.

Mortality of BMSB at -5°C was found to be between 18 and 24% (Cira et al, 2016). The mean supercooling point for BMSB in summer was found to be ~-9°C (Cira et al, 2016), however this was variable dependent on, sex, lifestage and location.

It is therefore, uncertain whether the combination of SO_2/CO_2 (1:6%) fumigation and cold treatment at 5°C would be sufficient to kill a sufficient number BMSB present in grape clusters.

Fresh Produce from the Southern Hemisphere

In the Southern Hemisphere, BMSB is known only from Santiago City, Chile, where the population is at low abundance (SAG unpublished). To date, there have been no records of BMSB in rural production areas of Chile (SAG unpublished) where Fresh Produce is likely to be sourced from.

There are IHSs for the import of apple (*Malus sylvestris*), plum (*Prunus domestica*) and grape (*Vitis vinifera*) from Chile. Of these, plums have been imported in April and May and grapes from December until the end of June and in August (Quancargo, 2018). There is no record of fresh apple imports from Chile.

Individual adults or nymphs may be associated with fresh fruit from Chile. However, adults and nymphs are mobile and easily disturbed and are unlikely to remain on items that are subjected to commercial packing processes.

Eggs could occasionally be laid on fruit and there have been reports on grapes and peaches (Leskey, 2011), but this is rare and not considered to be typical behaviour. There is a high likelihood that the export production systems would remove a large proportion of any eggs that may be present.

Given that

- *Halyomorpha halys* eggs are typically laid on the underside of leaves and very rarely on fruit
- First instar nymphs remain associated with their natal egg mass.
- There is a high likelihood that any egg masses (and first instar nymphs) on fruit or other fresh produce would be removed as part of the commercial handling process
- Adult and second to fifth instar BMSB nymphs are highly mobile, easily disturbed. There is a low likelihood that nymphs or adults would remain associated with fresh produce during the production process.
- Fresh Produce is subject to visual inspection and all stages of BMSB are easily visible to the naked eye, though the limitiations of viual inspection must be acknowledged- paticularly with pests occurring with low frequency on high volume pathways
- There have been rare detections of BMSB on fresh produce

and

Given that:

- There have been no interceptions of BMSB reported on grapes from California
- That shipments of grapes from California are received at a time of year when the likelihood of establishment is increased

and

Given that:

- BMSB adults and nymphs are highly mobile and easily disturbed
- BMSB eggs tend to be laid on the underside of leaves high in the canopy rather than on fruit
- In Chile, BMSB is only known to occur in urban Santiago and not in the agricultural or horticultural production regions

the risk of entry on Fresh Produce is estimated as per the entry assessment table EA3 below

Table EA3. The risk of BMSB entry on Fresh Produce

Between April and September, the Likelihood of BMSB:	Eggs	Being associated with Fresh Produce from the	Northern Hemisphere	is considered	Negligible	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult singles active		Northern Hemisphere		Negligible	**Very Low**	Low	Moderate	High

			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High
	Adult Aggregations		Northern Hemisphere		Negligible	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High
Between September and April, the Likelihood of BMSB:	Eggs		Northern Hemisphere		Negligible	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		Negligible	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High
	Adult singles active		Northern Hemisphere		Negligible	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High
	Adult Aggregation		Northern Hemisphere		Negligible	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High

N.B. The likelihood of BMSB egg masses, nymphs and solitary adults entering New Zealand on Fresh Produce from the Nothern Hemisphere is considered very low but non-negligible because of a combination of evidence from previous interceptions, and uncertainty around the efficacy of SO_2/CO_2 treatement of BMSB eggs and other life stages associated with grapes.

The likelihood of BMSB egg masses entering from the Southern Hemisphere is considered negligible because of the bug's current restricted distribution and limited abundance. Should BMSB distribution and abundance increase in Chile or elsewhere in the Southern Hemisphere, the risk should be re-assessed.

Cut flowers and foliage

The Import Health Standard (HIS) for Cut flowers and Foliage (Standard 152.02.04) manages imports by country rather than by commodity. It is a requirement of the IHS that all incoming cut flowers or foliage are free from Regulated pests. If a risk group 1 pest such as BMSB is detected on arrival inspection, the importer is obliged, to treat, reship or destroy the consignment it was found on.

Of the countries where BMSB is known to occur, only Canada and the USA have IHSs for import of cut flowers and foliage.

Only *Xerophyllum tenax* (bear grass) may be imported from Canada and this is not a known host of BMSB.

Of the species that may be imported under the Cut Flowers and Foliage IHS from the USA, only *Helianthus* spp. (sunflower) and *Myrica* spp. (wax myrtle) are reported as hosts (see Lee et al, 2013; USDA, 2018; CABI, 2018) However, there are no records of imports of either taxon within the last 5 years (Quancargo, 2019).

Eggs
Both *Helianthus* spp. and *Myrica* spp. can reach, or exceed a height of 2 metres. As *H. halys* typically lays its eggs on the underside of host leaves at heights at or greater than 2 metres, there is a very low likelihood that egg masses may be associated with cut flowers and foliage of *Helianthus* spp. and *Myrica* spp. from the USA. As first instar nymphs are sedentary, there is a very low likelihood they too would be associated with Cut Flowers and Foliage of these taxa.

Nymphs
Second to fifth instar nymphs are highly mobile but flightless. They are easily disturbed and can move 2-4 m per hour depending on temperature (Lee et al, 2014). There is a very low likelihood nymphs would remain associated with Cut Flowers and Foliage subjected to normal production procedures.

Adults
Adult BMSB are highly mobile, strong fliers and are easily disturbed. The likelihood that adult BMSB would remain associated with cut flowers and foliage subjected to normal production procedures is negligible.

All Cut Flowers and Foliage are subject to visual inspection and BMSB egg masses and nymphs are easily visible to the naked eye.

To date there has only been one interception, a single dead male on a wreath from the USA

Given that

- Only two known BMSB host genera may be imported as cut flowers and foliage from countries where BMSB are known to occur.
- These two genera have not been imported from those countries for at least five years.
- *Halyomorpha halys* eggs are typically laid on the underside of leaves but rarely on reproductive structures
- First instar nymphs remain associated with their natal egg mass.
- Adult and second to fifth instar BMSB nymphs are highly mobile, easily disturbed. There is a very low likelihood BMSB adults or nymphs would remain associated with fresh produce during the production process.
- To date, there have been no detections of any BMSB life stage on cut flowers and foliage
- Cut flowers and foliage are subject to visual inspection on arrival and all stages of BMSB are easily visible to the naked eye;
- Importers are required to treat, reship or destroy any consignment that a risk Group 1 pest is detected on

the risk of entry on Cut Flowers and Foliage is estimated as per the entry assessment table EA4 below

Table EA4. The risk of BMSB entry on Cut Flowers and Foliage

Between April and September, the Likelihood of BMSB:	Eggs	Being associated with Cut Flowers and Foliage from the	Northern Hemisphere	is considered	Negligible	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult singles active		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult Aggregations		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
Between September and April, the Likelihood of BMSB:	Eggs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High

	Adult singles active		Northern Hemisphere		Negligible	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High
	Adult Aggregation		Northern Hemisphere		Negligible	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	Moderate	High

N.B. The likelihood of BMSB egg masses entering New Zealand on Cut Flowers and foliage from the Nothern Hemisphere is considered **very Low**, but non negligible due to the combination of an open but inactive IHS for known hosts from a country where BMSB is known to occur and the uncertainty around the efficacy insecticide treatments of BMSB eggs.

Passenger pathway and personal effects

A total of 3,688,013 overseas visitors were recorded entering New Zealand between October 2016 and October 2017. Of the top thirty countries of origin, eight are countries where BMSB is known to be established (China, USA, Germany, Japan, Korea, Canada, France and Switzerland) equating to 1,194, 944 visitors from countries where BMSB is present in one year (Stats NZ, 2017). The peak period for arrival of visitors from overseas is November to March.

MPI applies interventions at a range of points in the passenger arrival process to manage biosecurity risk. All passengers are exposed to communications describing biosecurity requirements and are required to fill in the Passenger Arrivals Card (PAC) before arriving.
Upon arrival all passengers pass through immigration and collect their baggage from the carousel. During this process, passengers may be screened by detector dogs. However, there is currently only one dog fully trained to detect BMSB and three others close to completing training. None of these dogs is used on the Passenger (PAX) pathway.
All passengers are then assessed by a Quarantine Inspector and will either be referred to full inspection, x-ray, and item inspection or, if eligible, may be cleared to use the Green Lane exit. Inspected items may be treated or destroyed. Items may also be held at the airport for the passenger to retrieve on their departure (MPI 2013).

Eggs
Halyomorpha halys typically lays its eggs on the underside of leaves higher in the canopy. There is a very low likelihood that eggs could be deposited on luggage or personal effects stored outside on a first floor or high rise balcony or other elevated area, particularly if there is also host material present nearby. First instar nymphs would remain associated with such egg masses.

Nymphs/Adults
During the active feeding/breeding period between late April and early September in the Northern hemisphere (Lee et al, 2013, Haye et al, 2014, Maistrello et al, 2016, Costi et al, 2017, Leskey and Nielsen 2018), and between late-October and mid-March in Chile (SAG unpublished) It is possible that these life stages (including gravid females) may inadvertently land on and become trapped in personal effects or in luggage being packed. There is therefore a very low but non-negligible likelihood that adult BMSB and/or second to fifth instar nymphs could be associated with any personal effects or luggage.

Halyomorpha halys overwinters as an immature adult (Nielsen 2008). Eggs and nymphs are not produced during the overwintering period.

In some areas of the Northern Hemisphere (e.g. China) BMSB have been reported to begin aggregation as early as the last week in August (Zhang et al, 1993) and overwinter until late April, though some reports describe emergence occurring as late as June (Costi et al, 2017). In Chile, aggregation appears to begin in mid-March, though nymphs have been observed foraging as late as the third week in April (SAG unpublished). The bug is expected to remain quiescent over the Southern Hemisphere winter from the beginning of June until mid-to-late October.

Overwintering adult BMSB will seek shelter in cracks and crevices and could become associated with folded clothes, suitcase linings and many other forms of personal effects and luggage during this period, particularly if the items have been stored near host material.

Between 2005 and 2014 there were 19 border interception events of BMSB associated with air passengers from China (3) USA (11), Japan (1) Korea (1) Switzerland (1) and 2 recorded as being of unknown origin. Seven of these were associated with tents and seven were found in luggage.

Between 2005 and 2018 there were 12 post border detection events associated with personal effects (including luggage, textiles clothing and household effects) from Italy, Japan Germany and the USA. The detections occurred between October and February with five of the twelve being detected in November and five in February.

BMSB and Passengers from the Southern Hemisphere

In the Southern Hemisphere, BMSB is known only from Santiago City, Chile, where the population is at low abundance (SAG unpublished). To date, there have been no records of BMSB in rural production areas of Chile (SAG unpublished)

Adult BMSB are likely to be active in Chile between late-October and late-April. From mid-March until the end of May they are likely to be aggregating in preparation for overwintering. The bug will overwinter from the beginning of June until mid-to-late October.

Adult BMSB are highly mobile, strong flyers and are disturbed easily. Between late-October and mid-March, BMSB in Chile will be feeding and mating. During this time gravid females will look for sites to lay their eggs. The BMSB typically lays its eggs high in the canopy on the underside of leaves. It is possible, though not very likely, that mated females could enter dwellings (particularly in multi-storey buildings) and become trapped in personal effects or become entangled in drying clothing that are subsequently packed for travel.

Adult BMSB overwinter in human-made structures and may become associated with personal effects. Aggregation begins mid-March and all BMSB are expected to be overwintering by the end of May. The overwintering BMSB are unlikely to emerge until mid-October unless they are exposed to temperatures greater than 10°C (Lee et al. 2013) or their stored nutritional reserves become depleted (Funayama 2012).

Currently BMSB is known to occur only in urban Santiago (SAG unpublished). Based on trap and inspection data, the population appears to be most abundant around the semi-industrial Quinta Normal area. While there have been some reports of BMSB entering houses (MacLellan pers. comm.), they appear to be in low numbers compared to the large scale aggregations witnessed in the USA and Italy.

Nymphs

Second to fifth instar nymphs of BMSB are highly mobile and easily disturbed (Lee *et al*. 2014), but do not fly. They are mainly associated with the stems, leaves and fruit of their hosts where they feed. Nymphs are unlikely to enter and remain in dwellings.

Eggs

Brown marmorated stink bug eggs are typically laid on the underside of leaves high in the canopy of their host trees. Eggs have occasionally been reported being laid on fruit but there are no known reports of BMSB eggs being laid on personal effects. When they hatch, the first instar nymphs remain associated with the egg, where they harvest symbiotic bacteria from the egg chorion.

In the 2017-2018 season, monitoring was conducted using a combination of tree beating and sticky traps with pheromone lures. A total of 560 BMSB were detected across the entirety of Santiago city.

Given that:

- the passenger pathway is a high volume pathway and that about 1/3 of traffic comes from countries where BMSB are known to be present.
- BMSB are not known to lay eggs on non-host material
- BMSB adults and 2nd-5th instar nymphs are mobile and easily disturbed.
- BMSB nymphs do not fly
- adult BMSB will be actively foraging or seeking mates between spring and autumn
- adult BMSB will be aggregating and overwintering between autumn and spring
- BMSB are understood to be at low abundance in Santiago
- the centre of the BMSB infestation in Santiago is a semi-industrial area

the risk of entry on the Passenger pathway is estimated as per the entry assessment table EA5 below.

Table EA5. The risk of BMSB entry on Passengers and Personal Effects

Between April and September, the Likelihood of BMSB:	Eggs	Being associated with Passengers and Personal Effects from the	Northern Hemisphere	is considered	Negligible	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Nymphs		Northern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult singles active		Northern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult Aggregations		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
Between September and April, the Likelihood of BMSB:	Eggs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
	Nymphs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
	Adult singles active		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
	Adult Aggregation		Northern Hemisphere		Negligible	Very Low	Low	**Moderate**	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High

N.B. It should be noted that this assessment is based on the current known distribution and abundance of BMSB in Chile. Should the population increase in size or expand its distribution into production areas of Chile or other countries in the Southern Hemisphere, the risk will need to be re-assessed.

5.3 Exposure assessment

Inanimates (Containers, Vehicles and Machinery and Equipment)

Containers, vehicles machinery and tyres, may harbour overwintering adult BMSB. Adult BMSB that are actively foraging or seeking mates during the late spring or summer may occasionally be associated with containers, vehicles, machinery and tyres. Eggs and nymphs are unlikely to be ascociated with containers, vehicles machinery and tyres.

Vehicles and machinery may be moved from the port of entry for inspection anywhere within New Zealand.

Post-overwintering BMSB prioritise foraging for food (Haye 2017) and feed on a broad range of hosts, many of which are present in New Zealand (appendix Table A1.)

Temperatures in vessels en-route to New Zealand are likely to be greater than the 10-15 C (Grier and Chan, 1970; Weiskircher 2008) required to stimulate activity in overwintering BMSB (Li et al, 2007).

Overwintering BMSB entering New Zealand from the Northern Hemisphere winter will be moving to spring or summer. Overwintering BMSB coming from winter elsewhere in the Southern Hemsphere will be moving to the equivalent season in New Zealand where food may be sparse and temperatures would promote quiescence.

Conversely, BMSB coming from the active period in the Northern Hemisphere would arrive in New Zealand's autumn/ winter period. Any BMSB arriving from elsewhere in the Southern hemisphere during the active period would encounter New Zealand summer conditions.

Foraging BMSB have been reported to fly an average of 2.7km (Lee and Leskey, 2015). Experimental results have shown that BMSB may fly up to 75km in a single flight (Wiman et al, 2015). Flight capacity increases with temperature, at temperatures between 10°C and 15°C only 3% of BMSB undertake flight, whereas 87% will fly at temperatures between 25°C and 30°C (Lee and Leskey 2015).

Given that:

- Vehicles and machinery may be moved anywhere in the country for inspection.
- Temperatures in New Zealand Spring/Summer are likely to stimulate activity and flight in BMSB
- Post overwintering BMSB are highly mobile and actively seek food

The likelihood of Overwintering BMSB associated with inanimates from the Northern Hemisphere being exposed to suitable environment is considered **High**

The likelihood of actively foraging BMSB including gravid females associated with inanimates from the Northern Hemisphere being exposed to a suitable environment is considered **Negligible**

Given that

- On arrival in New Zealand, overwintering BMSB from elsewhere in the Southern Hemisphere will be subjected to a winter environment where suitable food sources are likely to be sparse and temerature will promote quiescence.
- It is uncertain whether BMSB are capable of surviving a second round of overwintering after a prolonged period of activity

The likelihood of overwintering BMSB associated with inanimates from the Southern Hemisphere being exposed to suitable environment is considered **Low with high uncertainty**

The likelihood of actively foraging BMSB including gravid females associated with inanimates from the Southern Hemisphere being exposed to suitable environment is considered **High**

Nursery Stock

BMSB are only likely to be associated with Nursery Stock imported as whole plants. Brown marmorated stink bug (as *Halyomorpha mista*) is on the pest lists of the *Citrus*, *Poncirus* and *Fortunella* Schedules of the Nursery Stock IHS. These schedules only allow entry as dormant cuttings or plants in tissue culture, which are very unlikely to have BMSB associated with them.

Prior to arrival, whole plants are required to undergo methyl bromide fumigation, hot water dipping or insecticide spraying, which should mitigate the risk of BMSB remaining associated with it.

Whole plants would be devanned in a transitional facility for inspection by a quarantine officer, loaded into a secure vehicle after inspection and moved to a post entry quarantine facility where they would be de-vanned in a secure environment.

Adult BMSB and second to fifth instar nymphs are highly mobile and easily disturbed by handling and other movement. Adults are capable of flight over long distances, whereas nymphs are flightless but can move 2-4 m hour dependent on temperature. Both adults and nymphs could easily move off the commodity they arrived on. However, any BMSB associated with incoming Nursery Stock should remain contained in the transitional facility, transit vehicle or PEQ site.

Post entry quarantine facilities may be several kilometres from the port of entry and levels of PEQ range from L1 (open field facilities) to Level 3B (high efficiency particulate air filtetering. Any PEQ facility that is Level 2 (bounded by 0.6mm mesh) or above should be sufficient to contain all BMSB life stages.

Given that:

- BMSB are unlikely to be associated with plants in tissue culture, dormant cuttings or bulbs
- All life stages of BMSB could be associated with whole plants imported as Nursery Stock
- All whole plants must be fumigated dipped or sprayed with insecticide
- Whole plants are inspected in a secure transitional facility (TF), transported from the TF to a post entry quarantine facility in a secure vehicle and devanned uner quarantine conditions.

The likelihood of BMSB being exposed to the New Zealand environment on the Nursery Stock pathway is considered **Negligible.**

Fresh Produce

Fresh Produce may either be inspected at the port of entry or transported from the port of entry to a transitional facility where it is subject to visual inspection.

Egg masses of BMSB may be associated with leafy Fresh Produce and very occasionally with fruit. In the Northern hemisphere egg masses are deposited between mid-May and late August

(Maistrello et al, 2016, Nielsen and Hamilton 2009) and are expected to be deposited between Mid–November and March in the Southern Hemisphere. Eggs develop between 15° and 33°C and can take between 22 and 26 days to hatch at 15° and 2-4 days at 30°C (Haye et al. 2014).

Eggs arriving on Fresh Produce from the Northern Hemisphere summer would be released into the New Zealand winter and would be unlikely to complete development into a mobile life-stage capable of finding suitable host material.

Eggs coming from the Southern hemisphere would be moving from summer to summer and could continue development. Such eggs remaining associated with discarded fruit and placed in an open compost may complete development and subsequent (2nd instar) nymphs could find suitable hosts in an urban or rural garden environment.

Adult BMSB and second to fifth instar nymphs are highly mobile and easily disturbed. There is a high likelihood that standard handling of fresh produce would dislodge them. Adults are capable of flight over long distances.

The likelihood of exposure to suitable hosts is dependent on where the produce is de-vanned. If fresh produce contaminated with BMSB is unpacked in a warehouse or supermarket in an urban or industrial area, the likelihood of exposure would be expected to be lower than if it were unpacked in a rural area. However, in its invaded range, BMSB is typically first reported from urban areas (reviewed in Haye et al, 2014), which offer both suitable habitat and increased overwintering survival compared to agricultural areas (Wallner et al, 2014).

The BMSB would need to exit the unpacking facility to find host material in the New Zealand environment. As BMSB nymphs are flightless, their likelihood of exiting a facility is likely lower than it would be for adults, which have been demonstrated to fly an average of 2.7 km in a single flight (Lee and Leskey, 2015).

Should adult BMSB remain associated with Fresh Produce that is purchased from a supermarket or other retail outlet, there is a low likelihood that they would be exposed to an urban garden environment either by independent flight or if they are placed in an open compost with discarded produce.

Given that

- BMSB eggs arriving from the Northern Hemisphere summer would be introduced into a New Zealand winter
- BMSB eggs do not develop below 15°C
- Eggs associated with fresh produce arriving when conditions are suitable for development would need to be discarded in compost rather than landfill.
- Second to fifth instar BMSB nymphs and adults are highly mobile, easily disturbed and unlikely to remain associated with Fresh Produce during commercial processing.

The likelihood of BMSB eggs or first instar nymphs from the Northern Hemisphere being exposed to suitable envioronmental conditions is considered **Negligible**

The likelihood of BMSB eggs or first instar nymphs from the Southern Hemisphere being exposed to suitable environmental conditions is considered **Low**

The likelihood of second to fifth instar BMSB nymphs and adults associated with Fresh Produce from the Northern Hemisphere being exposed to suitable envioronmental conditions is considered **Negligible**

The likelihood of second to fifth instar BMSB nymphs and adults associated with Fresh Produce from the Southern Hemisphere being exposed to suitable environmental conditions is considered **Low**

Cut Flowers and Foliage

Cut flowers and Foliage may only be imported from two countries where BMSB is known to occur. Both of these countries are in the Northern Hemisphere. Because of their ephemeral nature, cut flowers and foliage are imported by air rather than by sea. They may be refrigerated at temperatures <9°C prior to export. On arrival, the flowers or foliage may either be inspected at the point of entry or transported from the point of entry to a transitional facility where they are subject to visual inspection.

In the Northern hemisphere egg masses are deposited between mid-May and late-August (Maistrello et al, 2016, Nielsen and Hamilton 2009). Egg masses of BMSB may be associated with the underside of foliage (Nielsen and Hamilton 2009).

Eggs develop between 15° and 33°C and can take between 22 and 26 days to hatch at 15° and 2-4 days at 30°C (Haye et al. 2014). The forward hold of an aircraft is held at approximately 10°C and the aft is typically held at 18°C, though this may vary by as much as 17° depending on position in the hold (Emond et al. 1999). While some of these temperatures fall within the thresholds for development, the flight duration is likely to be less than one day and it is unlikely that eggs would complete development in transit. The eggs could complete their development whilst on sale and subsequently on display after purchase and may be discarded into a compost or landfill once the flowers or foliage have wilted.

Eggs or first instar nymphs arriving on foliage from the Northern Hemisphere would be released into the New Zealand winter and would be unlikely to complete development into a mobile life-stage capable of finding suitable host material.

The likelihood of exposure of adults and 2nd to 5th instar nymphs to suitable hosts is dependent on where the cut flowers or foliage are de-vanned, the efficacy of inspection and where they are sold, displayed and ultimately disposed of.
Adult BMSB and 2nd to fifth instar nymphs are highly mobile and easily disturbed. Adults are capable of flight over long distances.

If cut flowers or foliage contaminated with BMSB are de-vanned for inspection at the airport the BMSB are less likely to be exposed to the New Zealand environment than if they are de-vanned in an urban or industrial area. The likelihood of exposure would be expected to be lower in an urban or industrial area than if the material was unpacked in a rural area. However, in its invaded range, BMSB is typically first reported from urban areas (Wallner et al, 2014; Maistrello et al, 2016).

The BMSB would need to exit the unpacking facility to find host material in the New Zealand environment. Adult BMSB have been demonstrated to be capable of flying an average 2.7 km in a single flight (Lee and Leskey, 2015). This flight capacity is dependent on temperature, and fewer than 5% of BMSB take flight at temperatures between 10-15°C (Lee and Leskey, 2015). As BMSB nymphs are flightless, and the distance they move decreases with temperature (Lee et al, 2014), their likelihood of exiting a facility is lower than it would be for adults. BMSB routinely overwinters in human made structures and is capable of finding its way out of them when active.

Should Adult BMSB remain associated with cut flowers or foliage at a retail outlet, it is likely that they would be exposed to an urban garden environment either by independent flight or if they are placed in an open compost.

Given that

- Cut Flowers and Foliage may only be imported from BMSB host countries in the Northern Hemisphere. There is no IHS for import of Cut Flowers and Foliage from Chile.
- BMSB eggs or first instar nymphs may be associated with cut foliage or flowers
- Egg development is likely to continue in transit
- Cut Flowers and Foliage may be disposed of in compost bins in an urban or rural setting
- Adult BMSB are strong flyers, but flight capacity is dependent on temperature

The likelihood of BMSB eggs or first instar nymphs associated with Cut Flowers and Foliage from the Northern Hemisphere being exposed to suitable envioronmental conditions is considered **Negligible**

The likelihood of second to fifth instar BMSB nymphs and adults associated with Cut flowers and foliage from the Northern Hemisphere being exposed to suitable envioronmental conditions is considered **Negligible**

Passenger pathway and personal effects

Personal luggage may be transported from the point of first entry to any point in New Zealand. The likelihood of exposure of BMSB to the New Zealand environment is dependent on the type of luggage or personal effects being carried.

Eggs and first instar nymphs of BMSB are unlikely to be associated with personal effects and will not be considered further.

Second to fifth instar nymphs and active adults including gravid females are likely to occur from April and September in the Northern Hemisphere and between November and April in the Southern Hemisphere.

Any second to fifth instar nymphs and active adults including gravid females associated with personal effects from the Northern Hemisphere would be moving from spring/summer to New Zealand's Autumn/Winter where temperature and food availability may be limiting.

Second to fifth instar nymphs and active adults including gravid females associated with personal effects from the Southern Hemisphere would be moving between comparable seasons when temperature and food availability are not likely to be limiting

Aggregating and overwintering BMSB occur between September and April in the Northern Hemisphere and between April and October in the Southern Hemisphere (Chile).

Personal luggage such as suitcases and other baggage is likely to be opened and unpacked indoors, in a house or hotel, which limits exposure potential. Any overwintering BMSB in bag linings or clothing are likely to exit and seek food by crawling or flying and should be noticeable.

The BMSB has been intercepted in outdoor equipment such as tents or archery equipment carried among personal effects. Such items are likely to be opened and used outdoors. As adult BMSB are easily disturbed and strong flyers there is a high likelihood they will find suitable host material.

Given that:

- Most luggage will be unpacked indoors in a house or hotel
- Some luggage contains equipment unpacked outdoors

- Second to fifth instar BMSB nymphs and active adults form the Northern Hemisphere would arrive in New Zealand in the autumn or winter
- Overwintering BMSB adults from the Northern Hemisphere would arrive in the New Zealand Spring or Summer
- Second to fifth instar BMSB nymphs and active adults from the Southern Hemisphere would arrive in the same season as their country of origin
- Overwintering BMSB adults from the Southern Hemisphere would arrive in in the same season as their country of origin
- BMSB are highly mobile and easily disturbed.

The likelihood of second to fifth instar BMSB nymphs and active adults associated with personal effects arriving from the Northern Hemisphere being exposed to suitable envioronmental conditions is considered **Low**

The likelihood of second to fifth instar BMSB nymphs and active adults associated with personal effects from the Southern Hemisphere being exposed to suitable envioronmental conditions is considered **Low**

The likelihood of overwintering adults associated with personal effects arriving from the Northern Hemisphere being exposed to suitable envioronmental conditions is considered **Low**

The likelihood of overwintering adults associated with personal effects from the Southern Hemisphere being exposed to suitable envioronmental conditions is considered **Low**

5.4 Assessment of establishment and spread

Establishment

Halyomorpha halys is native to temperate/subtropical Asia and has successfully invaded and established in North America, Europe and Chile. The BMSB has a broad host range and is a pest of food crops, forest trees and ornamentals in both its native and invaded range.

Environmental requirements for establishment

It is reported that BMSB have specific daylength and temperature requirements at each stage of their development. These requirements are met by the New Zealand environment in many regions:

Daylength

The daylength requirements for diapause termination in BMSB could have a significant effect on their window for establishment in New Zealand. For example, across New Zealand daylengths of, or greater than ,13 hrs begin between the 8th and 18th of October and cease between the 20th February and 2nd of March in Auckland, and between 2nd and the 12th of March in Wellington, Christchurch and Dunedin (Royal New Zealand Astronomical society (https://rasnz.org.nz/in-the-sky/sun-rise-and-set). Diapausing adult BMSB requiring ≥ 13 hr daylength for diapause termination that arrive in New Zealand outside of this period would not receive the photoperiodic cues necessary to exit diapause. This window is based on observations of BMSB in Italy (Costi et al, 2017).

However, diapausing BMSB requiring 11.5 hour daylengths, such as those from Florida described by Penca and Hodges (2018) could receive the required cues anywhere in

New Zealand between the second week of September and the first week in April. The window would be narrower both temporally and spatially based on the increased critical daylength requirements presented in Watanabe (1979) or Yanagi and Hagihara (1980) (Error! Reference source not found.**).**

Daylength has also been demonstrated to have a significant effect on development rates from 2nd instar nymphs to adult. Musolin et al, (2019) report that under short day (12:12 L:D) condtions the accumulated degree days (LDT 13.3°C) was significantly shorter (530 DD) than under long day (15:9 L:D) conditions, which required 590 DD. In New Zealand such short days begin in April and extend to mid September (Figure 6.). Based on the reproductive period of BMSB observed in the Northern Hemisphere, it is estimated that the reproductive period in New Zealand would run from the beginning of December to the end of February (Table 2.). Daylengths during this period will range between 14-15 hours in December to approximately 13.5 hours at the end of February (Figure 6.), suggesting developing nymphs would be subject to longer daylengths comparable with those reported in Musolin et al (2019). Based on average monthly temperatures collected across New Zealand (NIWA 2018) and the lower developmental threshold of 13.3°C presented by Musolin et al (2019), approximately 560 degree days may be accumulated in the North of New Zealand between the beginning of December and the end of February.

Based on the combination of daylength and accumulated degree days at a minimum threshold of 13.3°C there is a high likelihood that BMSB nymphs could complete their development into adults and establish. Based on the findings of Musolin et al (2019), it is considered that one generation would be produced per year.

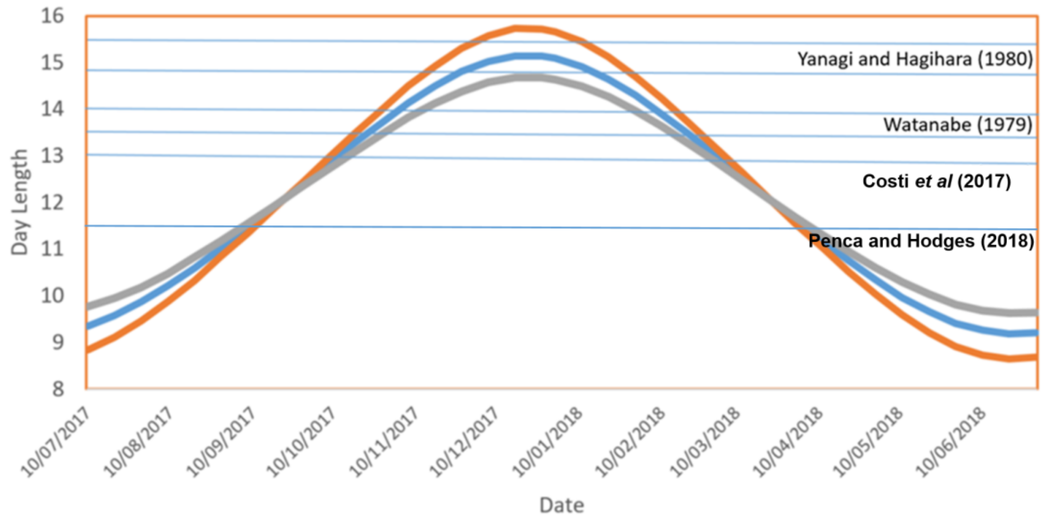

Figure 6: Day length (hours) for 2017/2018 in Dunedin (Orange line), Wellington (blue line) and Auckland (grey line) showing intercept with daylength cues necessary for *Halyomorpha halys* to exit reproductive diapause – lowest line 11.5 hours (Penca and Hodges, 2018), second line 13 hrs (Costi et al, 2017) third band 13.5 -14 hours (Watanabe, 1979) and upper band 14.8 – 15.5 (Yanagi and Hagihara, 1980)

Temperature

Temperatures in New Zealand meet or exceed the minimum requirements for sexual maturation of BMSB females. Watanabe (1980) estimated the lower developmental threshold for development of ovaries in post-diapause females to be 16.3°C and that 119 degree days at or above this temperature are required to complete development. Under natural conditions, this development is typically completed within two weeks (Watanabe et al, 1978). In the USA it was estimated that 147.6 degree days at a minimum 14.17°C was required for ovarian development to be completed, again equating to about two weeks under natural conditions (Nielsen et al, 2008).

In New Zealand, average daily temperatures reach 16.3 °C in late-October in Napier, early November in Auckland and Kaitaia, late-November in Nelson, early-December in Christchurch and mid-December in Wellington. Temperatures fall below 16.3°C in mid-February in Christchurch and Dunedin, late February in Wellington and Nelson, mid-March in Napier, late-March in Auckland and mid-April in Kaitaia (Niwa 2018) Figure 7.

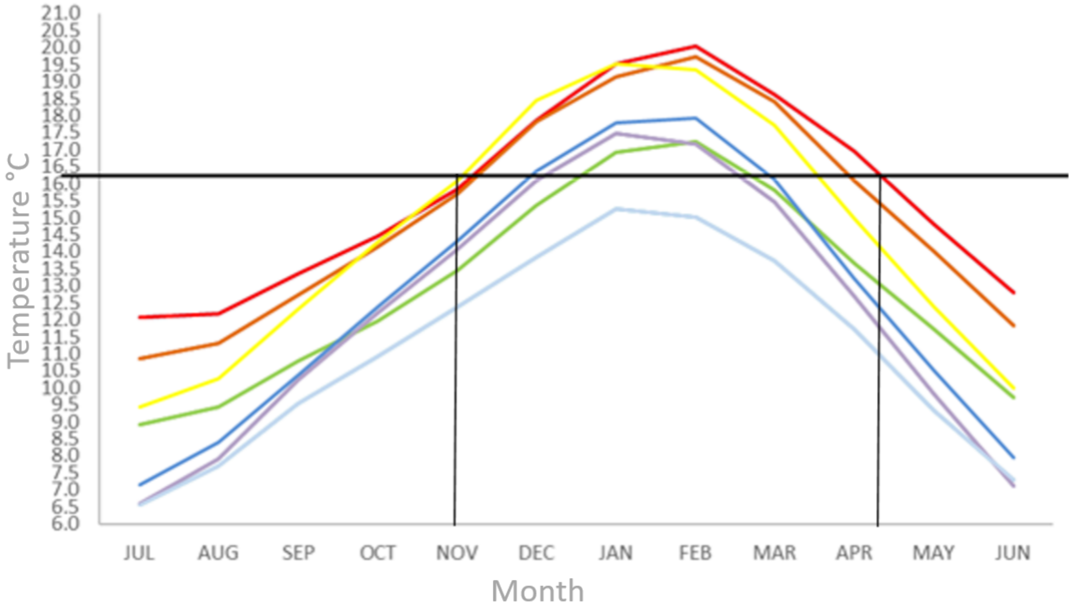

Figure 7: Average daily temperature for each month between 1981 and 2010 in Dunedin (violet line), Christchurch (indigo line), Nelson (blue line), Wellington (green line), Napier (yellow line), Auckland (orange line) and Kaitaia (red line). The horizontal black line represents the temperature threshold for ovarian development.

The likelihood of an insect establishing is often estimated using degree day models, which assume a linear relationship between insect development rates and temperature. However, this assumption is frequently not tested and uncertainty around the regression models they are based on is often not reported (Bergant & Trdan 2006, Moore et al, 2012). It has been suggested that linear degree day models are are not a reliable predictor of development rates for taxa such as BMSB, which are long lived and have overlapping generations (Nielsen et al, 2008; Haye et al, 2014, Leskey and Nielsen 2018). For this reason, agent based models that incorporate additional parameters such as photoperiod have been suggested as a better means of modelling phenology (Nielsen et al 2016; 2017).

Moore and Remais (2014) reported significant differences in predictive outcomes in degree day models based on linear and non-linear analyses. Nielsen (2008) reported poor fit when using a linear regression to model BMSB development data and found a non-linear Briere-1 regression model provided the most reliable predictor of the relationship between temperature and development in *H. halys.*

Degree day models of BMSB development based on Briere-1 analyses, identified the minimum and maximum temperatures for BMSB development in the United States and Europe as 14.17◦C and 12.97◦C and 35.76◦C and 36.5◦C, respectively. This equates to 538 DD14.17 and 588

DD12.97 to develop from the egg through the five instars to adult eclosion in the United States and Europe, respectively (Leskey and Nielsen 2018).

Based on accumulated degree days derived from average monthly temperatures in various regions of New Zealand (NIWA, 2018), temperatures in the upper North Island of New Zealand are suitable for BMSB to complete development from egg to adult at 538 DD14.17 (Table. 11). This estimate uses the highest reported developmental threshold temperature and represents a conservative estimate of BMSB's establishment potential.

It should be noted that considerable variation in what is understood to be the lower temperature threshold for development from egg to adult has been reported. The modelled threshold has been reported to range from 11.1° C (Fujiie, 1985) to 14.17°C (Nielsen et al, 2008) (Table 3). Fujiie (1985) describes regional variation in development rates across Japan, which may reflect Japan's heterogeneous climate and may be indicative of acclimation or adaptation to local climates.

Experimental studies at fixed (Nielsen et al, 2008) and variable ambient (Haye et al, 2014) temperatures suggest development from egg to adult occurs at temperatures greater than 17°C. Nielsen et al, (2008) report development from egg to adult occurred in an average 121.5 days at a constant 17°C, however survival rates were low (2%). Survival increased to 62% at 20°C. Development at 20° C takes between 76 and 81 days. Average daily temperatures in New Zealand exceed 17°C in much of the North Island between December and March and in January and February in the upper South Island (NIWA, 2018) (Appendix Table A2).

Other modelling indicates that BMSB could establish in New Zealand

Environmental niche modelling indicates that much of New Zealand is highly suitable for establishment of BMSB (Zhu et al, 2012).

Climex modelling by Kritikos et al, (2017) suggested that much of the North Island of New Zealand including the Bay of Plenty horticultural regions are climatically suitable for BMSB to establish. The models also indicated that BMSB could establish in Marlborough and the Eastern Canterbury plains.

Similarly, modelling by Fraser et al, (2017) indicates that most of New Zealand's North and South Islands are moderately to highly suited climatically for BMSB establishment. Furthermore the models indicate that suitability will increase as temperatures increase with climate change.

Based on a combination of daylength, degree day modelling, climate matching with known BMSB distribution and the findings of peer reviewed published articles using a variety of modelling methods, it is considered that the likelihood of BMSB establishing in New Zealand is **High**.

Table 11. Accumulated degree days for the egg to adult development threshold temperature of 14.17°C in five North Island locations. Where the total accumulated degree days meets or exceeds the 538 required to complete development at this temperature the numbers are presented in bold type.

Kaitaia		Accumulated degree days				
Degree days (14.17°C) / month		OCT	NOV	DEC	JAN	FEB
8.86	OCT	8.86				
50.00	NOV	58.86	50.00			
114.38	DEC	173.23	164.37	114.38		
165.97	JAN	339.21	330.35	280.35	165.97	
163.95	FEB	503.16	494.30	444.30	329.93	163.96
133.98	MAR	**637.14**	**628.28**	**578.28**	463.91	297.93
83.82	APR	**720.96**	**712.10**	**662.10**	**547.73**	381.75

Whangarei		Accumulated degree days				
Degree days (14.17°C) / month		OCT	NOV	DEC	JAN	FEB
15.08	OCT	15.08				
67.90	NOV	82.98	67.90			
134.73	DEC	217.71	202.63	134.73		
177.69	JAN	395.39	380.31	312.41	177.69	
169.09	FEB	**564.48**	**549.40**	481.50	346.78	169.09
143.24	MAR	**707.72**	**692.65**	**624.75**	490.02	312.33
73.46	APR	**781.18**	**766.10**	**698.20**	**563.47**	385.79

Auckland		Accumulated degree days				
Degree days (14.17°C) / month		OCT	NOV	DEC	JAN	FEB
0.00	OCT	0.00				
47.23	NOV	47.23	47.23			
112.24	DEC	159.47	159.47	112.24		
154.32	JAN	313.79	313.79	266.56	154.32	
155.69	FEB	469.48	469.48	422.25	310.01	155.69
131.69	MAR	**601.17**	**601.17**	**553.94**	441.70	287.38
58.22	APR	**659.39**	**659.39**	**612.16**	499.92	345.60

Gisborne		Accumulated degree days				
Degree days (14.17°C) / month		OCT	NOV	DEC	JAN	FEB
0.00	OCT	0.00				
48.35	NOV	48.35	48.35			
120.94	DEC	169.29	169.29	120.94		
157.43	JAN	326.73	326.73	278.37	157.43	
138.00	FEB	464.72	464.72	416.37	295.43	138.00
103.89	MAR	**568.61**	**568.61**	520.26	399.32	241.89
19.72	APR	**588.33**	**588.33**	**539.97**	419.04	261.60

Gisborne		Accumulated degree days				
Degree days (14.17°C) / month		OCT	NOV	DEC	JAN	FEB
4.24	OCT	4.24				
56.90	NOV	61.13	56.90			
132.68	DEC	193.81	189.58	132.68		
166.26	JAN	360.08	355.84	298.94	166.26	
145.49	FEB	505.57	501.33	444.44	311.76	145.49
110.21	MAR	**615.77**	**611.54**	**554.64**	421.96	255.70
23.89	APR	**639.66**	**635.42**	**578.53**	445.85	279.58

Hosts of *Halyomorpha halys* are cultivated in New Zealand

Brown marmorated stink bug is associated with more than 300 hosts (Bergmann et al, 2016; Funayama 2004; Lee et al, 2013; Maistrello et al, 2016; Musolin et al, 2017; Wermelinger et al, 2008; Yu and Zhang 2007; www.stopbmsb.org, 2018; EPPO 2018; CABI, 2018) (Appendix Table A1.). Many of these host species are present in New Zealand (NZOR, 2018, NZPCN 2018) (Appendix Table A 1).

The BMSB typically requires multiple food hosts to complete their development (Acebes-Doria 2016), but can complete its life cycle on single hosts including, *Prunus* spp., *Pyrus* spp. (Fengjie and Zhifang 1997; Acebes-Doria 2016) and *Phaseolus* spp. (Taylor et al, 2017), which are all cultivated in New Zealand.

Aggregations of overwintering BMSB are more likely to establish than individuals arriving in New Zealand from the Northern Hemisphere.

Reproduction in BMSB is typically sexual. In order to establish, two or more individuals of opposite sexes need to be present in the same area. An overwintering aggregation in a single vehicle or piece of machinery could deliver sufficient individuals into one area in one event to begin a population.

The minimum number of individuals for establishment to occur is not known, and is likely dependant on time of year and population source. The eastern USA population is estimated to have established from 2-18 females (Xu et al, 2014).However, it is likely that the optimum number will be a function of a combination of factors including overwintering mortality and sex ratios.

Overwintering mortality among diapausing adults has been reported to range between 39% (Haye et al, 2014) and 89% (Costi et al, 2017) and mortality in overwintering BMSB associated with cargo shipped by sea has been estimated to be 89.5% (Nixon et al, 2018). These reports are consistent with data for live and dead BMSB intercepted at the New Zealand border (MPI, 2018).

There is some disagreement over sex ratios in BMSB. Nixon et al, (2018) report finding a ratio of 2.4 male: 1 female in overwintering BMSB, indicating that approximately 70% of BMSB found will be male. However, Yuanmin and Yingman (1988) report a 1:1 ratio of males to females, indicating that there is an equal chance of finding a male or female. Interceptions at the New Zealand border (MPI 2018) typically find 1.4 females for every 1 male found, though this may be an artefact of overwintering survival asymmetry as there is evidence to suggest that more females survive overwintering than males (Chambers et al, 2019).

Given the variation in both reported mortality rates and sex ratio, a conservative estimate (i.e. using figures that equate to the highest risk) based on 40% mortality and a 1:1 sex ratio indicates that statistically the minimum aggregation size necessary for one living male and one living female BMSB to arrive and reproduce is 4. This is assuming the BMSB encounter suitable environmental conditions for diapause termination and ovarian development.

There is one report of parthenogenesis in *H. halys*. Fengjie and Zhifang (1997) collected diapausing female BMSB and reared them to sexual maturity in isolation from males. Approximately half of the unmated females studied produced eggs, but hatching rates are comparatively low (12.47%). Fengjie and Zhifang's (1997) results have never been replicated and have been questioned by other researchers, but their implications are considered here for completeness. Given that the average number of eggs in a single cluster is 28 (Watanabe et al. 1978) this would equate to an average of 3.5 viable offspring per cluster. However, it was not reported whether the hatched nymphs developed into viable adults.

Haplotype analysis by Xu et al, (2014) estimated that the population of BMSB in the eastern USA may have started from 2-18 females from Beijing, China. Subsequent haplotype analyses suggest that the eastern USA population remains the results of the original introduction but that at least four invasion events from China are responsible for the population in the West Coast USA (Valentin et al, 2017; Lee et al, 2018). The invasion of Europe is also generally thought to be the result of three invasions from China as well as movement of BMSB from the Eastern USA to Italy (Valentin et al, 2017; Lee et al, 2018). Analysis of the 22 haplotypes present in Italy suggests multiple invasions from different countries, both from other continents and from Europe (Cesari et al, 2017). It is noted that, with one exception in Greece, haplotypes from Korea were not found in BMSB's invaded range and that two haplotypes H1 and H3 were found more commonly in the invaded range than any of the other 43 native haplotypes identified (Lee et al, 2018). Whether this is indicative of a more invasive strain of BMSB remains uncertain.

BMSB from the Southern Hemisphere are likely to encounter the environmental conditions they require to establish in New Zealand

Unlike BMSB from the Northern Hemisphere, BMSB arriving from elsewhere in the Southern Hemisphere will not experience a change in seasons.

Currently, Chile is the only country in the Southern Hemisphere where *H. halys* is known to occur. There, BMSB is known only from Santiago City - the bug is not known to have spread into agricultural or horticultural production areas. Based on data from pheromone baited sticky traps, tree beating and visual inspection surveys, BMSB remains at low abundance in Santiago, though its range appears to be expanding across the city (SAG unpublished).

From mid-March until the end of May, BMSB in Chile are likely to be aggregating in preparation for overwintering. The bug is expected to overwinter from the beginning of June until mid-to-late October. During this period, BMSB may become associated with containers, vehicles and machinery or personal effects situated close to host plant material.

BMSB associated with cargo transported by sea are likely to be brought out of their quiescent state by vessel temperatures. Vessel hold temperatures are typically greater than the 10-15°C (Grier and Chan, 1970; Weiskircher 2008) necessary to bring overwintering BMSB out of their quiescent state and become mobile (Lee et al. 2013). However, they are not likely to be exposed to daylength sufficient to break their reproductive diapause. Activity during the overwintering period is known to deplete stored nutritional reserves more rapidly than remaining quiescent (Funayama 2012, Costi et al, 2017).

Assuming that elevated temperatures in transit have resulted in a depletion of nutritional reserves, and that there is little or no food or water available to the bugs, it is is likely that mortality rates would be comparable to those reported in Nixon et al, (2018). If this is the case, then only one in ten BMSB in any aggregation would be expected to survive. Assuming a 1:1 sex ratio, statistically a minimum of 40 BMSB would need to be present a single aggregation to ensure the presence of at least one live male and one live female. Given the low abundance of BMSB in Santiago, Chile it is uncertain whether aggregations of this size are likely to occur.

Diapausing BMSB entering New Zealand from Chile would be coming from Chilean winter to a New Zealand winter environment. They would not receive the daylength cues necessary to break diapause, but *are* likely to encounter temperatures on arrival in New Zealand that would result in a return to an immobile state before they have the opportunity to seek food. It is uncertain what, if any, effect this would have on their likelihood of establishment.

In Santiago, BMSB nymphs have been observed between the 21st of November and the 18th of April (SAG unpublished). Nymphal development to adulthood takes between 30 and 65 days dependent on temperature (Haye et al., 2014). The estimated lower threshold for nymphal development is 17°C. Average daily temperatures in New Zealand exceed 17°C in much of the North Island between December and March and in January and February in the upper South Island (NIWA, 2018) (Appendix Table A2). Any nymphs arriving in New Zealand during this period are likely to encounter the temperatures necessary to complete development.

Detections of BMSB eggs in Santiago are few. Two egg masses have been observed, the first on the 29th of January the second on the 7th of February 2018 (SAG unpublished). *Halyomorpha* *halys* eggs take between three and twenty six days to develop depending on temperature (Nielsen et al 2008; Haye et al, 2014). The lower threshold for development has been estimated to be between 12.97°C (Haye et al, 2014) and 14.17° (Nielsen et al 2008). It is unlikely that BMSB would establish in New Zealand from eggs arriving by sea as the combination of temperature on board a vessel and duration of travel would likely result in hatching before entry.

Should BMSB egg masses arrive undetected by air, temperature and host availability in New Zealand are likely to be conducive to their survival and development.

Table 12 Degree day estimates for development of *Halyomorpha halys* from egg to adult.

Location	Egg to adult (°days)	Threshold temperature (°C)	Reference
Chiba Japan	630.0	11.1	Fujiie (1985)
Japan	580.0	11.7	Kono et al. (1979 in Kiritani 2007)
Japan	648.2	11.9	Uchida (1986 in Kiritani 2007)
Nagano, Japan	598.0	12.1	Umetani et al, (1976 in Yanagi and Hagihara 1980)
Japan	649.0	12.1	Kita (1979 in Kiritani 2007)
Zurich, Switzerland	588.24	12.24	Haye et al, (2014)
Toyama Prefecture, Japan	625.0	12.9	Watanabe (1980)
Nagano, Japan	403.0	13.9	Yanagi and Hagihara (1980)
Pennsylvania, USA	537.6	14.17	Nielsen et al, (2008)

Given that:

- BMSB eggs develop at temperatures >15°C;
- BMSB nymphs require temperatures >17°C to develop;
- Overwintering adults require a minimum of 13 hours daylength to terminate diapause;
- The lower temperature threshold for ovarian development in BMSB has been reported to be 16.3°C
- >60% of foraging BMSB undertake a dispersal flight at temperatures between 15 and 20°C;
- Large areas of New Zealand achieve the day-length and minimum temperature requirements for diapause termination, BMSB development and adult dispersal during the period that overwintering BMSB from the Northern Hemisphere are likely to arrive in New Zealand;
- BMSB has a host range exceeding 300 species
- BMSB can complete its life cycle on singe hosts including *Prunus* spp, *Pyrus* spp. and *Phaseolus* spp.
- Many known host species of BMSB are present in New Zealand

the likelihood of a population of *Halyomorpha halys* establishing in New Zealand is estimated as per the Establishment assessment table EA6 below

Table EA6. The likelihood of a population of *Halyomorpha halys* establishing in New Zealand

Between April and September, the Likelihood of BMSB:	Eggs	Arriving from the	Northern Hemisphere	Establishing is considered	**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
	Nymphs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High

			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult singles active		Northern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
			Southern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
	Adult Aggregations		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	Very Low	Low	**Moderate**	High
Between September and April, the Likelihood of BMSB:	Eggs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
	Nymphs		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
	Adult singles active		Northern Hemisphere		**Negligible**	Very Low	Low	Moderate	High
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High
	Adult Aggregation		Northern Hemisphere		Negligible	Very Low	Low	Moderate	**High**
			Southern Hemisphere		Negligible	**Very Low**	Low	Moderate	High

the likelihood of a population of *Halyomorpha halys* establishing in New Zealand from sufficient numbers of over-wintering adults arriving from the Northern Hemisphere is considered **HIGH, and non-negligible for several other combinations of life stage and season.**

5.5 Consequence assessment

Halyomorpha halys has a wide range of commercially significant hosts spanning the arable, pipifruit, stonefruit, citrus berry fruit ornamental and forestry sectors (see Appendix Table 1.).

Economic consequences

An economic impact assessment of BMSB (MPI 2015) identified horticulture as the fourth largest export sector in New Zealand and cited wine and kiwifruit as the highest earning exports. The assessment identified impacts of BMSB including lost production, costs asscociated with increased pesticide use and resultant disruption of intergrated pest management systems and potential market access implications.The potential range of these impacts was estimated to lie between $364 million and $1.2 billion in twenty years.

Feeding damage by *H. halys* in tree fruits is most severe, mid-season when rapid growth and swelling is occurring, but can occur throughout the growing season (Nielsen and Hamilton, 2009). In apples and pears the damage manifests itself as brown, sometimes sunken, lesions on the skin and corky necrotic tissue in the flesh of the fruit. Early feeding may result in abortion or cat-faced fruit (Nielsen and Hamilton 2009). In cherry and peach necrotic areas are white (Nielsen and Hamilton 2009).

Availability of quantitative data on the proportion of crops that are damaged by BMSB feeding around the world is limited. A summary of available information is presented in Table 13 below.

Table 13 summary of percentage crop loss or damage of commercial host species.

Country	Region/State	Host	Damage	Source
China	Shandong Province	Pear	Typically 10-25% but up to 35%	Yang et al, 2009
China	Hebei	Pear	40-60%	Yang et al, 2009
China	Beijing	Pear	50-70%	Yang et al, 2009

China	Beijing	Peach	50-70%	Yang et al, 2009
China	Beijing	Apple	23.4-30.8% dependent on variety	Yang et al, 2009
China	Henan	Peach/ apricot	23-87%	Yang et al, 2009
China	Unspecified	Persimmon	23-44	Yang et al, 2009
Italy	Northern Italy	Pear	>50%	Maistrello et al 2017
Japan	Unspecified	strawberry	80%	Fukuoka et al, 2002 in Lee et al, 2013
Japan	Unspecified	Cucumber, pea eggplant	90%	Fukuoka et al, 2002 in Lee et al, 2013
Japan	Unspecified	Sweetcorn	70%	Fukuoka et al, 2002 in Lee et al, 2013
Japan	Unspecified	Aparagus soybean	60%	Fukuoka et al, 2002 in Lee et al, 2013
Japan	Unspecified	Pepper	8%	Fukuoka et al, 2002 in Lee et al, 2013
USA	Pennsylvania	Apple	65.4 - 95.8	Nielsen and Hamilton 2009
USA	New Jersey	Apple	40.5-50.9	Nielsen and Hamilton 2009
USA	Pennsylvania	Pear	58.9-79.5	Nielsen and Hamilton 2009
USA	New Jersey	Pear	21.1-33.5	Nielsen and Hamilton 2009
USA	Maryland	peach	>90%	Leskey et al, 2012
USA	Unspecified	pepper, tomato, eggplant	~ 20%	Leskey et al, 2012
USA	Unspecified	okra	>40%	Haye et al, 2017
USA	Maryland	Soybean	>50%	Leskey et al, 2012
USA	Unspecified	Maize	~100%	Leskey et al, 2012
Georgia	Unspecified	Hazelnut	>90%	Adamia, 2017

In addition to the physical damage *Halyomorpha halys* inflicts on fruit, it also known to vector a phytoplasma disease of *Paulownia tomentosa* in Asia (Hoebeke and Carter 2003) and is suspected to be able to vector other phytoplasmas (Jones and Lambdin 2009).

Given that;

- Horticulture is New Zealand's fourth largest export sector
- BMSB is known to feed on a wide variety of commercially significant species
- BMSB Is associated with crop yield losses ranging from 10-100%
- Management of BMSB requires increased insecticide use
- Increased insecticide use can disrupt integrated pest management systems and lead to secondary infestations
- BMSB is a known vector of at least one Phytoplasma
- The presence of BMSB may result in market access restrictions;

The potential economic impact of BMSB on New Zealand Agriculture is considered **High**

Environmental consequences

No direct, negative environmental impacts due to *H. halys* have been reported (Haye et al, 2014). However, *Halyomorpha halys* has been recorded from plants belonging to 75 different families (Appendix 1), of which Rosaceae and Fabaceae contain the most hosts (48 and 24 species respectively). There are 33 native Rosaceae species in New Zealand, of which one species, *Acaena rorida*, is classified Threatened: Nationally Critical and 11 are classified "At Risk" (4 Declining -Acaena buchananii, Acaena microphylla var *microphylla Acaena microphylla* var pauciglochidiata, *Acaena pallida*) and 7 Naturally Uncommon (*Acaena emittens*, *Acaena minor* var. *antarctica*, *Acaena minor* var. *minor*, *Acaena pallida*, *Geum albiflorum*, *Geum divergens*, *Geum pusillum*).

Similarly, of the 36 Fabaceae species native to New Zealand, 14 are classified as Threatened (6 Nationally Critical - *Carmichaelia carmichaeliae*, *Carmichaelia curta* , *Carmichaelia hollowayi*, *Carmichaelia torulosa*, *Clianthus maximus*, *Clianthus puniceus* 2 Nationally Endangered *Carmichaelia muritai*, *Carmichaelia stevens*onii and 4 Nationally Vulnerable *Carmichaelia corrugata*, *Carmichaelia crassicaulis* subsp. *racemosa*, *Carmichaelia juncea*, *Carmichaelia kirkii*) and a further 13 are classified 'At Risk' (6 Declining *Carmichaelia crassicaulis* subsp. *crassicaulis*, *Carmichaelia monroi* , *Carmichaelia petriei*, *Carmichaelia uniflora*, *Carmichaelia vexillata*, *Montigena novae-zelandiae* 6 Naturally Uncommon *Canavalia rosea*, *Carmichaelia appressa*, *Carmichaelia compacta*, *Sophora fulvida*, *Sophora longicarinata*, *Sophora molloyi* and 1 Relict *Carmichaelia williamsii*) (New Zealand Plant Conservation Network 2018).

In other countries *H. halys* has been associated with damage to *Rubus* and *Sophora* species and it is possible that it may attack their native congeners in New Zealand. None of the six native Rubus species present in New Zealand is considered threatened. There are eight native species of *Sophora* in New Zealand, of which four are classified At Risk: Naturally Uncommon (New Zealand Plant Conservation Network 2017).

Feeding activity on flowers and young fruits by BMSB nymphs and adults has been demonstrated to reduce seed yield and quality (Owens et al, 2013, Vetek pers.com 2017), cause fruit abortion (Nielsen and Hamilton, 2009), and thus reduce reproductive potential; the severity of losses are likely to be density dependent and will vary with community composition. However, the effect of *H. halys* feeding on populations of native plant species, and consequent impacts on invertebrate and bird populations, is unknown.

The possibility that the greatest environmental impact of BMSB will be indirect should also be considered. Given the high dose and frequency of insecticide treatment necessary to manage populations of BMSB chemically, there are likely to be associated environmental costs. Consequences such as increased greenhouse gas emmisions (Heimpel et al, 2013) and non-target effects on pollinators (Brittain and Potts 2010) have been demonstrated in the chemical management of other invasive pest species.

Given that:

- the most commonly attacked families, Rosaceae and Fabaceae, contain one and twelve threatened species respectively in New Zealand;
- fruit damage is likely to impair seed development and fruit formation;
- No significant environmental impacts of *H. halys* have been reported in its invasive range;

The environmental consequences of establishment are considered to be **Low** with high uncertainty.

Socio-cultural consequences

The brown marmorated stink bug is a nuisance pest in parts of its invaded range (Rice et al, 2014). Large numbers of overwintering adults invade houses and other man-made structures, particularly in rural areas and those close to host material (Leskey et al, 2012, Maistrello et al, 2016). Large numbers of bugs (up to 26,205 recorded in a single house over the course of six months (Inkley 2012) over winter in walls, insulation, attics and other suitable crevices. Video of comparable sized home invasions by BMSB in Fiuli, Italy was been released on the Udine Today news website in 2018 (http://www.udinetoday.it/cronaca/invasione-cimici-marmorata-asiatica-talmassons-medio-basso-friuli.html).

The bug secretes an unpleasant odour when disturbed and where this has occurred en masse property resale values have anecdotally been reported to decline.

Based on the available information, the potential socio-cultural impacts of BMSB is considered to be **moderate.**

Human health consequences

There are few published reports of human health consequences associated with BMSB. However, it has been reported that exposure to BMSB proteins can induce clinically significant allergic sensitization, resulting in symptoms including rhinitis and/ or conjunctivitis (Mertz et al. 2012). This sensitization is suggested to be particularly problemematic when large numbers of BMSB enter homes during the overwintering period.

There is a report of slight contact dermatitis among fruit crop workers repeatedly exposed during harvesting to the defensive compound secreted by BMSB when the bug is disturbed (Anderson et al, 2012).

A more recent report, describes chemical burns to the eye of a 74 year old male, who had BMSB defensive compound squirted into his eye whilst trying to crush a bug in his home (Shen and Hu, 2017). A pH value of 6.0 was recorded in the patient's eye, which was inflamed and vison was impaired when they presented at the Emergency Room of the hospital and these researchers attribute the burns to the oxidation of aldehydes contained in the bug's defensive secretions. The patient required treatment initially with saline washes, followed by a topical antibiotic and steroid. Symptoms cleared within a week.

Given that:

- there have been only two reports of human health effects associated with BMSB
- Health impacts have been mild and symptoms cleared within a week with minimal medical intervention

The potential human health consequences within New Zealand are considered to be **very low**, but non-negligible

5.6 Risk estimation

Aggregations of overwintering brown marmorated stink bug are the most likely lifestage to become associated with a pathway of entry into New Zealand. This pathway is most likely to be inanimate including containers and their contents, vehicles machinery and tyres. Based on distribution, abundance and season of entry, aggregations are more likely to enter from countries in the Northern Hemisphere than from the Southern Hemisphere.

All Pathways have been assessed assuming compliance with existing measures. Non-complaince or treatment failure will increase the likelihood of entry.

The likelihood of exposure varies from Negligible to High and is considered most likely for aggregations of overwintering adults coming from Northern Hemisphere winter into New Zealand summer.
Based on a combination of environmental factors and host availability, the likelihood of brown marmorated stink bug establishing is considered high. Once established, the likelihood of spread is also considered high. Based on host range and damage reported from the BMSB's invaded range, the potential economic consequences are considered high. The environmental consequences

are considered low with high uncertainty. The socio cultural consequences are considered moderate and the human health consequences are considered very low, but non-negligible.

Based on the available information, the overall risk of entry, establishment, spread and impact of BMSB on all pathways is estimated in the Risk estimation table below:

***Halyomorpha halys* on all pathways**						
Risk assessment stage	**Pathway**	**Considered to be:**				
		Negligible	**Very Low**	**Low**	**Moderate**	**High**
Likelihood of entry	Inanimates				■	
	Nursery stock		■			
	Fresh Produce		■			
	Cut Flowers and Foliage	■				
	Passenger Personal Effects			■	■	
Likelihood of entry of specific lifestages	Eggs	■	■			
	Nymphs		■			
	Adult single				■	
	Adult Aggregations				■	
Likelihood of exposure	Inanimates					■
	Nursery Stock		■			
	Fresh produce		■			
	Cut Flowers and Foliage	■				
	Passenger Personal Effects				■	
Likelihood of	Aggregated populations					■

establishment	Individual adults					
	Egg masses					
	Nymphs					
Likelihood of spread	Established populations					
Magnitude of consequences	Economic					
	Environmental					
	Socio-cultural					
	Health					

6 Surveillance options

6.1 Volatile organic compounds

Dixon et al,, (2018) report that the volatile organic compounds released by diapausing BMSB when disturbed by agitation during diapause are tridecane, (E)-2-decenal, and 4-oxo-(E)-2-hexenal, with a small abundance of dodecane. New Zealand and Australian researchers are currently investigating means of detecting these compounds in containers using electronic sniffers and other chemical detection systems.

6.2 Environmental DNA (eDNA)

Methods for detection of BMSB at low population densites using environmental DNA are currently in development.

Valentin et al, (2016) developed a real-time PCR (qPCR) assay for BMSB in a conserved region of the ribosomal DNA interspacer 1 (ITS1). The qPCR was able to detect evidence of BMSB in the guano of big brown bat, *Eptesicus fuscus*, which is a known predator of BMSB in the USA.

As BMSB spend extended periods on host plants, they leave detectable quantities of DNA as they feed defecate or moult. Valentin et al, (2018) collected and concentrated rinsate from harvested produce and were able to extract, amplify and identify BMSB DNA. Comparison of results using eDNA with those for conventional monitoring traps indicated eDNA provides substantially higher sensitivity and detection effectiveness particularly when BMSB are at low density. (Valentin et al, 2018).

6.3 Aggregation pheromones

The aggregation pheromone for BMSB is produced by the male (Khrimian et al, 2014; Harris et al, 2015). The two main compounds in the pheromone have been identified as (1S,4S)-4-((R)-4-((S)-3,3-dimethyloxiran-2-yl) butan-2-yl)-1-methylcyclohex-2-enol and (1R,4S)-4-((R)-4-((S)-3,3-dimethyloxiran-2-yl)butan-2-yl)-1-methylcyclohex-2-enol (Khrimian et al,2014), or, using terpene nomenclature (3S,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol and (3R,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol (Weber et al, 2014). These compounds, in combination with a synthetic isolate of the aggregation pheromone of the brown-winged green bug *Plautia stali* Methyl (E,E,Z)-2,4,6-decatrienoate (MDT) have been shown to be more effective as BMSB lures than any of the compounds individually (Weber et al, 2014).

There are three types of commercially produced BMSB traps available: the AgBio pyramid trap, the Trécé sticky trap and the Rescue funnel trap. Each brand of trap has an associated lure that is a combination of BMSB aggregation pheromone and the MDT synergist. These lures may be purchased independently of the traps and several trap and lure combinations are possible.



Figure 8. The AgBio Pyramid Trap (left) stands a little over a metre tall. BMSB are attracted to the lure contained in the trap at the top of the black core flute pyramid, crawl up it and become trapped. The Trécé trap is a clear sticky trap that is approximately the same size as a sheet of A4 paper. The Rescue funnel trap (right) works on the same principle as the AgBio trap, but is smaller (~ 300mm high) and can be mounted in a fruit tree or vine. The Rescue trap may also be placed on the top of a long pole so that it sits at the top of fruit trees where BMSB often congregate.

Trécé sticky traps with high load Trécé lures offer a reliable means of monitoring BMSB at all population densities. Trapping efficiency is improved when placed on a wooden stake ~1m high as opposed to within the plant canopy (Nielsen pers. com). A study by Acebes –Doria et al, (2018) found that while sticky traps captured fewer adults and nymphs than pyramid traps, their captures rates showed a strong positive correlation with BMSB population denisties. The study also found that adult and nymphal captures were significantly greater in traps baited with high loading rate Trécé lures than with Low loaded Trécé lures. There was no difference in BMSB captures between clear and yellow sticky traps, but yellow was found to capture more non-target species.

Deployment of lures in Chile

Preliminary data from Tracy Leskey on trap efficacy using a lure containing 5 mg pheromone and 50 mg MDT indicated that traps lure BMSB within a 3.5ha radius and offer 21% recapture within 10m of the trap declining to 2% at 60m.

Based on Leskey's (unpublished) information and the fact a stronger lure containing 20 mg pheromone and 200 mg MDT was to be used, it was decided to place the traps in the infested region of Santiago City, Chile at approximately 120m intervals at a height of 2m in host trees or on stakes close to host plants found within the target area.

Fifty traps were placed with the lure placed above the trap to maximise the chance that BMSB would cross the sticky trap in order to reach the lure. Traps were attached using either building staples, zip ties threaded through the trap and lure and around the trunk or branch of the host tree or hung on nails driven into the trees. A numbered cow tag was placed at the bottom of each trap for identification and the area below the trap was marked with warning tape to reduce the chance of tampering/vandalism. Traps were checked approximately weekly.

Figure 9. Trécé sticky BMSB trap and lure attached to host tree within the target area. The lure was placed above the sticky surface in order to maximise the chance a BMSB would become trapped

7 Management options

7.1 Chemical Risk management options

Methyl Bromide

A full evaluation is provided in Ormsby, 2018. In summary:

Methyl bromide is a gas at room temperature and a liquid at 4°C. Effective fumigation may only be achieved at temperatures at or above 10°C, because the gas begins to condense at temperatures apporoching 4°C. Penetration may be limited by elevated moisture content in subtrates.

The 2nd and 3rd nymphal instars of BMSB are the most methyl bromide tolerant life stages of non-diapausing BMSB. A USDA-ARS study (not sighted), examining the efficacty of methyl bromide on the 2nd and 3rd nymphal instars at 16°C indicated that 99% mortality was achieved at 40.494 g.h/m^3 (confidence limits of 31.571 to 59.887) and 99.99683% at 90.033 g.h/m^3 (confidence limits of 60.675 to 179.997). However, approximately twice the dose was necessary to achieve the same levels of mortality in diapausing BMSB.

As long as reasonable steps are taken to ensure compartments within vehicles are unsealed (opened) during fumigation, the following reduced methyl bromide fumigation rates should be sufficient to ensure an efficacy of 99.9% (no more than one survivor in 1,000) at the 95% level of confidence:

a reduced methyl bromide fumigation rate of >140 g.h/m3 at >10°C

Or

a reduced methyl bromide fumigation rate >120 g.h/m3 at >15°C

applied over a 12-24 hour period.

Sulfuryl fluoride

A full evaluation is provided in Ormsby, 2018. In summary:

Sulfuryl fluoride is not yet available in New Zealand but is the preferred gas for treatment of vehicles in the USA and Europe. Dose rates for different insect species vary significantly and sulfuryl fluoride is known to be less effective on insect egg than it is on adult insects.

The dose necessary to achieve 99.9% mortality (no more than one bug surviving in a thousand) is not known. However, a reduced sulfuryl fluoride fumigation rate of >135 g.h/m^3 for treatments at >10°C, applied over a >12 hour period at a minimum concentration of 8 g/m^3, should ensure (at the 95% level of confidence) no more than one (non-diapausing) BMSB adult survives in 290 exposed individuals.

Pyrethroids

Leskey et al, (2012) developed a lethality index of 0-100 to compare multiple (37) residual insecticides based on their effect on BMSB in insecticide treated petri dishes over time. The highest ranked insecticides were organophosphates, pyrethroids, an organochlorine and a carbamate. Organophosphates, organochlorines and carbamates are not considered suitable for fogging because of their high level of toxicity to mammals, fish and other non-target organisms.

Table 15. The top 5 Synthetic pyrethroid based treatments ranked in Leskey et al, (2012) are as follows:

Ranking (out of 37)	Insecticide	Lethality index (a scale of 0-100 with 100 being most effective)	Initial efficacy	Efficacy change (after seven days)
3	Bifenthrin	91.5	High	Stable
9	Fenpropathrin	78.3	High	Stable
10	Permethrin	77.1	High	Stable
13	Gamma-cyhalothrin	64.2	High	Decreasing
17	Beta-cyßuthrin	54.8	High	Decreasing

It should be noted that *Halyomorpha halys* has been demonstrated to have the ability to recover from a moribund state induced by exposure to pyrethroid based insecticides by contact with residues on a substrate, ingestion or direct application (Nielsen et al, 2008; Krawczyk et al, 2011; Leskey et al, 2012; Kuhar et al, 2012). A study by Krawczyk *et al*., (2011) found Bifenture EC, a bifenthrin based insecticide, was the only pyrethroid based product that achieved (after 120 hours) 100% mortality of a sample of 60 active BMSB adults (30 male and 30 female) when 2µl of the insecticide was applied at field rate directly to the bug's abdomen. Brigade 2EC, an alternative bifenthrin based insecticide, resulted in 95% mortality in the under the same conditions after the same period of time. The field application rate of Brigade was lower than Bifenture, potentially indicating dose related efficacy.

The use of pyrethroids carries a potential advantage in detection of BMSB as they act as an irritant inducing uncoordinated irregular movement within 10 minutes of exposure (Lee et al, 2013). This excitation decreased significantly within 1.5 hrs of exposure to pyrethroid residues as insects became incapacitated (Lee et al, 2013). However, it is also possible that this excitation may result in BMSB moving from their overwintering spot in vehicles to other localities within a vessel's hold.

Information required

BMSB associated with vehicles are likely to secrete themselves in narrow secluded spaces. A key question that will need to be answered is whether fogged insecticide reaches these spaces. For this reason, any insecticide fogging trail should be conducted under operational conditions, or trials be completed on the ability of fogging to disperse to all likely infested areas of the vehicle.

The expected treatment efficacy for New Zealand is that no more than one BMSB in 1000 (99.9%) survive treatment. In order to prove this with 95% confidence, a minimum of 3000 diapausing or non-diapausing (depending on which condition leads to the greatest tolerance of the treatment) adult BMSB need to be treated with no survivors (i.e. three replicates with a minimum of 1000 bugs in each) (Ormsby, 2018).

Given, BMSB's ability to recover from moribund states induced by exposure to insecticides such as pyrethroids, survival should be assessed at 24 hour intervals for seven days (168 hours) after treatment.

Depending on when and where treatment is proposed, the likelihood that treatment with pyrethroid insecticide will displace over-wintering adults must also be examined. The proportion of overwintering adult BMSB that leave their overwintering spot after treatment and the distance travelled should be examined.

7.2 Temperature-based Risk Management Options

Heat Treatment:

Aigner and Kuhar (2016) collected male and female BMSB from lab reared colonies and housed them in petri dishes in groups of ten. The sample lots were then haphazardly assigned to treatments exposing them to either 35, 38, 40, 42 or 45°C for four hours, or either 40, 45, or 50°C for 15 minutes or 1 hour. 100% mortality (based on no movement for 24 hours) was achieved at 45°C for one and four hours and after 15 minutes at 50°.

A full evaluation is provided in Ormsby, (2018). In summary:

A heat treatment of 56°C for 30 minutes or 60°C for 1 minute at the coldest location BMSB could be found on any treated vehicle should ensure no more than one BMSB adult survives in 1,000 exposed individuals

Cold treatment

Insect Cold Tolerance Strategies

Three broad insect cold tolerance categories exist to describe the relationship between freezing and mortality (Lee 2010):

- freeze-tolerant insects - able to live after the formation of ice within their bodies,
- freeze-intolerant insects - live up until the point at which they freeze
- chill-intolerant insects - die before freezing occurs

Halyomorpha halys is a chill-intolerant species (Cira et al, 2016). *Halyomorpha halys* mediates exposure to cold in a variety of ways. Previous research demonstrated that *H. halys* enters diapause, aggregates, and seeks shelter. Diapause can enhance insect cold tolerance but does not always necessarily do so (Denlinger 1991**).**

Supercooling point of *H. halys*

Cira et al, (2016) highlight an additional means by which *H. halys* reduces exposure to lethal temperatures; by acclimating seasonally and thus lowering the temperatures which would result in mortality.

Based on pooled data from bugs collected in Minnesota and Virginia, Cira et al, (2016) demonstrated that seasonal acclimation lowered BMSB supercooling points (i.e., the temperature at which body fluids begin to freeze). The means recorded were:

- -9.43 ± 0.42°C in summer
- -15.40 ± 0.43°C in autumn
- -16.11± 0.37°C in winter

This suggests that insects arriving in New Zealand in refrigerated containers will suffer higher mortality in summer than winter, (which has implications for Fresh Produce from Chile).

Cira et al, (2016) demonstrated that *Halyomorpha halys* is a *chill-intolerant* species; adults died at significantly warmer temperatures than they froze. See table below.

Table 1. Proportion mortality ± SEM of adult *H. halys* acclimated outdoors in Minnesota in 2013 and 2014 and exposed to one of five temperatures. Numbers in parentheses indicate the total number of adults that were either chilled (unfrozen) or frozen upon reaching the target temperature

	2013		2014	
Temperature (°C)	Chilled	Frozen	Chilled	Frozen
−20	– (0)	1.00 ± 0.00 (17)	1.00 ± 0.00 (1)	1.00 ± 0.00 (16)
−15	0.64 ± 0.12 (14)	1.00 ± 0.00 (3)	0.13 ± 0.08 (16)	1.00 ± 0.00 (1)
−10	0.18 ± 0.09 (17)	– (0)	0.29 ± 0.11 (17)	– (0)
−5	0.18 ± 0.09 (17)	– (0)	0.24 ± 0.10 (17)	– (0)
25 (control)	0.00 ± 0.00 (17)	– (0)	0.00 ± 0.00 (17)	– (0)

It should be noted, that these forecasts do not apply to chronic exposures to cold nor do they account for other causes of winter mortality such as starvation or desiccation. For chill-intolerant species, estimates will be biased, consistently forecasting less mortality (i.e., greater survivorship) than will be observed.

Cira et al, (2018) report a decrease in median super cooling point field reared BMSB from -8.66°C in October to -17.09°C in March.

Based on the findings of Cira et al, (2016) a lethal minimum temperature for BMSB potentially lies between -15°C and -17.86°C unless the cold temperature is mitigated by a suitable shelter/ thermal buffer. These findings are supported in Cira et al, (2018), which reported third quartile supercooling points of -17.59°C in field raised diapausing BMSB tested in March 2015.

8 Uncertainties and areas requiring further research

Many aspects of BMSB biology remains uncertain or have been the subject of studies with conflicting results. Elements of this risk analysis are uncertainties.

Does BMSB require a period of cold to produce viable eggs?

Taylor et al. (2017) presented experimental evidence that diapausing BMSB require a minimum period of 7 weeks at or below 10°C in order to produce consistently viable eggs. However, the study did not report the light /dark regime that the experimental colonies were maintained under. As daylength is a critical factor in diapause termination, it is uncertain whether the failure to produce viable eggs was the result of lack of exposure to reduced temperature or sufficient daylength. If BMSB do require a minimum of 7 weeks at below 10°C, the window for entry and establishment from the Northern Hemisphere would be signifcantly reduced.

Can BMSB reproduce by Parthenogenesis?

Fengjie and Zhifang (1997) report parthenogenesis in 53% of BMSB females observed and 12.5% hatching rates in ubfertikised eggs. It is not clear whether the resultant nymphs were haploid or diploid, whether they reached maturity or if they were able to produce viable offspring. Fengjie et al, (1997) appears to be the only paper reporting parthenogenetic reproduction in *H. halys.* Given the age of the paper and that it has been translated in somewhat broken English, it would be useful to verify the paper's findings. If BMSB is capable of parthenogentic reproduction, the risk associated with entry of single diapausing female BMSB may be understated. However, in conducting life-table analysis, Nielsen et al, (2008) evaluated reproductive output of unmated female BMSB. While eggs were produced, no nymphs hatched out of these unfertilized eggs.

Can overwintering BMSB re-enter a quiescent state and survive until spring?

There is considerable uncertainty as to the risk associated with overwintering aggregations of BMSB from Southern Hemisphere populations.

Quiescence in BMSB appears to be distinct from diapause and has been suggested to be a function of temperature. Overwintering BMSB entering New Zealand from Chile or other Southern Hemisphere countries would encounter temperatures in transit likely to stimulate activity, but would not encounter daylength cues that would terminate diapause. On arrival in New Zealand BMSB would be subjected to temperatures that would promote a return to a quiescent state. Presumably, the period of activity in transit would deplete stored resources. This reduction in stored resources may reduce the bug's potential to survive the winter. Research is required to understand whether BMSB arriving from Chile are able to remain in a dormant state and emerge in spring in New Zealand.

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9 Appendix

Table A1. A list of the reported hosts of *Halyomorpha halys* organised by family. Where an IHS exists for the import of the host as Nursery Stock, the quarantine level and import schedule is also listed. Where a host has been identified to genus level only, its import status has been recorded as "Requires Assessment". Some species in the genus may be eligible for import

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Aceraceae	Acer	buergerianum	trident maple	L2,L3 see 155.02.06 under Acer	USDA 2019
Aceraceae	Acer	campestre	hedge maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	circinatum	vine maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	freemanii	Freeman maple	L2,L3 see 155.02.06 under Acer	Bergmann et al,, 2016; USDA 2019
Aceraceae	Acer	griseum	paperbark maple	L2,L3 see 155.02.06 under Acer	USDA 2019
Aceraceae	Acer	japonicum	Amur (Japanese Downy) maple, full-moon maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	macrophyllum	bigleaf maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	negundo	box elder	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	palmatum	Japanese maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	pensylvanicum	striped maple	L2,L3 see 155.02.06 under Acer	Bergmann et al,, 2016; USDA 2019
Aceraceae	Acer	platanoides	Norway maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	pseudoplatanus		L2,L3 see 155.02.06 under Acer	Haye et al,2013
Aceraceae	Acer	rubrum	red maple	L2,L3 see 155.02.06 under Acer	Bergmann et al,., 2016; USDA 2019; CABI 2019
Aceraceae	Acer	saccharinum	silver maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	saccharum	sugar maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Aceraceae	Acer	tegmentosum	Manchurian snakebark maple	L2,L3 see 155.02.06 under Acer	USDA 2019, CABI 2019
Actinidiaceae	Actinidia	deliciosa	Kiwifruit/Chinese gooseberry	IHS Suspended	Lee et al., 2013
Adoxaceae	Sambucus	racemosa	red elderberry	L2 see 155.02.06 under Hydrangea	Lee et al., 2013
Adoxaceae	Sambucus	spp.	Elder	Requires assessment	USDA-APHIS-PPQ 2010
Adoxaceae	Viburnum	opulus	American cranberry viburnum	L2 see 155.02.06 under Viburnum	Nielsen, 2008
Adoxaceae	Viburnum	sp.	Viburnum	Requires assessment	Lee et al., 2013

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Altingiaceae	Liquidambar	styraciflua	sweetgum	L2 see 155.02.06 under Hebe	Bergmann et al,., 2016; Nielsen 2008; USDA 2019 CABI 2019
Amaranthaceae	Amaranthus	caudatus	love-lies-bleeding (amaranth)	L2 (Basic)	USDA 2019, CABI 2019
Amaranthaceae	Beta	vulgaris ssp. cicla	Swiss chard	Requires assessment	USDA,Lee et al., 2013
Amaranthaceae	Celosia	spp.	cock's comb	Requires assessment	USDA 2019; CABI 2019; Lee et al., 2013
Amaranthaceae	Celosia	argentea	Celosia	Requires assessment	Gyeltshen et al. 2011; USDA-APHIS-PPQ 2010; Hoebeke and Carter 2003
Anacardiaceae	Pistacia	chinensis	Chinese pistache	L2 see 155.02.06 under Hebe	USDA 2019
Anacardiaceae	Rhus	spp.	sumac	Requires assessment	USDA-APHIS-PPQ 2010, Yu and Zhang 2007
Anacardiaceae	Rhus	typhina	staghorn sumac	L2 see 155.02.06 under Aesculus	USDA,Lee et al., 2013
Annonaceae	Asimina	triloba	pawpaw	L2 (Basic)	USDA 2019; CABI 2019
Apiaceae	Musineon	divaricatum	leafy wild, woodland parsley	Requires assessment	USDA 2019
Aquifoliaceae	Ilex	aquifolium	English holly	L2 see 155.02.06 under Hebe	USDA 2019; CABI 2019
Araliaceae	Aralia	elata	Japanese angelica tree	L2 see 155.02.06 under Araucaria	Wermelinger et al. 2008
Arecaceae	Trachycarpus	fortunei	Chinese windmill palm	L2 see 155.02.06 under Acrocomia	Maistrello et al,2016
Asparagaceae	Asparagus	falcatus		Requires assessment	Haye et al,2103
Asparagaceae	Asparagus	officinalis	Asparagus	L3 see 155.02.06 under Asparagus	Lee et al., 2013
Asteraceae	Ageratum	houstonianum vr. nana	Flossflower	Requires assessment	Maistrello et al,2016
Asteraceae	Arctium	minus	lesser burdock	Entry Prohibited	USDA 2019; CABI 2019
Asteraceae	Arctium	spp.	burdock	Requires assessment	Lee et al., 2013
Asteraceae	Artemisia	argyi	Argyi wormwood	L2 see 155.02.06 under Acacia	Lee et al., 2013
Asteraceae	Chrysanthemum	spp.	Chrysanthemum	Requires assessment	Musolin et al,2017
Asteraceae	Dendranthema	morifolium	mums, Chrysanthemum	Requires assessment	Lee et al., 2013
Asteraceae	Helianthus	spp.	sunflower	Requires assessment	USDA 2019; CABI 2019
Balsaminaceae	Impatiens	balsamina	Rose balsam	L2 see 155.02.06 under Delphinium	Lee et al., 2013
Basellaceae	Basella	alba	Malabar spinach	Requires assessment	CABI 2019
Basellaceae	Basella	rubra	T'ang ts'oi	Requires assessment	Lee et al., 2013
Berberidaceae	Mahonia	aquifolium	hollyleaved barberry (Oregon grape)	L2 see 155.02.06 under Berberis	USDA 2019; CABI 2019
Betulaceae	Alnus	sp.	Alder	Requires assessment	Lee et al., 2013
Betulaceae	Betula	nigra	river birch	Requires assessment	USDA 2019; CABI 2019
Betulaceae	Betula	papyrifera	paper birch	Requires assessment	USDA 2019; CABI 2019
Betulaceae	Betula	pendula	European white birch	Requires assessment	USDA 2019; CABI 2019

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Betulaceae	Carpinus	betulus	European hornbeam	L2 see 155.02.06 under Carpinus	USDA 2019; CABI 2019
Betulaceae	Corylus	avellana	hazelnut	L3 see 155.02.06 under Corylus	Maistrello et al,2016
Betulaceae	Corylus	colurna	filbert, hazelnut	L3 see 155.02.06 under Corylus	USDA 2019
Betulaceae	Corylus	ponticha		Requires assessment	Musolin et al,2017
Bignoniaceae	Campsis	grandiflora	Trumpet creeper	Requires assessment	Haye et al,2103
Bignoniaceae	Catalpa	speciosa	catalpa	L2 see 155.02.06 under Hebe	Musolin et al,2017
Bignoniaceae	Catalpa	spp.	catalpa	Requires assessment	Lee et al., 2013; USDA 2019; CABI 2019
Boraginaceae	Myosotis	spp.	Forget-me-not	Requires assessment	Maistrello et al,2016
Boraginaceae	Symphytum	spp.	comfrey	Requires assessment	USDA 2019
Brassicaceae	Armoracia	rusticana	horseradish	Requires assessment	USDA 2019; CABI 2019
Brassicaceae	Brassica	juncea	wild, woodland mustard	Requires assessment	USDA 2019
Brassicaceae	Brassica	napus	rapeseed	Requires assessment	Lee et al., 2013
Brassicaceae	Brassica	oleracea	cabbage, collards	Requires assessment	USDA 2019; CABI 2019
Buddlejaceae	Buddleja	spp.	butterflybush	Requires assessment	USDA 2019
Calycanthaceae	Calycanthus	sp.	Sweetshrub	Requires assessment	Maistrello et al,2016
Cannabaceae	Cannabis	sativa	hemp	Entry Prohibited	USDA 2019
Cannabaceae	Celtis	occidentalis	hackberry	L2 see 155.02.06 under Hebe	USDA-APHIS-PPQ 2010
Cannabaceae	Humulus	lupulus	common hop	Requires assessment	USDA 2019; CABI 2019
Cannabaceae	Humulus	scandens	hop	Requires assessment	Lee et al., 2013
Caprifoliaceae	Abelia	× grandiflora	glossy abelia	L2 (Basic)	USDA 2019; CABI 2019
Caprifoliaceae	Heptacodium	miconioides	seven sons flower	Requires assessment	USDA 2019
Caprifoliaceae	Lonicera	spp.	honeysuckle	Requires assessment	USDA 2019; CABI 2019
Caprifoliaceae	Lonicera	tatarica	Tatarian honeysuckle	L2 see 155.02.06 under Aesculus	USDA 2019; CABI 2019
Caprifoliaceae	Viburnum	× burkwoodii	viburnum	L2 see 155.02.06 under Viburnum	USDA 2019
Caprifoliaceae	Viburnum	dilatatum	linden arrowwood	L2 see 155.02.06 under Viburnum	USDA 2019
Caprifoliaceae	Viburnum	prunifolium	viburnum (blackhaw)	L2 see 155.02.06 under Viburnum	USDA 2019
Caprifoliaceae	Weigela	hortensis	Japanese weigela	L2 (Basic)	Lee et al., 2013
Celastraceae	Celastrus	orbiculatus	Oriental bittersweet	Entry prohibited	USDA 2019; CABI 2019
Celastraceae	Euonymus	japonicus	Japanese spindle	Entry prohibited	Lee et al., 2013
Cercidiphyllaceae	Cercidiphyllum	japonicum	katsura tree	L2 (Basic)	USDA 2019; CABI 2019
Chenopodiaceae	Chenopodium	berlandieri	pitseed goosefoot	Requires assessment	USDA 2019
Cleomaceae	Cleome	spp.	Cleome	Requires assessment	USDA-APHIS-PPQ 2010

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Cornaceae	Cornus	× Stellar series	dogwood	Requires assessment	USDA 2019; CABI 2019
Cornaceae	Cornus	florida	flowering dogwood	L2 see 155.02.06 under Acacia	USDA 2019; CABI 2019
Cornaceae	Cornus	kousa	kousa dogwood	L2 see 155.02.06 under Acacia	USDA 2019
Cornaceae	Cornus	macrophylla	(large-leaf) dogwood	L2 see 155.02.06 under Acacia	USDA 2019
Cornaceae	Cornus	officinalis	Asiatic (Japanese cornel) dogwood	L2 see 155.02.06 under Acacia	USDA 2019; CABI 2019
Cornaceae	Cornus	racemosa	gray dogwood	L2 see 155.02.06 under Acacia	USDA 2019; CABI 2019
Cornaceae	Cornus	sericea	redosier dogwood	L2 see 155.02.06 under Acacia	USDA 2019; CABI 2019
Cornaceae	Nyssa	sylvatica	blackgum (tupelo)	L2 (Basic)	USDA 2019
Cucurbitaceae	Cucumis	sativus	garden cucumber	Requires assessment	USDA, CABI,Lee et al., 2013, Musolin et al,2017
Cucurbitaceae	Cucurbita	pepo	field pumpkin (summer squash)	Requires assessment	USDA, CABI
Cucurbitaceae	Sicyos	angulatus	Burcucumber	Requires assessment	USDA-APHIS-PPQ 2010
Cupressaceae	Chamaecyparis	obtusa	Hinoki cypress	L3 see 155.02.06 under Cedru	Lee et al., 2013
Cupressaceae	Cryptomeria	japonica	Japanese cedar	L3 see 155.02.06 under Juniperus	EPPO 2010; USDA-APHIS-PPQ 2010
Cupressaceae	Cupressus	spp.	cypress	Requires assessment	EPPO 2010; USDA-APHIS-PPQ 2010
Cupressaceae	Juniperus	virginiana	eastern redcedar	L3 see 155.02.06 under Juniperus	USDA 2019; CABI 2019
Cupressaceae	Metasequoia	glyptostroboides	dawn redwood	L2 (Basic)	USDA 2019
Cupressaceae	Platycladus	orientalis	Oriental arbovitae	L2 see 155.02.06 under Platanus	Lee et al., 2013
Cupressaceae	Sequoia	sempervirens	Giant redwood	L2 see 155.02.06 under Arbutus	Maistrello et al,2016
Ebenaceae	Diospyros	kaki	Japanese persimmon	L3 see 155.02.06 under Diospyros	USDA 2019; CABI 2019
Ebenaceae	Diospyros	spp.	persimmon	Requires assessment	Lee et al., 2013
Elaeagnaceae	Elaeagnus	angustifolia	Russian olive	L2 (Basic)	USDA 2019; CABI 2019
Elaeagnaceae	Elaeagnus	umbellata	autumn olive	L2 (Basic)	USDA 2019; CABI 2019
Ericaceae	Vaccinium	corymbosum	highbush blueberry	L2,L3 see 155.02.06 under Vaccinium	USDA 2019; CABI 2019
Euphorbiaceae	Manihot	esculenta	cassava, tapioca	Requires assessment	Lee et al., 2013
Euphorbiaceae	Vernicia	fordii	tung	Requires assessment	Lee et al., 2013
Fabaceae	Acacia	spp.	Acacia	Requires assessment	Lee et al., 2013
Fabaceae	Astragalus	sinicus	Chinese milk vetch	L2 (Basic)	Lee et al., 2013
Fabaceae	Baptisia	australis	blue wild, woodland indigo	L2 (Basic)	USDA 2019
Fabaceae	Caragana	arborescens	Siberian peashrub	L2 (Basic)	USDA 2019; CABI 2019
Fabaceae	Cercis	canadensis	eastern redbud	L2 see 155.02.06 under Hebe	Bergmann et al,., 2016; USDA 2019; CABI 2019

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Fabaceae	Cercis	canadensis var. texensis	Texas redbud	L2 see 155.02.06 under Hebe	USDA 2019
Fabaceae	Cladrastis	kentukea (syn.Lutea)	Kentucky (American) yellowwood	L2 (Basic)	USDA, CABI, Bergmann et al,., 2016
Fabaceae	Gleditsia	triacanthos var. inermis	thornless common honeylocust	L2 see 155.02.06 under Hebe	USDA 2019; CABI 2019
Fabaceae	Glycine	max	soybean	Requires assessment	USDA 2019; CABI 2019
Fabaceae	Lupinus	sp.		Requires assessment	USDA 2019; CABI 2019
Fabaceae	Mimosa	spp.	sensitive plant (mimosa)	Requires assessment	USDA 2019; CABI 2019
Fabaceae	Phaseolus	coccineus	stringbean, runner bean	Requires assessment	Lee et al., 2013
Fabaceae	Phaseolus	lunatus	lima bean	Requires assessment	CABI 2019
Fabaceae	Phaseolus	spp.	bean	Requires assessment	USDA 2019; CABI 2019
Fabaceae	Phaseolus	vulgaris	common bean, kidney bean	Requires assessment	CABI,Lee et al., 2013
Fabaceae	Pisum	sativum	pea	Requires assessment	CABI 2019
Fabaceae	Pueraria	montana var.lobata	kudzu	Requires assessment	Lee et al., 2013
Fabaceae	Robinia	pseudoacacia	blackLocust	L2 (Basic)	USDA 2019; CABI 2019
Fabaceae	Sophora	japonica	Japanese pagoda tree, weeping scholar tree	L2 (Basic)	USDA, Bergmann et al,., 2016,Lee et al., 2013
Fabaceae	Trifolium	repens	clover	Requires assessment	Lee et al., 2013
Fabaceae	Vicia	sp.		Requires assessment	Haye et al,2103
Fabaceae	Vicia	villosa	Hairy vetch	Requires assessment	Lee et al., 2013
Fabaceae	Vigna	angularis	Adzuki bean	Requires assessment	Lee et al., 2013
Fabaceae	Vigna	sesquipedalis	ChineseLongbean	Requires assessment	Lee et al., 2013
Fabaceae	Vigna	unguiculata	cowpea	Requires assessment	Lee et al., 2013
Fabaceae	Wisteria	sinensis	Chinese wisteria	L2 (Basic)	Lee et al., 2013
Fagaceae	Quercus	alba	white oak	L3 see 155.02.06 under Quercus	USDA 2019; CABI 2019
Fagaceae	Quercus	coccinea	scarlet oak	L3 see 155.02.06 under Quercus	USDA 2019; CABI 2019
Fagaceae	Quercus	robur	English oak	L3 see 155.02.06 under Quercus	USDA 2019; CABI 2019
Fagaceae	Quercus	rubra	northern red oak	L3 see 155.02.06 under Quercus	USDA 2019; CABI 2019
Ginkgoaceae	Ginkgo	biloba	maidenhair tree (ginkgo)	L2 see 155.02.06 under Hebe	USDA 2019; CABI 2019
Hamamelidaceae	Hamamelis	japonica	invasive witchhazel	L2 see 155.02.06 under Arbutus	CABI 2019
Hamamelidaceae	Hamamelis	virginiana	American witchhazel	L2 see 155.02.06 under Arbutus	USDA 2019; CABI 2019
Hippocastanaceae	Aesculus	× carnea	red horse-chestnut	L2 see 155.02.06 under Aesculus	USDA 2019
Hippocastanaceae	Aesculus	glabra	Ohio buckeye, Texas Buckeye	L2 see 155.02.06 under	USDA 2019; CABI 2019

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
				Aesculus	
Juglandaceae	Carya	illinoinensis	pecan	L2 see 155.02.06 under Carya	USDA 2019; CABI 2019
Juglandaceae	Carya	ovata	shagbark hickory	L2 see 155.02.06 under Carya	USDA 2019; CABI 2019
Juglandaceae	Juglans	nigra	black walnut	L3 see 155.02.06 under Juglans	USDA 2019; CABI 2019
Lamiaceae	Clerodendrum	trichotomum	Harleyquin glorybower	Entry Prohibited	Lee et al., 2013
Lamiaceae	Ocimum	basilicum	Basil	L2 see 155.02.06 under Anthurium	Maistrello et al,2016
Lamiaceae	Thymus	sp.	Thyme	Requires assessment	Maistrello et al,2016
Lamiaceae	Vitex	negundo	Chinese chaste tree	L2 see 155.02.06 under Hebe	Lee et al., 2013
Lardizabalaceae	Akebia	spp.	Chocolate vine	Requires assessment	Lee et al., 2013
Lardizabalaceae	Decaisnea	fargesii	Blue sausage tree	L2 (Basic)	Wermelinger et al. 2008
Lauraceae	Cinnamomum	camphora	Camphor tree	L2 see 155.02.06 under Arbutus	Lee et al., 2013
Lauraceae	Laurus	nobilis		L2 see 155.02.06 under Arbutus	Haye et al,2103
Lauraceae	Sassafras	albidum	sassafras	L2 (Basic)	USDA 2019; CABI 2019
Lythraceae	Lagerstroemia	indica	crapemyrtle	L2 see 155.02.06 under Hebe	USDA 2019; CABI 2019
Lythraceae	Lythrum	salicaria	purpleLoosestrife	Requires assessment	USDA 2019; CABI 2019
Lythraceae	Punica	granatum	pomegranate	L2 see 155.02.06 under Epipremnum	Lee et al., 2013
Magnoliaceae	Liriodendron	tulipifera	tuliptree	L2, L3 see 155.02.06 under Carya ovata	USDA 2019; CABI 2019
Magnoliaceae	Magnolia	grandiflora	southern magnolia	L2 see 155.02.06 under Arbutus	USDA 2019; CABI 2019
Magnoliaceae	Magnolia	stellata	star magnolia	L2 see 155.02.06 under Arbutus	USDA 2019
Malvaceae	Abelmoschus	esculentus	okra	L2 see 155.02.06 under Hebe	USDA 2019; CABI 2019
Malvaceae	Alcea	spp.	hollyhock	Requires assessment	Lee et al., 2013
Malvaceae	Althaea	rosea	common hollyhock	Requires assessment	Yu and Zhang 2007
Malvaceae	Firmiana	platanifolia	Chinese parasol tree	Requires assessment	Lee et al., 2013
Malvaceae	Gossypium	hirsutum	upland cotton	Requires assessment	Lee et al., 2013
Malvaceae	Hibiscus	moscheutos	crimsoneyed rosemallow	L2 see 155.02.06 under Hebe	USDA 2019
Malvaceae	Hibiscus	rosa-sinensis	China-rose	L2 see 155.02.06 under Hebe	CABI,Lee et al., 2013
Malvaceae	Hibiscus	sp		Requires assessment	Haye et al,2103
Malvaceae	Hibiscus	syriacus	rose of Sharon (hibiscus)	L2 see 155.02.06 under Hebe	USDA 2019

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Malvaceae	Malva	sylvestris	Common mallow	L2 see 155.02.06 under Acacia	Lee et al., 2013
Malvaceae	Tilia	americana	linden arrowwood	L2 (Basic)	USDA-APHIS-PPQ, 2010
Malvaceae	Tilia	spp.	Basswood	Requires assessment	USDA-APHIS-PPQ, 2010
Marantaceae	Maranta	arundinacea	arrowroot	L2 (Basic)	Lee et al., 2013
Moraceae	Broussonetia	papyrifera	Paper mulberry	L2 see 155.02.06 under Araucaria	Maistrello et al,2016
Moraceae	Ficus	carica	edible fig	L2 see 155.02.06 under Ficus	Bergmann et al,., 2016; USDA 2019; CABI 2019
Moraceae	Morus	alba	white mulberry	L2 see 155.02.06 under Hydrangea	USDA 2019; CABI 2019
Moraceae	Morus	spp.	mulberry	Requires assessment	CABI, 2019
Myricaceae	Myrica	spp.	Wax myrtle	Requires assessment	Lee et al., 2013
Oleaceae	Chionanthus	retusus	Chinese fringetree	L2 see 155.02.06 under Hebe	USDA, 2019
Oleaceae	Chionanthus	virginicus	white fringetree	L2 see 155.02.06 under Hebe	USDA, 2019
Oleaceae	Forsythia	suspensa	weeping forsythia	L2 (Basic)	USDA 2019; CABI 2019
Oleaceae	Fraxinus	americana	white (American) ash	L2 see 155.02.06 under Aesculus	USDA 2019; CABI 2019
Oleaceae	Fraxinus	chinensis	Chinese ash	L2 see 155.02.06 under Aesculus	Lee et al., 2013
Oleaceae	Fraxinus	excelsior	European ash	L2 see 155.02.06 under Aesculus	Maistrello et al,2016
Oleaceae	Fraxinus	pennsylvanica	green ash	L2 see 155.02.06 under Aesculus	USDA 2019; CABI 2019
Oleaceae	Ligustrum	japonicum	Japanese or wax-leaf privet	L2 see 155.02.06 under Hebe	USDA, 2019
Oleaceae	Ligustrum	sinense	Chinese privet	Entry Prohibited	USDA 2019; CABI 2019
Oleaceae	Olea	europea var. Taggiasca	Olive tree	L3 see 155.02.06 under Olea	Maistrello et al,2016
Oleaceae	Olea	oleaster	wild olive	Requires assessment	Lee et al., 2013
Oleaceae	Syringa	pekinensis	Peking (Chinese) treeLilac	L2 see 155.02.06 under Aesculus	Bergmann et al,., 2016; USDA 2019; CABI 2019
Oleaceae	Syringa	retuiculata	Jaanese treeLilac	L2 see 155.02.06 under Aesculus	Bergmann et al., 2016,Lee et al., 2013
Orchidaceae	Brassia	spp.	Orchid	Requires assessment	Lee et al., 2013
Orchidaceae	Phalaenopsis	spp.	moth orchid	Requires assessment	USDA 2019; CABI 2019
Paulowniaceae	Paulownia	spp.	Empress tree	Requires assessment	Lee et al., 2013
Paulowniaceae	Paulownia	tomentosa	princesstree (paulownia)	L2 see 155.02.06 under Paulownia	USDA 2019; CABI 2019
Phytolaccaceae	Phytolacca	americana	American pokeweed	L2 (Basic)	USDA, 2019
Phytolaccaceae	Phytolacca	dioica	Ombú	Requires assessment	Maistrello et al,2016
Pinaceae	Cedrus	spp.	cedar	Requires assessment	Lee et al., 2013

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Pinaceae	Larix	kaempferi (syn.Leptolepis)	JapaneseLarch	L3 see 155.02.06 under Cedrus	USDA 2019; CABI 2019
Pinaceae	Pinus	spp.	pine	Requires assessment	Lee et al., 2013
Pinaceae	Tsuga	canadensis	eastern hemlock	L3 see 155.02.06 under Cedrus	USDA 2019; CABI 2019
Pittosporaceae	Pittosporum	tobira (Thunb.)		L2 see 155.02.06 under Aesculus	Musolin et al,2017
Platanaceae	Platanus	occidentalis	American sycamore	L2 see 155.02.06 under Platanus	USDA, 2019
Poaceae	Panicum	miliaceum	Common millet	Requires assessment	Lee et al., 2013
Poaceae	Secale	cereale	cereal rye	Requires assessment	USDA 2019
Poaceae	Setaria	italica	Pearl millet	Requires assessment	Lee et al., 2013
Poaceae	Sorghum	bicolor	Sorghum	Requires assessment	Lee et al., 2013
Poaceae	Triticum	aestivum	wheat	Requires assessment	USDA-APHIS-PPQ 2010; Yu and Zhang 200,Lee et al., 2013
Poaceae	Zea	mays	corn	Requires assessment	USDA, CABI
Poaceae	Zea	mays subsp. mays	sweetcorn	Requires assessment	CABI 2019
Polygonaceae	Polygonum	perfoliatum	Mile-a-minute weed	Entry Prohibited	Lee et al., 2013
Rhamnaceae	Rhamnus	cathartica	common buckthorn	L2 see 155.02.06 under Aesculus	USDA 2019; CABI 2019
Rhamnaceae	Ziziphus	jujuba	jujube	L2 see 155.02.06 under Epipremnum	CABI 2019
Rhamnaceae	Ziziphus	sativa	Chinese date	Requires assessment	CABI, Yu and Zhang 2007
Rosaceae	Amelanchier	laevis (syn. × grandiflora)	Allegheny (apple) serviceberry	L2,L3 see 155.02.06 under Crataegus	USDA 2019; CABI 2019
Rosaceae	Amelanchier	lamarckii	juneberry	L2,L3 see 155.02.06 under Crataegus	Haye et al,2103
Rosaceae	Chaenomeles	speciosa	quince	L2,L3 see 155.02.06 under Crataegus	Lee et al., 2013
Rosaceae	Crataegus	laevigata	smooth (English) hawthorn	L2,L3 see 155.02.06 under Crataegus	USDA 2019; CABI 2019
Rosaceae	Crataegus	monogyna	oneseed hawthorn	Entry Prohibited	USDA 2019; CABI 2019
Rosaceae	Crataegus	pinnatifida	Chinese hawthorn	L2,L3 see 155.02.06 under Crataegus	Lee et al., 2013
Rosaceae	Crataegus	viridis	green hawthorn	Requires assessment	USDA 2019; CABI 2019
Rosaceae	Eriobotrya	japonica	Loquat	L2 see 155.02.06 under Eriobotrya	Lee et al., 2013
Rosaceae	Fragaria	× ananassa	strawberry	L2,L3 see 155.02.06 under Fragaria	Lee et al., 2013
Rosaceae	Malus	× zumi	crab apple	L2,L3 see 155.02.06 under Malus	USDA 2019; CABI 2019
Rosaceae	Malus	baccata	Siberian crab apple	L2,L3 see 155.02.06 under Malus	USDA 2019; CABI 2019
Rosaceae	Malus	domestica	apple	L2,L3 see 155.02.06 under	USDA 2019; CABI 2019

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
				Malus	
Rosaceae	Malus	pumila (syn. domestica)	paradise apple	L2,L3 see 155.02.06 under Malus	USDA 2019
Rosaceae	Malus	sargentii	Sargent's crab apple	L2,L3 see 155.02.06 under Malus	USDA 2019
Rosaceae	Malus	spp.	apple	Requires assessment	Bergmann et al., 2016
Rosaceae	Photinia (syn. Aronia)	spp.	chokeberry	Requires assessment	USDA 2019
Rosaceae	Prunus	× incam	cherry	Requires assessment	USDA 2019
Rosaceae	Prunus	apetala	Japanese flowering cherry	Requires assessment	Funayama 2004
Rosaceae	Prunus	armeniaca	apricot	L2,L3 see 155.02.06 under Prunus	USDA 2019
Rosaceae	Prunus	avium	sweet cherry	L2,L3 see 155.02.06 under Prunus	USDA 2019; CABI 2019
Rosaceae	Prunus	cerasifera	cherry plum	L2,L3 see 155.02.06 under Prunus	USDA 2019; CABI 2019
Rosaceae	Prunus	domestica	plum	L2,L3 see 155.02.06 under Prunus	EPPO 2010; USDA-APHIS-PPQ 2010; Yu and Zhang 2007
Rosaceae	Prunus	dulcis		L2,L3 see 155.02.06 under Prunus	Haye et al,2103
Rosaceae	Prunus	grayana	Japanese bird cherry	Requires assessment	Lee et al., 2013
Rosaceae	Prunus	incisa	Fuji cherry	L2,L3 see 155.02.06 under Prunus	USDA 2019
Rosaceae	Prunus	laurocerasus	cherryLaurel	L2,L3 see 155.02.06 under Prunus	USDA 2019; CABI 2019
Rosaceae	Prunus	mume	Japanese apricot tree	L2,L3 see 155.02.06 under Prunus	CABI 2019
Rosaceae	Prunus	persica	peach	L2,L3 see 155.02.06 under Prunus	USDA 2019; CABI 2019
Rosaceae	Prunus	persica var. nucipersica	peach	L2,L3 see 155.02.06 under Prunus	Haye et al,2103
Rosaceae	Prunus	pseudocerasus	Cambridge cherry	Requires assessment	Lee et al., 2013
Rosaceae	Prunus	serotina	black cherry	Entry Prohibited	USDA 2019; CABI 2019
Rosaceae	Prunus	serrulata	Japanese flowering cherry	L2,L3 see 155.02.06 under Prunus	USDA 2019; CABI 2019
Rosaceae	Prunus	spinosa		L2,L3 see 155.02.06 under Prunus	Haye et al,2103
Rosaceae	Prunus	subhirtella	winter-flowering (Higan) cherry	L2,L3 see 155.02.06 under Prunus	USDA 2019; CABI 2019
Rosaceae	Pseudocydonia	sinensis	Chinese-quince	Requires assessment	USDA 2019
Rosaceae	Pyracantha	coccinea	firethorn	L2 see 155.02.06 under Aesculus	USDA-APHIS-PPQ 2010
Rosaceae	Pyrus	calleryana	Callery (Bradford) pear	Requires assessment	USDA 2019; CABI 2019
Rosaceae	Pyrus	communis	European pear	L2,L3 see 155.02.06 under Pyrus	CABI 2019

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Rosaceae	Pyrus	fauriei	Korean sun pear	Requires assessment	USDA 2019
Rosaceae	Pyrus	prifolia	Japanese pear	Requires assessment	USDA-APHIS-PPQ, 2010
Rosaceae	Pyrus	pyrifolia	Chinese (Asian) pear	Requires assessment	USDA 2019; CABI 2019
Rosaceae	Pyrus	spp.	pear	Requires assessment	USDA 2019; CABI 2019
Rosaceae	Rhodotypos	scandens	Jetbead	Requires assessment	USDA-APHIS-PPQ, 2010
Rosaceae	Rosa	canina	dog (native) rose	L2 see 155.02.06 under Rosa	USDA 2019; CABI 2019
Rosaceae	Rosa	multiflora	mulitflora rose	L2 see 155.02.06 under Rosa	USDA 2019; CABI 2019
Rosaceae	Rosa	rugosa	rugosa rose	L2 see 155.02.06 under Rosa	USDA 2019; CABI 2019
Rosaceae	Rubus	fruticosus		L2,L3 see 155.02.06 under Rubus	Haye et al,2103
Rosaceae	Rubus	idaeus	raspberry	L2,L3 see 155.02.06 under Rubus	CABI 2019
Rosaceae	Rubus	phoenicolasius	wine raspberry (wineberry)	L2,L3 see 155.02.06 under Rubus	USDA 2019; CABI 2019
Rosaceae	Rubus	spp.	raspberry, blackberry	Requires assessment	USDA 2019; CABI 2019
Rosaceae	Sorbus	airia	winterbeam	L2,L3 see 155.02.06 under Crataegus	USDA 2019; CABI 2019
Rosaceae	Sorbus	americana	American mountain ash	L2,L3 see 155.02.06 under Crataegus	USDA 2019; CABI 2019
Rosaceae	Sorbus	aucuparia	ash	L2,L3 see 155.02.06 under Crataegus	Haye et al,2103
Rosaceae	Spiraea	spp.	spirea	Requires assessment	USDA 2019
Rubiaceae	Cephalanthus	occidentalis	common buttonbush	Requires assessment	USDA 2019; CABI 2019
Rutaceae	Citrus	junos	yuzu	L2,L3 see 155.02.06 under Citrus	CABI 2019
Rutaceae	Citrus	reticulata	mandarin	L2,L3 see 155.02.06 under Citrus	Lee et al., 2013
Rutaceae	Citrus	sinensis	orange	L2,L3 see 155.02.06 under Citrus	Lee et al., 2013
Rutaceae	Citrus	spp.	Citrus	Requires assessment	CABI 2019
Rutaceae	Evodia	Daniellii		Requires assessment	Bergmann et al,., 2016
Rutaceae	Evodia	hupehensis		Requires assessment	Bergmann et al,., 2017
Rutaceae	Tetradium (syn. Euodia)	daniellii (syn. hupehensis)	bee-bee tree (Korean euodia)	Requires assessment	USDA 2019
Salicaceae	Populus	tomentosa	Chinese white poplar	Requires assessment	Lee et al., 2013
Salicaceae	Salix	spp.	willow	Requires assessment	USDA 2019; CABI 2019
Sapindaceae	Acer	spp.	maple	Requires assessment	EPPO 2010; Wermelinger et al. 2008
Sapindaceae	Aesculus	hippocastanum	Horse chestnut	L2 see 155.02.06 under Aesculus	Maistrello et al,2016
Sapindaceae	Koelreuteria	paniculata	goldenrain tree	L2 see 155.02.06 under Hebe	Bergmann et al,., 2016; USDA 2019; CABI 2019

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
Scrophulariaceae	Antirrhinum	majus	garden snapdragon	L2 see 155.02.06 under Epipremnum	USDA 2019; CABI 2019
Scrophulariaceae	Buddleja	davidii	Butterfly bush	Entry Prohibited	EPPO 2010, Wermelinger et al. 2008
Simaroubaceae	Ailanthus	altissima	tree of heaven	Entry Prohibited	USDA 2019; CABI 2019
Solanaceae	Capsicum	annuum	cayenne pepper, Bell Pepper	Requires assessment	USDA 2019; CABI 2019
Solanaceae	Capsicum	chinense	YellowLantern Chili	Requires assessment	Maistrello et al,2016
Solanaceae	Lycium	barbarum	Goji berry	Requires assessment	Yu and Zhang 2007
Solanaceae	Nicotiana	alata	jasmine tobacco	Requires assessment	Lee et al., 2013
Solanaceae	Solanum	lycopersicum	garden tomato	Requires assessment	USDA 2019; CABI 2019
Solanaceae	Solanum	melongena	eggplant	Requires assessment	USDA 2019; CABI 2019
Solanaceae	Solanum	nigrum	black nightshade	Requires assessment	CABI 2019
Styracaceae	Halesia	tetraptera	mountain (Carolina) silverbell	L2 (Basic)	USDA 2019
Styracaceae	Styrax	japonicus	Japanese snowbell	L2 (Basic)	USDA 2019; CABI 2019
Texaceae	Taxus	cuspidata	Japanese yew	L2 see 155.02.06 under Arbutus	Lee et al., 2013
Theaceae	Camellia	oleifera	Oil-seed camellia	L2 see 155.02.06 under Camellia	Lee et al., 2013
Theaceae	Camellia	sinensis	Chinese tea	L3 see 155.02.06 under Camellia sinensis	Lee et al., 2013
Theaceae	Stewartia	pseudocamellia	Japanese stewartia	L2 (Basic)	USDA 2019
Tiliaceae	Tilia	cordata	littleleafLinden	L2 (Basic)	USDA 2019; CABI 2019
Tiliaceae	Tilia	tomentosa	silverLinden	L2 (Basic)	Bergmann et al,., 2016; USDA 2019; CABI 2019
Tropaeolaceae	Tropaeolum	majus	Nasturtium	L2 see 155.02.06 under Delphinium	Wermelinger et al. 2008
Ulmaceae	Celtis	koraiensis	Korean hackberry	Requires assessment	USDA 2019
Ulmaceae	Celtis	occidentalis	common hackberry	L2 see 155.02.06 under Hebe	USDA 2019; CABI 2019
Ulmaceae	Ulmus	americana	American elm	L3 see 155.02.06 under Ulmus	Bergmann et al,., 2016; USDA 2019; CABI 2019
Ulmaceae	Ulmus	parvifolia	Chinese elm	L3 see 155.02.06 under Ulmus	Bergmann et al,., 2016; USDA 2019; CABI 2019
Ulmaceae	Ulmus	procera (syn. minor)	English (smoothleaf) elm	L3 see 155.02.06 under Ulmus	Bergmann et al,., 2016; USDA 2019; CABI 2019
Ulmaceae	Ulmus	pumila	elm	L3 see 155.02.06 under Ulmus	Lee et al., 2013
Ulmaceae	Zelkova	spp.	Japanese zelkova	Requires assessment	Lee et al., 2013
Vitaceae	Cayratia	japonica	bushkiller	Requires assessment	Lee et al., 2013
Vitaceae	Parthenocissus	sp.		Requires assessment	Haye et al,2103
Vitaceae	Parthenocissus	tricuspidatus	Japanese creeper	L2 see 155.02.06 under Acacia	Maistrello et al,2016
Vitaceae	Vitis	riparia	riverbank wild, woodland grape	L2,L3 see 155.02.06 under	USDA 2019; CABI 2019

Family	Genus	Species	Common Name	Imported as Nursery Stock	Source
				Vitis	
Vitaceae	Vitis	vinifera	wine grape	L2,L3 see 155.02.06 under Vitis	USDA 2019; CABI 2019

Table A 2. Average Monthly temperatures across New Zealand. Key agricultural production areas are highlighted in red. Months where temperatures exceed meet or the 16.3°C necessary for ovarian devbvelopment are highlighted in yellow. Months where temperatures meet or exceed the 17°C threshold for development from egg to adult are highlighted green.

Average Daily temperatures (°C) across New Zealand													
Area	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Source
Kaitaia	19.5	20.0	18.6	17.0	14.8	12.8	12.1	12.2	13.4	14.5	15.8	17.9	https://www.niwa.co.nz/
Whangarei	19.9	20.2	18.8	16.6	14.4	12.4	11.6	11.9	13.3	14.6	16.4	18.5	https://www.niwa.co.nz/
Auckland	19.1	19.7	18.4	16.1	14.0	11.8	10.9	11.3	12.7	14.2	15.7	17.8	https://www.niwa.co.nz/
Tauranga	19.4	19.6	18.0	15.5	13.2	10.8	10.2	10.7	12.3	13.9	15.8	18.0	https://www.niwa.co.nz/
Hamilton	18.4	18.8	17.1	14.5	11.9	9.5	8.9	9.8	11.6	13.2	14.9	16.9	https://www.niwa.co.nz/
Rotorua	17.7	17.9	16.0	13.3	10.7	8.5	7.8	8.4	10.2	12.0	13.9	16.2	https://www.niwa.co.nz/
Gisborne	19.2	19.1	17.5	14.8	12.5	10.3	9.7	10.4	12.0	13.9	15.8	18.1	https://www.niwa.co.nz/
Taupo	17.0	17.1	14.9	12.0	9.4	7.4	6.5	7.2	9.2	11.1	13.1	15.6	https://www.niwa.co.nz/
New Plymouth	17.8	18.0	16.8	14.5	12.2	10.4	9.5	10.3	11.5	12.8	14.5	16.3	https://www.niwa.co.nz/
Napier	19.5	19.4	17.7	15.0	12.4	10.0	9.4	10.3	12.3	14.3	16.1	18.4	https://www.niwa.co.nz/
Wanganui	18.3	18.5	17.1	14.6	12.4	10.4	9.5	10.2	11.9	13.3	14.8	16.9	https://www.niwa.co.nz/
Palmerston North	17.8	18.3	16.4	13.6	11.4	9.1	8.6	9.2	11.0	12.4	13.8	16.2	https://www.niwa.co.nz/
Masterton	18.1	17.7	16.3	13.1	10.5	8.6	7.6	8.4	10.5	12.3	14.2	16.4	https://www.niwa.co.nz/
Wellington	16.9	17.2	15.8	13.7	11.7	9.7	8.9	9.4	10.8	12.0	13.5	15.4	https://www.niwa.co.nz/
Nelson	17.8	17.9	16.1	13.2	10.5	7.9	7.2	8.4	10.4	12.4	14.3	16.4	https://www.niwa.co.nz/
Blenheim	18.0	17.6	15.8	13.0	10.2	7.7	7.0	8.2	10.3	12.2	14.2	16.5	https://www.niwa.co.nz/
Westport	16.3	16.7	15.3	13.3	11.3	9.3	8.7	9.3	10.7	11.8	13.2	15.0	https://www.niwa.co.nz/
Kaikoura	16.4	16.4	15.1	13.0	11.2	9.0	8.1	8.8	10.4	11.7	13.2	15.2	https://www.niwa.co.nz/
Hokitika	15.6	16.0	14.5	12.4	10.2	8.2	7.4	8.4	9.9	11.1	12.6	14.4	https://www.niwa.co.nz/
Christchurch	17.5	17.2	15.5	12.7	9.8	7.1	6.6	7.9	10.3	12.2	14.1	16.1	https://www.niwa.co.nz/
Lake Tekapo	15.2	14.8	12.4	9.2	5.9	2.6	1.4	3.6	6.5	8.8	11.1	13.2	https://www.niwa.co.nz/
Timaru	15.9	15.5	13.8	11.0	8.1	5.6	5.0	6.5	8.7	10.4	12.3	14.4	https://www.niwa.co.nz/
Milford Sound	14.7	14.8	13.3	11.0	8.4	5.9	5.3	6.9	8.6	10.1	11.8	13.4	https://www.niwa.co.nz/
Queenstown	15.8	15.6	13.0	9.7	7.0	4.1	3.0	5.0	7.7	9.8	11.6	14.0	https://www.niwa.co.nz/
Alexandra	18.0	17.4	14.9	10.9	7.6	3.6	2.9	6.0	9.3	11.7	14.0	16.3	https://www.niwa.co.nz/
Dunedin	15.3	15.0	13.7	11.7	9.3	7.3	6.6	7.7	9.5	10.9	12.4	13.9	https://www.niwa.co.nz/
Invercargill	14.2	13.9	12.5	10.4	8.0	5.9	5.3	6.6	8.5	9.9	11.4	13.0	https://www.niwa.co.nz/

Table A 3 Average daylengths for each month in New Zealand at four locations with daylengths >13 hours necessary for diapause termination are highlighted in yellow.

New Zealand Average Daylength hrs													
Area	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Source**
Auckland	14:20	13:27	12:29	11:19	10:11	9:39	9:58	10:50	11:56	13:05	14:07	14:39	http://rasnz.org.nz/
Wellington	14:44	13:41	12:33	11:11	9:51	9:13	9:36	10:36	11:55	13:16	14:29	15:06	http://rasnz.org.nz/
Christchurch	14:58	13:49	12:35	11:07	9:40	8:58	9:23	10:29	11:54	13:22	14:40	15:22	http://rasnz.org.nz/
Dunedin	15:14	13:58	12:38	11:02	9:26	8:41	9:08	10:21	11:53	13:28	14:55	15:40	http://rasnz.org.nz/