Ministry for Primary Industries
Manatū Ahu Matua

Risk analysis of *Halyomorpha halys* (brown marmorated stink bug) on all pathways

ISBN No: 978-0-478-40464-7 (online)

November 2012

New Zealand Government

Growing and Protecting New Zealand

Contributors to this risk analysis

Primary author

Dr. Catherine Duthie	Advisor – Science and Risk Assessment – Plants and Pathways

Secondary contributors

Internal reviewers from the Ministry for Primary Industries BMSB Working Group:

Michael Tana	Senior Advisor – Plants, Food and Environment – Biosecurity and Environment
Dr. Barney Stephenson	Senior Science Advisor – Strategy, Systems and Science – Science Policy
Dr. Emmanuel Yamoah	Senior Advisor – Compliance and Response – Response Plants and Environment
Brendan McDonald	Senior Advisor – Plants, Food and Environment – Fresh Produce

Internal reviewers from Biosecurity Risk Analysis Group:

Melanie Newfield	Team Manager – Science and Risk Assessment – Plants and Pathways
Dr. Michael Ormsby	Senior Advisor – Science and Risk Assessment – Animals and Aquatic
Dr. Jo Berry	Senior Advisor – Science and Risk Assessment – Plants and Pathways
Dr. Sarah Clark	Senior Advisor – Science and Risk Assessment – Plants and Pathways

External peer review

Sandy Toy	Independent reviewer/ consultant – Riwaka – New Zealand
Dr Anne Nielsen	Research Associate – Michigan State University Department of Entomology – Michigan, USA

Cover photos from left:

First and second instar nymphs of *Halyomorpha halys* dispersing from an egg mass (Gary Bernon, USDA-APHIS)
Fifth instar nymph on raspberry (Gary Bernon, USDA-APHIS)
Adult *Halyomorpha halys* (Susan Ellis, USDA forest service)

Disclaimer

Every effort has been made to ensure the information in this report is accurate.

MPI does not accept any responsibility or liability whatsoever for any error of fact, omission, interpretation or opinion that may be present, however it may have occurred.

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries website at http://www.mpi.govt.nz/news-resources/publications.aspx

Approved for general release

Christine Reed
Manager, Biosecurity Risk Analysis Group
Ministry of Agriculture and Forestry

Contents

Page

1 Executive summary

Purpose

This analysis assesses the biosecurity risks associated with *Halyomorpha halys* entering New Zealand via all likely entry pathways. The results of this work will determine how effective the existing risk management on the main entry pathways is for managing the biosecurity risks posed by *H. halys.* The analysis also considers alternative risk management options.

Background

Halyomorpha halys, or brown marmorated stink bug, is a temperate/subtropical species of stink bug native to China, Japan, Korea and Taiwan and has recently become invasive in the USA. *Halyomorpha halys* overwinters as an adult throughout most of its range. Its tendency to aggregate indoors increases the likelihood of transportation on inanimate objects. The host range of this bug is wide, including many fruit trees, field crops and forest trees. It infests both cultivated and wild hosts and feeding damage results in economic loss. Additionally *H. halys* is a vector of a phytoplasma disease and a significant public nuisance in its aggregation phase.

Risk assessment findings

Halyomorpha halys is not present in New Zealand. This analysis examines the biosecurity risk posed by *H. halys* entering New Zealand as a hitchhiker on inanimate pathways, and associated with the fresh produce, cut flowers and nursery stock pathways.

The likelihoods of entry and exposure are pathway-dependent and are assessed separately for each pathway. The pathways that pose the highest likelihood of entry and exposure are containers (and items within), and vehicles and machinery; and the pathways that pose the lowest likelihood of entry and exposure are vessels and aircraft, fresh produce and cut flowers, and nursery stock. While there is a low likelihood of entry on fresh produce, cut flowers and nursery stock imported under current import health standards, the risk should be assessed in risk analyses in support of new import health standards for host commodities from source countries.

The likelihood of establishment is independent of the pathways of entry and exposure. Based on the biology, phenology and current global distribution of *H. halys* the likelihood of establishment is considered to be high for aggregated populations and moderate for individuals. The likelihood of spread throughout New Zealand, given successful establishment, is considered to be high.

The economic consequences of establishment are likely to be moderate to high, the environmental consequences are considered to be low, and the socio-cultural consequences are likely to be moderate. There are unlikely to be many adverse effects on human health.

Risk estimation conclusion

The risk estimation for *H. halys* is non-negligible and this bug is considered to be a risk, even with existing management in place. Therefore, the risk is worth considering and further analysis undertaken to evaluate additional management options.

Analysis of risk management options

Existing measures on all current pathways will go some way to mitigate the likelihood of entry of *H. halys* however additional measures on higher risk pathways may be warranted. The most likely pathways of entry are containers (and their contents), and vehicles and machinery; on these pathways visual inspection may be the only available detection tool. Videoscope inspection may be a practical routine measure that could be used for inspection of certain shipments considered to be higher risk, or for items that are more difficult to inspect, such as damaged vehicles.

Robust identification and recording of interceptions on all pathways will provide critical information for risk management. It would enable the most likely component pathways of entry to be identified and targeted for biosecurity risk management. Better recording and reporting of interception information would enable interceptions to be used in a predictive manner to reduce the likelihood of entry on pathways where other management options are limited.

The presence of *H. halys* on transported items relates specifically to the conditions in which that item was used and stored prior to its arrival in New Zealand. Therefore, when one individual is found on a particular pathway there is an increased likelihood that others will be found on items from the same source.

Increased awareness of the identity and biology of *H. halys* by staff at transitional facilities and members of the public likely to receive goods from infested countries would help ensure detection of *H. halys* before it has an opportunity to establish and spread in New Zealand. This could be achieved by the provision of fact sheets and other awareness initiatives.

Factors for consideration in the development of risk management options are presented in Appendix 2.

2 Risk Analysis of *Halyomorpha halys* – Brown Marmorated Stink Bug

Scientific name: *Halyomorpha halys* (Stål 1855) (Hemiptera: Pentatomidae)

Other relevant scientific names: *Halyomorpha mista*, *H. brevis*, *H. remota*

Common name: brown marmorated stink bug

Halyomorpha halys, or brown marmorated stink bug, is 12 - 17 mm in length and mottled brownish or greyish. Adults and nymphs feed on leaves and fruit of their hosts. These fruits become blotchy, dimpled and discoloured and are rendered unmarketable. *Halyomorpha halys* is a vector of several phytoplasmas, most notably to *Paulownia* spp. causing witches' broom. In addition to the impact on crops, *H. halys* overwinters in the adult stage and has a tendency to aggregate indoors; when disturbed they discharge a foul smelling scent.

2.1 PURPOSE

This analysis assesses the biosecurity risks associated with *Halyomorpha halys* entering New Zealand via all likely entry pathways. The results of this work will determine how effective the existing risk management on the main entry pathways is for managing the biosecurity risks posed by *H. halys.* The analysis also considers alternative risk management options.

2.2 BACKGROUND

The literature in English on the brown marmorated stink bug (*Halyomorpha halys*) is relatively sparse as it has only recently been found outside of Asia. This bug has been causing concern in North America over the last two years, although it has been present since about 1996. Prior to 1996 it had been known only from its native range in Asia, but it now also occurs in both the USA and Europe.

H. halys has been considered in a number of recent risk analyses and reports, including some from New Zealand. In the recent import risk analysis: "Pears (*Pyrus bretschneideri, Pyrus pyrifolia* and *Pyrus* sp. nr. *communis*) Fresh Fruit from China" (MAFBNZ 2009a) it was recognised that *H. halys* was unlikely to remain on pears during harvest and packing, making the likelihood of entry negligible. However it was also recognised that it is likely to be transported internationally as overwintering adult hitchhikers on commodities other than host material. This information was reported in a Risk Watch article in Biosecurity Buzz in August 2009[1].

Managing the biosecurity risk from organisms entering New Zealand as hitchhikers is challenging because they have an opportunistic association with a commodity or item with which there is no biological host relationship. This means that it can be difficult to understand their association with pathways. However analysis of a hitchhiker organism's biology and life cycle, together with analysis of interception records, can help in understanding these associations and consequently in managing the

[1] Available on the MPI intranet at: http://intranet.maf.govt.nz/intra/business/biosecurity/biosecurity-buzz/issue-13-aug-09.pdf

biosecurity risk posed by the organism, hence the need for a more detailed pest risk analysis.

2.3 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 inanimate pathways, fresh produce, cut flowers and nursery stock. Likely pathways were identified with the aid of records of *H. halys* intercepted on commodities at the New Zealand border or post border (known as interception records) and published records of introduction and interception in the USA and Switzerland.

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

Deciding on specific biosecurity risk management options is outside the scope of this analysis. However, current management options relating to specific pathways are discussed in section 2.7 and relevant considerations for developing risk management options are presented in Appendix 2.

3 Hazard Identification

3.1 TAXONOMY

Halyomorpha halys has multiple synonyms; *Halyomorpha mista*, *H. brevis*, *H. remota*, *Poecilometis mistus*, *Dalpada brevis* and *D. remota*; however, only one species of *Halyomorpha* is found in Eastern China, Japan and Korea and this should be referred to as *H. halys* (Rider 2005; Hoebeke and Carter 2003; Rider *et al*. 2002). The name *H. mista* has been used in Japan until very recently and is possibly still in use; Rider *et al.* (2002) state "it appears that many workers in Japan still refer to it as *H. mista*". *Halyomorpha halys* has also been frequently confused with *H. picus*, an Indian species.

3.2 NEW ZEALAND STATUS

Halyomorpha halys is not known to be present in New Zealand. *Halyomorpha halys* is not recorded in Gordon (2010) or PPIN (2010).

3.3 GEOGRAPHIC DISTRIBUTION

Summary: *Halyomorpha halys* is native to China, Japan, Taiwan, (Rider *et al*. 2002) and Korea (Son *et al*. 2009), and invasive in the USA and Switzerland (Wermelinger *et al*. 2008; Hoebeke and Carter 2003). The current global distribution is detailed in Table 1.

Halyomorpha halys was first detected in the USA in about 1996 in Allentown, Pennsylvania (Hoebeke and Carter 2003) possibly introduced through the movement of "bulk containers" (Hamilton 2009). By 2002 it was reported from six counties in Pennsylvania (Hoebeke and Carter 2003). A specimen was found in a New Jersey blacklight trap in 1999 (Hamilton 2009). By 2005 it was detected on the opposite coast in Oregon and California (Jones and Lambdin 2009). As of summer 2011 it has been detected in 35 states including the entire Atlantic coast. Some years, such as 2005, 2008, and 2010 had a spike in the number of state records, but it is unknown if this is due to increased knowledge or biological parameters that were amenable to dispersal (Nielsen pers. comm. 2011). A recent study suggests that the current population in the USA resulted from just one single mated female or egg mass from China or Korea (Nielsen 2011).

Halyomorpha halys has been reported from Switzerland but is only present as a few occurrences in the Zurich region (Wermelinger *et al*. 2008).

Table 1: *Halyomorpha halys* – Global distribution in 2011

Region	Country	State/Areas
Asia	China	Native and widespread. Present in Anhui, Fujian, Guandong, Guangxi, Guizhou, Heibei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Nei Menggu, Shaanxi, Sichuan, Tibet, Yunnan and Zhejiang (Rider *et al.* 2002)
	Japan	Native (Rider *et al.* 2002)
	Republic of Korea	Native (Son *et al.* 2009, Rider *et al.* 2002)
	Taiwan	Native (Rider *et al.* 2002)
North America	USA	Restricted distribution; recorded from: Alabama (2010), Arizona (2010), California (2005), Colorado (2010), Connecticut (2010), Delaware* (2004), District of Columbia*, Florida (2009), Georgia (2010), Illinois (2010), Indiana (2010), Iowa (2011), Kentucky (2010), Maine (2010), Maryland* (2003), Massachusetts (2010), Michigan (2011), Minnesota (2010), Mississippi (2008), Nebraska (2011), New Hampshire (2010), New Jersey* (1999), New York* (2007), North Carolina* (2008), Ohio* (2007), Oregon* (2005), Pennsylvania* (1996), Rhode Island (2008), South Carolina (2010), Tennessee (2008), Vermont (2011), Virginia* (2005), Washington (2010), West Virginia* (2004), Wisconsin (2010) (Nielsen personal communication 2011, EPPO 2010, Gyeltshen *et al.* 2010, Hamilton 2009, Jones and Lambdin 2009, Nielsen and Hamilton 2009, Welty *et al.* 2008, Khrimian *et al.* 2007, Hoebeke and Cater 2003)
Europe	Switzerland	Only a few records at five different places within a 40 km^2 area in the Zurich region (Wermelinger *et al.* 2008)

** These states have reported crop damage*

3.4 PLANT ASSOCIATIONS

Halyomorpha halys infests both cultivated and wild hosts. The host range is wide; *H. halys* has been recorded in various sources (*e.g.* CPC 2011; EPPO 2010; USDA-APHIS-PPQ 2010; Nielsen and Hamilton 2009a; Nielsen 2008; Wermelinger *et al*. 2008; Yu and Zhang 2007) on host plants belonging to a total of 49 different families, with the most commonly infested family Rosaceae.

Halyomorpha halys feeds on flowers, stems, leaves and fruit of a variety of plant species including many fruit crops, field crops and forest trees (EPPO 2010). Nymphs and adults have piercing-sucking mouthparts and feed by piercing the plant tissue. Small necrotic spots on fruit and leaf surfaces often result from feeding damage, and damage may be compounded by secondary infections and scarring as the fruit matures.

Horticultural crops relevant to New Zealand include [2]: *Citrus* spp., *Diospyros* spp. (persimmon), *Malus domestica* (apple), *Prunus armeniaca* (apricot), *P. avium* (cherry), *P. domestica* (plum), *P. persica* (peach), *Pyrus communis* (pear), *Pyrus pyrifolia* (nashi pear), *Rubus idaeus* (raspberry) and *Vitis vinifera* (grapevine) (Gyeltshen *et al*. 2011; EPPO 2010; AQSIQ 2007).

Field crops relevant to New Zealand include: *Asparagus officinalis*, *Phaseolus vulgaris* (common bean), *Pisum sativum* (pea) and *Zea mays* (corn) (Gyeltshen *et al*. 2011; EPPO 2010).

[2] A comprehensive list of host plants is provided in Appendix 1

Forest and ornamental trees/shrubs relevant to New Zealand include: *Acer* spp. (maple), *Buddleia davidii* (butterfly bush), Cupressaceae (cypress), *Hibiscus* spp., *Lonicera* spp. (honeysuckle), *Paulownia tomentosa* (princess tree), *Rosa* spp. (rose), *Salix* spp. (willow) and *Sophora japonica* (pagoda tree), (Gyeltshen *et al*. 2011; EPPO 2010; Yu and Zhang 2007).

In Asia, *H. halys* has also been found on herbaceous weeds (*e.g. Arctium* spp. (burdock) and *Solanum nigrum* (black nightshade)) (Gyeltshen *et al*. 2011; EPPO 2010).

3.5 COMMODITY ASSOCIATIONS

Both New Zealand and international biosecurity risk analyses have identified *H. halys* as being associated with fresh produce pathways. Some considered the likelihood of entry to be negligible. Those analyses that concluded a negligible likelihood of entry stated that adults and nymphs are likely to have a low prevalence at harvest time, are easily disturbed, and unlikely to remain with fruit during harvest and packing (AQIS 2009; MAFBNZ 2009a; USDA-APHIS-PPQ 2006; AQIS 1998).

New Zealand has recently assessed the risk of entry of *H. halys* on fresh pears from China (MAFBNZ 2009a) and while it was considered that the risk of entry associated with pears was negligible it was recognised that *H. halys* is likely to be transported internationally on commodities other than its host material.

Halyomorpha halys is considered to have entered the USA on packing crates from Asia (EPPO 2010) and is thought to have entered Switzerland as a hitchhiker on woody or floral ornamentals, or fruit (Wermelinger *et al*. 2008). Inanimate objects are considered the most likely means of entry, particularly for overwintering aggregations; however, given the wide host range of *H. halys* the fresh produce, cut flowers and nursery stock pathways are also considered in this analysis.

Halyomorpha halys has been intercepted at the US border on aircraft, machinery, woodenware crating, machinery crating, personal baggage, tractor soil and miscellaneous cargo from China, Japan and Korea (Hoebeke and Carter 2003). However, it was unclear from this paper whether the interceptions were of individuals or aggregations. Between 2001 and 2010 there were 54 reported interceptions of *H. halys* at the US border and 44 of these interceptions were on inanimate objects (USDA-APHIS-PPQ 2011). As an example of its excellent hitchhiking capabilities, it has also been found on numerous occasions on recreational vehicles (RV) and tractor-trailers passing state lines within the USA as well as on containers or boxes moved from personal storage (Nielsen pers. comm. 2011).

Halyomorpha halys has been recorded in the MPI interception database eight times between 1999 and 2010 (data retrieved 31 May 2011). It has been intercepted, both dead and alive, at the border on imported vehicles, air freighted and sea freighted containers, within the hold of a vessel, within an aircraft, within a shipment of clothing and within the personal luggage of an airline passenger. In addition to these records from the MPI interception database, Harris (2010) identified an individual that was found post-border in a used vehicle imported from Japan.

Other bugs in the family Pentatomidae have been recorded in the MPI interception database 168 times on fresh produce and cut flowers, 154 times on inanimate items between 1988 and 2011, and once as eggs on nursery stock in 1992 (data retrieved 23 June 2011); 109 of the interceptions on fresh produce and cut flowers were unidentified to genus and none of the identified interceptions were *H. halys*.. On the inanimate pathway 66 of the interceptions were unidentified to genus.

3.6 POTENTIAL FOR ESTABLISHMENT AND IMPACT

Halyomorpha halys is a temperate/subtropical species native to Asia. It is a pest of crops, ornamentals, forest trees and weed species and an economic threat to fruit crops such as peaches, pears and apples in China (Yu and Zhang 2007), apples in Japan (Funayama 2004), persimmon in Korea (Son *et al*. 2009) and apples and pears in the USA (Nielsen and Hamilton 2009b). *Halyomorpha halys* is 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).

In addition to its status as a plant pest and a disease vector *H. halys* is a significant public nuisance. Adults aggregate in large numbers on the outside of buildings in the late autumn, eventually entering structures to overwinter (Hamilton 2009). When disturbed they discharge an unpleasant and long lasting odour (EPPO 2010).

Halyomorpha halys has recently become invasive in North America and had caused economic losses in tree fruit and heavy pest pressure in soybean crops within eight years of detection (Nielsen *et al.* 2011; Nielsen and Hamilton 2009b). It could enter New Zealand as a hitchhiker on inanimate items, fresh produce, cut flowers or nursery stock. Based on its current global distribution it appears to have the potential to establish in many areas of New Zealand. Additionally, recent modelling by Zhu *et al.* (2012) highlights New Zealand as having high climate suitability for establishment of *H. halys*.

3.7 HAZARD IDENTIFICATION CONCLUSION

Halyomorpha halys:

- has been intercepted as a hitchhiker on inanimate objects from infested areas;
- has a wide host range and may be associated with fresh produce, cut flowers and nursery stock;
- is widespread in China, Japan and Korea;
- is present in parts of Switzerland, Taiwan and the USA;
- is not recorded from New Zealand;
- has the potential to establish in New Zealand;
- has the potential to cause unwanted impacts in New Zealand;

Halyomorpha halys is therefore considered a potential hazard on inanimate objects, and associated with fresh produce, cut flowers and nursery stock, entering New Zealand from China, Japan, Korea, Switzerland, Taiwan, and the USA.

4 Risk Assessment

4.1 BIOLOGY

4.1.1 Description and identification

Detailed descriptions of all life stages of *Halyomorpha halys* can be found in Hoebeke and Carter (2003). A summary of these stages is presented below.

Egg clusters (Fig. 1a) consist of 20 – 30 regularly arranged eggs which are individually about 1.6 x 1.3 mm wide and white in colour. Egg masses are generally deposited on the underside of host plant leaves or on stems (Hoebeke and Carter 2003); however occasionally may be deposited on fruit or inanimate objects (Leskey 2011; Nielsen pers. comm. 2011).

Halyomorpha halys has five nymphal instars. The nymphal instars average 2.4 mm, 3.7 mm, 5.5 mm, 8.5 mm and 12 mm in length for first (Fig. 1b) through to fifth instars respectively. The head and thorax of the first two instars are mostly black and the abdomen is yellowish red, while instars three and four have a brownish black head and thorax and a white abdomen with reddish spots and junctions. The fifth instar (Fig. 1c) has a brownish black head and thorax with a metallic lustre and a yellowish white abdomen with a dense covering of black metallic punctures and reddish spots and junctions. The eyes of all nymph stages are reddish black (Hoebeke and Carter 2003).

Adult *H. halys* (Fig. 1d) are 12 – 17 mm long and 7 – 10 mm wide (Hoebeke and Carter 2003). They are of variable colour but are generally mottled brown with alternating light and dark bands on the antennae, legs and the lateral margins of the abdomen (Hamilton 2009).

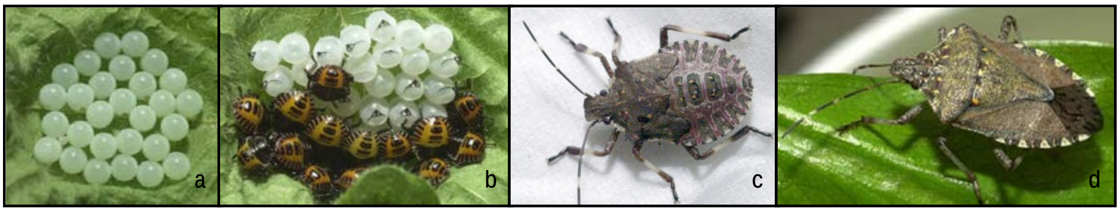


Figure 1 Life stages of *H. halys* [3]: a) egg mass on the underside of a leaf; b) egg mass with first instar nymphs; c) fifth instar nymph; d) adult

4.1.2 Vector status of Halyomorpha halys

Halyomorpha halys is a vector of a phytoplasma disease (witches' broom) of *Paulownia tomentosa* (princess tree) in its native range in Japan. Infection with this phytoplasma reduces growth and vigour causing severe decline and premature death (Hoebeke and Carter 2003). The phytoplasma causing witches' broom in *Paulownia* is the same phytoplasma causing rose witches' broom in China (*in* Jones and Lambdin 2009).

[3] Pictures from: http://massnrc.org/pests/pestFAQsheets/brownmarmoratedstinkbug.html

Polyphagous vectors have the potential to inoculate a wide range of plants and conversely may be able to acquire and transmit phytoplasmas from many different species (Weintraub and Beanland 2006); therefore, *H. halys* may be able to vector other phytoplasmas that could infect a broader range of host plants (Jones and Lambdin 2009), however it is not known how likely this is to take place. Populations in the USA have not been found to carry any phytoplasma at this time (Nielsen pers. comm. 2011).

4.1.3 Biology and phenology

The life-cycle of *H. halys* consists of the egg stage and five nymphal instars, followed by the adult stage (Hoebeke and Carter 2003). Overwintering adults gradually emerge from aggregation sites in early spring. In the laboratory mating and egg-laying commence two weeks after adult emergence (Nielsen *et al*. 2008a). In the field, the minimum threshold to begin reproductive maturation is unknown, but flight activity (as indicated by blacklight traps) can be used as a biofix to begin accumulating the 148 degree days (base 13.4 °C) required for reproductive development. At this point, it takes approximately two weeks, depending on temperature for egg deposition to commence in the field (Nielsen pers. comm. 2011).

Eggs are usually laid on the underside of host plant leaves, however can also be deposited on stems, fruit (Fig. 2a) and inanimate objects. Eggs hatch three to six days (at 30 °C and 25 °C respectively) after deposition (Hoebeke and Carter 2003). Newly emerged nymphs aggregate around the egg mass (Hamilton 2009). Adults generally feed on reproductive tissue whereas nymphs feed on stems, flowers and fruit (Fig. 2b and c) (Hoebeke and Carter 2003). *Halyomorpha halys* differs from many pentatomid species in that it will reproduce and develop within field crops, as opposed to migrating in closer to harvest (Nielsen pers. comm. 2011).

The period between oviposition and emergence of adults is between 37 days at a constant 33 °C and 121 days at a constant 17 °C (Nielsen *et al*. 2008a). The minimum temperature threshold for egg development in Japan is around 12 °C (Kiritani 1997), no development beyond the first instar occurs below 15 °C, and no development in any stage occurs at or above 35 °C (Nielsen *et al*. 2008a). The optimal temperature for development is 25.5 °C (Nielsen *et al*. 2008a).

Development and longevity is highly temperature dependant. Only one generation per year is produced throughout most of Japan with up to two generations in Heibei province in northern China and up to six annual generations in southern China (Hoebeke and Carter 2003). In its northern distribution in the USA *H. halys* produces one generation annually, and two generations have been reported in Maryland and West Virginia (Nielsen *et al.* 2008a).

Sexually mature females may mate multiple times; as many as five times a day, and copulation times are unusually short in this species (Kawada and Kitamura 1983). After mating only once the female can lay eggs over half her life span; however, fecundity increases with the number of matings (Hoebeke and Carter 2003; Kawada and Kitamura 1983).

Halyomorpha halys deposits eggs in masses comprising 20 – 30 eggs with a median of 28 eggs (Wermelinger *et al*. 2008) and under laboratory conditions each female will produce around 200 eggs over her life-time, corresponding to eight egg masses

(Nielsen *et al*. 2008a). The reported hatch rate is between 70 and 90%. (Nielsen *et al*. 2008a).

Halyomorpha halys is a mobile species and can disperse up to two kilometers (Yu and Zhang 2007); adults have been reported to "invade persimmon orchards flying out of nearby forests" (Son *et al.* 2009) and make short flights on warm days (Wermelinger *et al*. 2008). Adults migrate seasonally among different fruiting plants and will immigrate into orchards from surrounding vegetation (Funayama 2004).

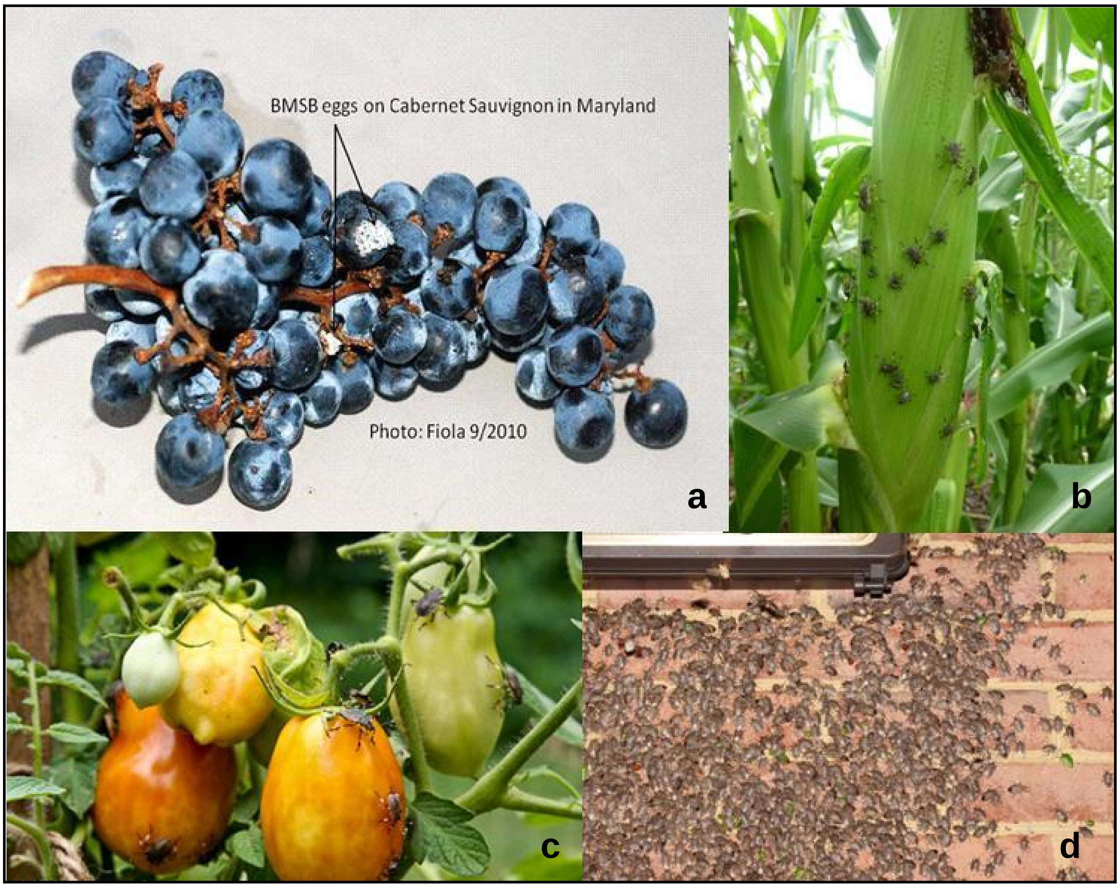


Figure 2 habits of various lifestages of *H. halys* [4] a) eggs deposited on grapes b) adults and nymphs on corn c) adults feeding on tomatoes d) aggregation on the outside of a home

4.1.4 Overwintering

Overwintering adults of *H. halys* commonly aggregate in large numbers in narrow dark spaces, often on the sides of houses (Fig. 2d) and other man-made structures, in the autumn (Toyama *et al*. 2011; Hamilton 2009) before moving inside. Aggregation behaviour is not temperature dependant (Toyama *et al*. 2006); rather it is initiated by reproductive diapause which is determined by day length during the later nymphal stages (Niva and Takeda 2003). The aggregation behaviour of diapausing adults is mediated by olfactory and/or tactile cues (Toyama *et al*. 2006). *Halyomorpha halys* does not require an overwintering period to reach sexual maturity but they do require

[4] Pictures from: a: Virginia Tech http://www.northeastipm.org/neipm/assets/File/BMSB%20Resources/ESA%20Eastern%20Branch%202011/07-Impact-of-BMSB-on-Wine-Grapes-and-Research-Plans-for-2011.pdf; b and c: University of Maryland extension http://growit.umd.edu/plantandpestproblems/StinkBug.cfm; d: Texas A&M agrilife extension http://insectsinthecity.blogspot.co.nz/2011/11/stink-bug-sighting.html

time for sexual development between moulting from the final nymphal stage into the adult stage (Nielsen *et al*. 2008a).

Those nymphs subjected to short days during early instars enter reproductive diapause in the adult stage while nymphs exposed to long days during early development have a much lower incidence of reproductive diapause (Niva and Takeda 2003). This photoperiod induced change in physiology maintains a univoltine life history in areas where there are significant seasonal differences in day length (Nielsen *et al*. 2008a).

Halyomorpha halys undergoes reproductive diapause throughout all of its native and introduced range; however, the timing of reproductive diapause varies depending on location. In Japan aggregations begin to build up at the end of September (early autumn) and by the end of November all adult flight has ceased (Hoebeke and Carter 2003). They return to the environment in April (Funayama 2004).

In Pennsylvania, USA, adults enter homes beginning in mid-September (autumn) and continuing through the first frost (Hamilton 2009) and move outside beginning in April (spring) after which they will become reproductively mature, mate and lay eggs (Nielsen *et al*. 2011).

In Heibei province, northern China, adults begin overwintering from late August to late October (late summer to mid autumn) and return to the environment from early April to mid June (mid spring to summer). In contrast in Canton, southern China, there are as many as six generations each year with eggs laid at the end of September (early autumn) producing nymphs as late as mid October (Hoebeke and Carter 2003).

Adults are usually inactive during this period of reproductive diapause and aggregation, but may have periods of activity on warm days (Hamilton 2009). A mean winter temperature of 4 °C causes only 31% mortality among overwintering adults in natural environments; every 1 °C rise in mean temperature is predicted to result in a reduction of about 15% in winter mortality (Kiritani 2006). The overwintering stage is a non-feeding stage and in a natural environment energy reserves are sufficient to last through the winter if they remain relatively inactive.

Adults never copulate in an overwintering area (Kawada and Kitamura 1983), and the threshold temperature for ovarian development is reported to be 16.3 °C (*in* Funayama 2004). Adults taken from overwintering sites at the beginning of their reproductive diapause (in late autumn) and reared in conditions simulating summer, with longer day length and warmer temperatures, will become sexually mature within 14 - 15 days (Kawada and Kitamura 1983).

4.2 ENTRY ASSESSMENT

4.2.1 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 taxa 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 taxonomically by species 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.

Halyomorpha halys has been intercepted nine times both at the New Zealand border and post border between 1999 and 2010 (MPI Interception Database 2011; Harris 2010). All interceptions occurred in New Zealand's late spring to early autumn period between late October and mid March.

Border interceptions consisted of:

- one live adult (sex not reported) found in the boot of a used car that was sea freighted from Japan in December 1999;
- one live adult male detected within an aircraft from Japan in February 2009;
- two dead adults (sex not reported) found within a sea container from Japan in January 2009;
- one dead adult (sex not reported) detected within the hold of a vessel from Hong Kong during the vessels survey (survey number: VS09LCMAR17/17) in March 2009;
- one dead adult (sex not reported) detected in a new car from Japan during the new vehicles survey (survey number: NV09TVNOV13/6) in November 2009;
- one dead adult female found within an air freighted container from Australia in December 2009;

Post border interceptions consisted of:

- one live adult (sex not reported) detected in the personal luggage of an air passenger from Japan in November 2005;
- one live adult (sex not reported) detected within a used car imported from Japan in March 2010;
- one live adult (sex not reported) found within a shipment of clothing that was air freighted from the USA in October 2010;

It is likely that the specimen recorded on the air container from Australia may have originated elsewhere, since *H. halys* is not known to be present in Australia. Additionally the interception within the vessel from Hong Kong may have originated from mainland China since *H. halys* is not reported from Hong Kong.

Halyomorpha halys has been intercepted at the US border on aircraft, machinery, woodenware crating, machinery crating, personal baggage, tractor soil and miscellaneous cargo from China, Korea and Japan (Hoebeke and Carter 2003). Between 2001 and 2010 there were 54 reported interceptions of *H. halys* at the US border and 44 of these interceptions were on inanimate objects (USDA-APHIS-PPQ 2011).

These interceptions demonstrate the association of *H. halys* with imported vehicles, containers and aircraft. They also indicate the ability of adult *H. halys* to survive sea and air transit from the USA and Asia and cross the New Zealand border.

Interceptions in the same genus or even family can also provide some useful information. Related species may have similar life histories, feeding strategies and hosts. In this case the family Pentatomidae are herbivorous, surface feeding invertebrates, with mobile nymphs and adults, and eggs are deposited externally on plants. Their presence on pathways that have been the subject of management measures is an indication of the general likelihood of entry of species within this family.

In addition to the specific interceptions of *H. halys*, other bugs in the family Pentatomidae (in 20 different genera) have been intercepted in New Zealand on inanimate pathways 154 times between 1988 and 2011. Of these interceptions 66 were unidentified to genus, and of these unidentified interceptions 22 came from countries with recorded populations of *H. halys.* These interceptions were primarily on used vehicles but some were on packing material, sawn timber and camping equipment.

Fifteen different genera in the family Pentatomidae have been intercepted in New Zealand on fresh produce 169 times between 1988 and 2011. Of these interceptions 109 were unidentified to genus, and of these unidentified interceptions nine came from countries with recorded populations of *H. halys.* These unidentified Pentatomids were intercepted on a range of fruit, vegetables, leaves, cut flowers and nursery stock.

Of the unidentified interceptions on fresh produce; eggs comprised 54, adults made up 15, and nymphs a further 23 (the lifestage was not recorded in 17 of these records). Eggs and nymphs were associated primarily with leaves while adults were associated with fruit or vegetables. Nine of these consignments originated from China, Japan and the USA; countries where *H. halys* is present. However, given that most of the commodities they were intercepted on are not recorded as hosts of *H. halys* and those that are recorded hosts were interceptions from the USA prior to 1996 (when *H. halys* was not present) these unidentified Pentatomidae were unlikely to have been *H. halys*. While these individual interceptions were unlikely to have been *H. halys* the presence of other bugs in the family Pentatomidae means that *H. halys* cannot be excluded for consideration for entry on the fresh produce pathway.

In summary, *H. halys* has been identified both at the New Zealand border and post border. All interceptions were adults and half of these were alive. They were intercepted on a variety of inanimate items which were both air and sea-freighted from Asia and the USA. *Halyomorpha halys* is also frequently intercepted at the US border providing additional evidence for the importance of hitchhiker pathways.

4.3 ENTRY OF DIFFERENT LIFE STAGES ACROSS ALL CURRENT PATHWAYS

4.3.1 Entry of eggs and nymphs

Eggs are usually deposited on the leaves or stems of host plants and are unlikely to be present on an inanimate pathway. Nymphs are not present in overwintering aggregations making their likelihood of entry as hitchhikers on inanimate objects negligible. However, both eggs and nymphs may be associated with fresh produce, cut flowers and nursery stock, and may enter New Zealand on these pathways.

Fresh produce and nursery stock that is host material for *H. halys* is imported into New Zealand from countries with recorded populations of *H. halys.* Between 2000 and 2010 there were around 7,900 consignments of fresh produce (comprising asparagus, apple, grapes, stonefruit and citrus fruit) and 13 consignments of nursery stock roses imported from the USA. Between 2004 and 2010 there were 107 consignments of nashi pear imported from South Korea. There were small quantities of nashi pear imported from China and small quantities of citrus fruit imported from Taiwan (QuanCargo 2011).

Eggs of *H. halys* hatch three to six days after deposition reducing the likelihood of entry of this lifestage. Most eggs deposited on fresh produce prior to export are likely to hatch during transit. There have been numerous interceptions of nymphs of Pentatomidae on a range of fresh produce from relevant countries and host material, and while none of these were identified as *H. halys* 109 of the 169 interceptions were unidentified to genus.

Leaves and stems are typically required to be removed from the imported fresh produce that is host to *H. halys* (*e.g.* tree and berry fruit and vegetables), lessening the likelihood of egg masses (or the resulting hatched nymphs) entering New Zealand on the fresh produce pathway. Nymphs are easily disturbed from fruit during routine handling prior to export reducing the likelihood of association. However, egg masses may be associated with leaves and stems of imported nursery stock, cut flowers and leafy vegetables, and small nymphs may go unnoticed.

Consignments of imported nursery stock must be treated for insects and mites in the country of origin and be accompanied by a phytosanitary certificate certifying that the nursery stock has been inspected in the exporting country and been found free of any visually detectable regulated pests (MAFBNZ 2010c). In addition to this certificate

600 units randomly drawn from each lot will be inspected for visually detectable quarantine pests. Organisms that are intercepted are identified where possible to determine their regulatory status; however, all unidentified interceptions are treated as regulated.

For practical purposes, when an organism is detected on a commodity at the border, but hasn't been specifically identified in the Import Health Standard, the status of that organism is determined using the BORIC database[5]. If that organism is not included in the BORIC database, an urgent assessment is done. If the same organisms are regularly intercepted on this pathway a formal risk assessment should be undertaken for those organisms.

Standard management measures, as laid out in the relevant import health standard, are designed to reduce the prevalence of pests on the commodity (as determined by sampling) to no more than 0.5% of units in a consignment (MAFBNZ 2011b; 2010c). There have been border interceptions of Pentatomidae both egg masses and nymphs on cut flowers, leafy vegetables and nursery stock; therefore, even with management measures in place, both egg masses and nymphs of this kind of organism that are associated with these pathways may enter New Zealand, although the prevalence will be low.

Given that:

- eggs and nymphs are associated with fresh produce cut flowers and nursery stock (and may enter on these pathways);
- fresh produce and nursery stock that is host material for *H. halys* is imported into New Zealand from countries with recorded populations of *H. halys*;
- eggs hatch within about five days and are likely to hatch during transit reducing the likelihood of eggs entering on fresh produce, cut flowers or nursery stock;
- neither eggs nor nymphs are commonly associated with inanimate pathways;

The overall likelihood of ***entry of eggs across all pathways*** *is considered to be* ***extremely low***

The overall likelihood of ***entry of nymphs across all pathways*** *is considered to be* ***low***

4.3.2 Entry of adults

Adults may be present on fresh produce or nursery stock even with the application of standard management measures for surface feeding invertebrates, as is indicated by the detection of unidentified pentatomid bugs on these pathways. However adults are easily disturbed (Wermelinger *et al.* 2008), lessening the likelihood of entry on this pathway.

Solitary adults entering New Zealand pose a particular hazard if they are mated females; however, adult *H. halys* are most likely to enter New Zealand on inanimate objects during the period of winter aggregation.

The life stage most likely to enter New Zealand on inanimate pathways is the pre-reproductive adult. These adults seek sites in the late autumn to overwinter in

[5] Available online at http://www.maf.govt.nz/biosecurity-animal-welfare/pests-diseases/boric.aspx

reproductive diapause. Pre-reproductive adults will aggregate in large numbers possibly mediated by visual and/or olfactory cues. Overwintering adults of *H. halys* commonly aggregate in narrow dark spaces often on the sides of houses and other man-made structures in large numbers in the autumn before moving inside (Toyama *et al*. 2011; Hamilton 2009).

The aggregation behaviour of adult *H. halys* is likely to facilitate transport on pathways such as containers and vehicles which have suitable crevices and are stored outside. *Halyomorpha halys* can be difficult to detect because of nocturnal activity and hiding behaviour (Nielsen and Hamilton 2009b).

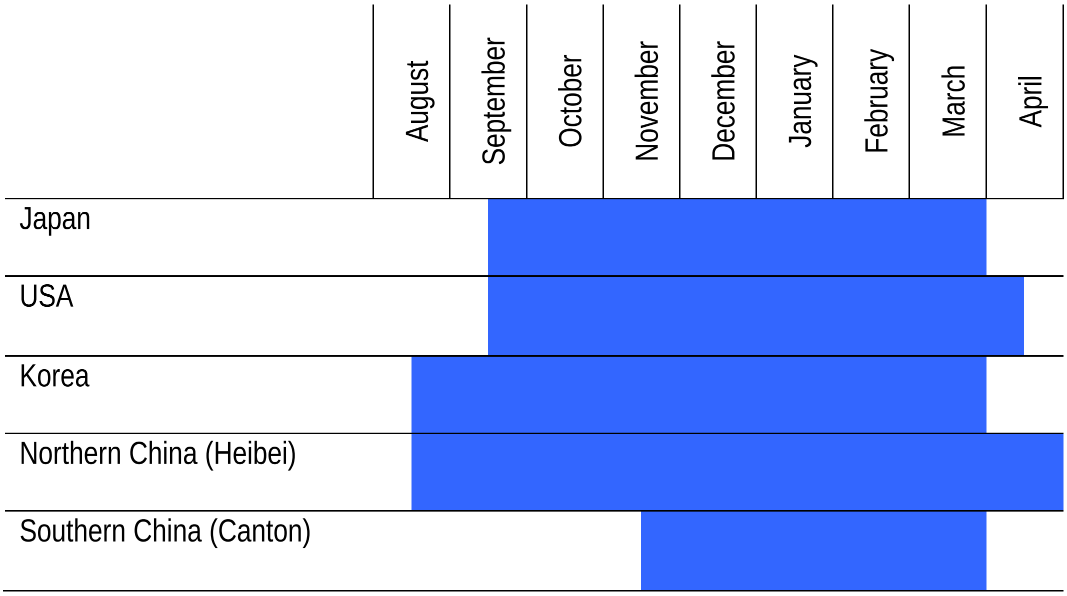
Settling in dark places is a fundamental behaviour of *H. halys*. This behaviour is exhibited by both diapausing and non diapausing individuals and is more pronounced at lower temperatures. Additionally, during the daytime in the reproductive season adults will avoid sunshine and often remain still in shady places (Toyama *et al*. 2011).

Border and post border interceptions of *H. halys* indicate the ability of adults to enter New Zealand. These interceptions have been on a range of inanimate pathways; however, have been restricted to the northern hemisphere late autumn to early spring period (November to March). The timing of these interceptions indicates that the overwinter aggregation behaviour of *H. halys* may influence the likelihood of entry, although they may also reflect the timing of the surveys during which they were found.

During the late autumn period items stored outdoors near host plants may be inhabited by adults seeking aggregation sites. Additionally once adults have moved indoors any items within these indoor areas may be used as a refuge and thereby transport adults if imported into New Zealand. Overwintering adults are frequently found in luggage or boxes stored in an attic space and could be accidentally transported in this manner during the overwintering period.

The timing of reproductive diapause varies depending on location and therefore the likelihood of entry will vary by country during different months (Table 2). In Japan aggregations begin to build up at the end of September (Hoebeke and Carter 2003). In Pennsylvania, USA, aggregations occur from September to November (Hamilton 2009). In Korea adults are most numerous in aggregations in early August. In Heibei province, northern China, adults begin overwintering from late August to late October. In contrast in Canton, southern China, adults aggregate in late November (Hoebeke and Carter 2003).

Table 2 Approximate overwintering periods for *H. halys*



It is likely that larger items such as containers, vehicles and the holds of ships and aircraft will contain larger numbers of adults as these items may be used as overwintering aggregation sites. Smaller items that have been stored inside infested areas, such as clothing and luggage, may only transport small numbers of adults, as adults have a tendency to move around once indoors if the temperature is elevated.

At lower temperatures aggregations are maintained by direct contact using antennation (direct contact with another individual using antenna) (Toyama *et al*. 2006); however, adult activity will temporarily increase on warm days (Hamilton 2009). Although *H. halys* has been intercepted at the border only as one or two individuals, given the tendency of over wintering adults to use dark crevices there may have been others present that were not detected.

Given that:

- adults are associated with fresh produce but are unlikely to remain with it during harvest, packing and transport;
- adults will aggregate in large numbers to overwinter in reproductive diapause;
- aggregation behaviour is likely to facilitate transportation;
- aggregation behaviour occurs from autumn to spring and therefore the likelihood of entry is increased during this period;
- the likelihood of entry varies by country during different months of the northern hemisphere autumn and winter period;
- border and post border interceptions of *H. halys* indicate the ability of live adults to enter New Zealand;
- the tendency of *H. halys* to aggregate in crevices means that they may not be detected during routine inspection procedures;
- inanimate commodities such as containers and vehicles are imported in large numbers from the countries in which *H. halys* occurs (see below);

The overall likelihood of ***entry of adults across all pathways*** *is considered to be* ***moderate***

4.4 PATHWAYS

Halyomorpha halys could enter New Zealand as a hitchhiker on inanimate objects and it is the use and storage of these objects in the country of origin prior to transportation to New Zealand which will influence whether or not the items will carry *H. halys*. *Halyomorpha halys* may also enter New Zealand associated with fresh produce, cut flowers or nursery stock, either as egg masses or as nymphs on leaves or stems, or nymphs and adults on fruit. Based on the interception data, and the likely pathways of introduction to the USA and Switzerland, the most likely pathways for introduction to New Zealand are assessed below.

4.4.1 Containers and items within

Air and sea freighted containers are a high volume pathway and their construction provides suitable spaces for overwintering aggregations. The likelihood of aggregations being present on containers depends on the storage conditions of the containers in the country of origin.

Aggregations of *H. halys* tend to build up externally before seeking refuge; therefore, the containers would need to be present in the environment for some weeks prior to shipment during the months when adults are seeking overwintering sites. Once present on the container the hiding behaviour of *H. halys* may mean that small aggregations and individuals are likely to go unnoticed during routine inspections.

The high volume of containers imported into New Zealand increases the likelihood of multiple introductions. *Halyomorpha halys* has been intercepted on both air and sea freighted containers at the border.

Approximately 500,000 sea containers arrive in New Zealand annually (MAFBNZ 2011a) with 17% of all containers coming from China, 7% from North America and 2% from Japan (MAFBNZ 2010b). Air containers were surveyed over a 33 day period between July and August 2008 and during this time 4,426 air containers arrived in New Zealand; of these 1,644 (37%) came from Asia and 464 (10%) from North America (MAFBNZ 2008a).

During the air container survey (MAFBNZ 2008a) foliage and leaves were the most frequently found contaminant (56% of all contaminants). *Halyomorpha halys* deposits eggs on leaves therefore it is possible that egg masses could enter on this contamination.

All sea containers for importation must be inspected and all containers of high regulatory interest must receive a six-sided inspection or be directed for treatment if not managed under an equivalent offshore system (MAFBNZ 2009c). All parts of imported air containers must be free of contamination both internally and externally. Air containers may be held air-side without inspection unless contamination is observed. Those air containers removed from the air-side location and transported elsewhere will be subject to inspection by an approved operator (MAFBNZ 1998); these management measures will go some way to mitigate the likelihood of entry.

Container contents including wood packaging (wood or wood products used in material supporting, protecting or carrying a commodity), cardboard boxes, and unaccompanied goods may provide additional sites either for overwintering aggregations or incidental contamination as a result of proximity to aggregations.

Wood packaging, especially if it has been stored outdoors, may be one of the more likely means of introduction of *H. halys*. This pathway has been suggested to be the probable means of introduction to the USA. Wood packaging may originate from a variety of different environments and are not confined to more managed areas such as sea and airports.

Wood packaging, and items within, has the opportunity to be present in an infested environment for some time before shipment, increasing the likelihood of infestation with either individuals or overwintering aggregations.

All wood packaging for importation must be free of regulated pests, extraneous material and bark and be treated and certified. Wood packaging is subject to risk profiling with a sample selected for inspection (MAFBNZ 2009e); these management measures will go some way to mitigate the likelihood of entry.

Unaccompanied goods pose a similar likelihood of contamination as personal luggage (section 2.5.4.4). Unaccompanied goods require a declaration of any biosecurity risk goods and will be subject to inspection on arrival. These measures will not prevent goods from becoming incidentally contaminated by *H. halys*. If any item has originated in an infested area it may become incidentally contaminated. Unaccompanied goods and personal effects are more likely to harbour individuals than aggregations; however, there remains an opportunity for introduction on this pathway particularly if previously mated females were associated with these goods.

Given that:

- a large number of containers are imported from countries in which *H. halys* occurs;
- overwintering aggregations may be present on containers;
- egg masses could enter on contamination present in containers;
- all sea containers are inspected but not necessarily on all sides;
- wood packaging is considered the likely means of introduction to the USA;
- wood packaging may harbour overwintering aggregations;
- management measures for wood packaging will mitigate the likelihood of entry to some degree, but not entirely;
- unaccompanied goods are likely to be only incidentally contaminated;

The likelihood of ***entry on containers and items within,*** *taking into account the current risk management is considered to be* ***moderate.***

4.4.2 Fresh produce and cut flowers

Individual *H. halys* may enter New Zealand associated with fresh produce or cut flowers. Adults and nymphs may be associated primarily with fruit but also with leaves, and eggs and nymphs may be associated with leaves and stems. However; adults and nymphs are easily disturbed (Wermelinger *et al.* 2008) and are unlikely to remain associated with the commodity during routine harvest and packing activities.

Different commodities are subject to different export production systems (post-harvest 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.

Egg masses have occasionally been observed on fruit (grapes and peaches, (Leskey, 2011)); however, this is considered a rare occurrence and it is expected that the export production system for fresh fruit will remove most of these egg masses from the commodity.

Fresh produce and nursery stock that is host material for *H. halys* is imported into New Zealand from countries with recorded populations of *H. halys.* These consignments are comprised of asparagus, apple, citrus fruit, nashi pear and stonefruit imported from the USA, South Korea, China and Taiwan (QuanCargo 2011).

The only time that *H. halys* is likely to be associated with imported fresh produce and cut flowers is during the northern hemisphere spring to autumn period when reproductive adults, egg masses, nymphal instars and young adults are present on host plants. Therefore, neither the fresh produce nor cut flowers pathway is likely to provide opportunity for entry during the overwintering period when individuals are not present on host plants.

In addition to commercial practices to reduce the abundance of pests on commodities all fresh produce and cut flowers imported into New Zealand are covered by an import health standard specific to that commodity and country combination. This import health standard sets out measures to ensure that the commodity is free of biosecurity contaminants; these management measures will go some way to mitigate the likelihood of entry. Samples are taken from each lot and examined for the presence of contamination in order to verify that the required management has been undertaken (MAFBNZ 2011b). The records of live Pentatomids of all life stages being detected during verification at the New Zealand border indicate that the specific measures are not always managing the risks of similar species.

Given that:

- *Halyomorpha halys* may be associated with fresh produce and cut flowers of host plants imported from relevant countries;
- host material is imported from relevant countries;
- adults and nymphs are easily disturbed and it is assumed they would leave the commodity during routine handling for harvest and packing;
- *Halyomorpha halys* will only be associated with host plant commodities during the northern hemisphere spring to autumn period;
- fresh produce and cut flowers are covered by import health standards which contain requirements which will reduce the likelihood of entry;
- given the different production systems, management measures, countries of origin, and architecture of different commodities the likelihood of entry will differ within this general pathway and is likely to range from negligible to moderate;

*The overall likelihood of **entry on fresh produce and cut flowers**, taking into account the current risk management is considered to be **low.***

4.4.3 Nursery stock

Individual nymphs and adults and egg masses of *H. halys* may enter New Zealand associated with nursery stock. Adults and nymphs are associated primarily with fruit but also with leaves, and eggs and nymphs may be associated with leaves and stems. Adults and nymphs are easily disturbed and if plants are handled individually these lifestages are unlikely to remain associated with nursery stock during handling and transportation prior to shipping. However, if plants are not handled individually this may reduce the disturbance and increase the likelihood that adults and nymphs remain associated with nursery stock.

Halyomorpha halys is likely to be associated with imported nursery stock only during the spring to autumn period when reproductive adults, egg masses, nymphal instars and young adults are present on host plants. Therefore, this pathway is not likely to pose an opportunity for entry during the overwintering period when individuals are not present on host plants.

All nursery stock imported into New Zealand is covered by an import health standard which sets out measures to ensure that the commodity is free of biosecurity contaminants. Prior to arrival in New Zealand non-dormant nursery stock must be subject to treatment with a chemical dip or spray with two active ingredients (one organophosphorous and one other selected from the list within the import health standard). Once in New Zealand samples are taken from each lot and examined for the presence of contamination; additionally all nursery stock is required to be held in a quarantine facility for no less than three months after entry to New Zealand (MAFBNZ 2010c).

Resulting from a survey of contamination of nursery stock conducted between June 2007 and July 2008 (MAFBNZ 2008b) it was concluded that the nursery stock pathway is a highly compliant pathway. Potential host material for *H. halys* (budwood cuttings, whole plants and rooted cuttings) is a small portion of the nursery stock pathway, comprising only 2.5% of nursery stock imports. The other 97.5% of imports consisted of dormant bulbs and tissue culture.

Only 1.8% of plants sent to post entry quarantine were contaminated. Of this contamination 13% were insects, 58% were fungi and the remainder were “worms and plants”. Imported nursery stock comes primarily from the Netherlands; of the countries with populations of *H. halys* 14% of imports originated in the USA and 9.6% from China.

An additional survey between August 2009 and May 2010 (MAFBNZ 2010d) concluded that only 1% of whole plants and 1.3% of budwood and cuttings were contaminated after post entry quarantine. Most of the contamination was fungal, with arthropods making up only 0.005% of contamination. The low levels of contamination and low volumes of imports from countries with *H. halys* combine to reduce the likelihood of entry on this pathway.

Given that:

- adults and nymphs are easily disturbed and it is assumed they would leave the commodity during handling for harvest and packing;
- *Halyomorpha halys* will only be associated with nursery stock during the northern hemisphere spring to autumn period;
- nursery stock is covered by import health standards which specify both chemical treatment and post entry quarantine;
- the nursery stock pathway is a highly compliant pathway;
- nursery stock is a low volume import from countries with populations of *H. halys*;

*The likelihood of **entry on nursery stock**, taking into account the current risk management is considered to be **negligible***

4.4.4 Personal luggage

Halyomorpha halys has previously been intercepted in New Zealand in personal luggage post border. It is unlikely to be transported intentionally but luggage may become contaminated by individual *H. halys* if present in an environment containing overwintering aggregations. These items are not likely to be sites for aggregations rather they are more likely to become incidentally contaminated.

Adults are usually inactive during the period of reproductive diapause and aggregation but internal heating may keep them active indoors. When active they tend to move frequently and will move away from aggregations and seek shelter in any suitable small space.

> Current risk management measures for personal luggage require the declaration or disposal of biosecurity risk goods prior to entering New Zealand. These include, but are not limited to; fruit and vegetables, wooden items and used camping equipment. The most commonly seized risk goods in 2009-10 were contaminated used equipment (such as shoes, boots and tents) (43%), followed by fruit (23%), and meat products (9%) (MAFBNZ 2010b). These measures are specific to risk goods rather than live hitchhiker organisms and the seized goods are not types of material that would be most commonly infested by *H. halys* therefore risk management measures may not reduce the likelihood of entry on this pathway.

Personal luggage is a high volume pathway; approximately 4.79 million people arrived in New Zealand between July 2009 and June 2010. Of these 4.79 million passengers, 200,000 (4%) arrived from the USA, although not all of these will have originated in areas in which *H. halys* is present. 150,000 (3%) arrived from China, 100,000 (2%) passengers came from Japan and another 100,000 from Korea (MAFBNZ 2010b). Therefore, 11% of all passengers arriving in New Zealand came from countries where *H. halys* is present.

Given that:

- luggage is likely to be only incidentally contaminated;
- current measures may not reduce the likelihood of entry on this pathway;
- personal luggage originating in countries in which *H. halys* occurs is a high volume pathway;

The likelihood of ***entry on personal luggage,*** *taking into account the current risk management is considered to be* ***low***

4.4.5 Vehicles and machinery

New and used vehicles and other machinery are likely entry pathways for *H. halys.* These are commonly stored outdoors, and in the case of used vehicles, often for considerable periods of time, before shipment to New Zealand. Those vehicles and machinery that are in the vicinity of host plants during the months when adults are seeking overwintering sites could become objects for overwintering aggregations.

Host plants are likely to be present near areas where new and used vehicles and machinery are stored prior to export. For example:

- *Cayratia japonica* (bushkiller) is widespread throughout China, Korea, Japan and Taiwan and is prevalent in disturbed areas and roadsides;
- *Humulus scandens* (Japanese hop) is a weedy species that inhabits wastelands it is widespread throughout China and present also in Japan and Korea;
- *Sophora japonica* (Pagoda tree) is cultivated throughout China and is native to Japan and Korea (Flora of China 2011);
- *Arctium* spp. (burdock) is and exotic weed species and widespread throughout the USA;
- *Tilia americana* (linden) is a native species in the USA and widespread throughout North America;
- *Acer* (maple) is a widespread genus in the USA with 21 species present both exotic and native to North America; some species can be weedy or invasive (Kartesz 2011, USDA 2011).

Approximately 120,000 used vehicles arrived in New Zealand annually prior to 2011 (MAFBNZ 2011a), in 2007 around 95% of these vehicles came from Japan (MAFBNZ 2007). However due to a global downturn and the high value of the New Zealand dollar, used vehicle imports have declined and now number around 50,000 per year (Mike Tana pers. comm. 2011).

New cars were surveyed over 130 days between October 2009 and April 2010, and of the 5,226 new cars imported 1,775 (34%) came from Japan, 393 (7%) came from South Korea and a further 146 (3%) came from the USA (MAFBNZ 2010a). Imported machinery was surveyed over 88 days between March and June 2009 and during this time 214 items of new machinery arrived in New Zealand (MAFBNZ 2009b). The country of origin of these arrivals was not recorded.

All vehicles and machinery imported into New Zealand are required to be clean internally and externally. Most imported vehicles and machinery are subjected to a biosecurity inspection unless covered by an equivalent offshore system (MAFBNZ 2009d) these management measures will go some way to mitigate the likelihood of entry.

The construction of vehicles and machinery provides numerous suitable spaces for aggregations and these aggregations may not be easily detected during quarantine inspections. *Halyomorpha halys* has been intercepted on both new and used vehicles, at the border and post border, confirming both the association with the pathways and ability of *H. halys* to enter alive on these pathways.

Given that:

- a large number of new and used vehicles are imported from countries in which *H. halys* occurs;
- host plants are likely to be present near areas where new and used vehicles and machinery are stored prior to transport;
- the storage of vehicles and machinery prior to shipment provides opportunity for contamination;
- the construction of vehicles and machinery provides numerous suitable spaces for aggregations;
- most imported vehicles and machinery are subjected to biosecurity inspection, but *H. halys* is likely to be difficult to detect;

*The likelihood of **entry on vehicles and machinery,** taking into account the current risk management is considered to be **moderate***

4.4.6 Vessels and aircraft

As with vehicles, machinery, and containers, vessels and aircraft provide suitable locations for overwintering aggregations of *H. halys* as well as suitable sites for individuals seeking shelter. However, in order for a vessel or aircraft to become infested it would need to be present in an environment containing host plants during the period when overwintering aggregations are forming and for those individuals to remain undetected for the period during aggregation and movement indoors. This period can sometimes take several weeks.

All aircraft arriving in New Zealand are required to be disinsected by application of an approved residual aerosol spray to protect New Zealand from potential disease vectors and harmful pests (AQIS/MAFBNZ 2010). The application of this residual insecticide will ensure that any *H. halys* will not survive within the hold or cabin of the aircraft and thereby pose little likelihood of introduction on this pathway. However, as this insecticide is sprayed within the hold and cabin and not used to disinsect cargo any *H. halys* remaining within the cargo may still enter New Zealand.

Halyomorpha halys has been detected both within the hold of a vessel and within an aircraft; however, it is possible that these individuals may have been transported on some other item and subsequently sought shelter. 30,500 aircraft arrived in New Zealand between July 2009 and June 2010 (4% from the USA, 3% from China and 2% each from Japan and Korea; totalling 11% of all flights) (MAFBNZ 2010b). Approximately 3,000 vessels visit by sea annually (this includes cargo vessels, cruise vessels and private yachts) (MAFBNZ 2010b).

Given that:

- vessels and aircraft provide suitable locations for overwintering aggregations;
- to become infested vessels and aircraft need to be present in environments with *H. halys* for several weeks, or transport infested commodities;
- all aircraft entering New Zealand are required to be treated with residual insecticide;

*The likelihood of **entry on vessels and aircraft,** taking into account the current risk management is considered to be **low***

4.5 EXPOSURE ASSESSMENT

Halyomorpha halys is most likely to enter New Zealand on an inanimate pathway as a pre-reproductive adult present in an overwintering aggregation. Adults, including those in reproductive diapause, are highly mobile and able to move off the commodity they arrived on. The conditions they are exposed to on arrival in New Zealand will break the reproductive diapause and they will be able to feed and consequently mature sexually soon after entry.

In order for *H. halys* to become established in New Zealand, it would need to leave the entry pathway and reach a suitable host. A wide range of documented feeding hosts are common throughout New Zealand in commercial and backyard situations. *Halyomorpha halys* is a highly mobile pest (Welty *et al*. 2008) and adults commonly migrate to suitable food sources and switch hosts to feed (Nielsen and Hamilton 2009a; Funayama 2004). As adults are very mobile (Son *et al.* 2009; Wermelinger *et al*. 2008; Yu and Zhang 2007; Funayama 2004) they are likely to be able to leave the commodity on which they entered New Zealand and find suitable host plants at almost any point once entry has occurred. However, the likelihood of exposure will vary depending on the pathway.

For the purpose of this exposure assessment the contents of containers have been assessed separately from the likelihood of exposure from containers. Container contents have been separated into boxes and unaccompanied goods, and wood packaging.

4.5.1 Boxes and unaccompanied goods

Boxes and unaccompanied goods may be transported anywhere in the country. However, they are less likely to harbour overwintering aggregations and more likely to transport individuals. Goods such as outdoor furniture would provide an ideal opportunity for exposure to a suitable environment. It is not known what proportion of imports fall in this category but it is assumed to be small. Any goods that are recorded as outdoor furniture must be inspected; this relies on the importer correctly manifesting the shipment. However, even if the goods are stored indoors, any associated *H. halys* could leave an indoor environment and locate a nearby suitable host plant.

Given that:

- boxes and unaccompanied goods may be transported anywhere in the country;
- some boxes and unaccompanied goods may end up in outdoor environments;

*The likelihood of **exposure from boxes and unaccompanied goods** is considered to be **low***

4.5.2 Containers

The likelihood of *H. halys* associated with sea or air containers leaving the container and finding a suitable host plant increases the longer the container is in the country and the more widely it travels. All sea containers are required to be held at a transitional facility until such time as they receive biosecurity clearance (MAFBNZ 2009c); whereas air containers may either remain within the confines of the airport without inspection, be delivered directly to a consignee if inspected by the operator prior to delivery, or be delivered to a transitional facility (MAFBNZ 1998). However, border clearance of containers may occur some time after arrival in New Zealand and any *H. halys* arriving on these items may escape and find a host plant prior to biosecurity clearance.

Some transitional facilities are located many kilometers distance from the port of arrival increasing the likelihood of exposure prior to inspection. The likelihood of exposure is lower for those containers devanned at the port or airport and then removed from the country; however, items within the containers could also harbour *H. halys* and be transported throughout the country. Even for those containers present only briefly in New Zealand the flight behavior of *H. halys* may provide the opportunity for successful exposure if suitable host plants are present in the vicinity of the port or airport.

Given that:

- some containers may travel anywhere within New Zealand;
- containers devanned at the port or airport present less opportunity for exposure;
- sea containers may travel some distance to transitional facilities prior to inspection;
- most air containers never move beyond airside and are present in New Zealand only briefly;
- adults may fly some distance when disturbed;

The likelihood of ***exposure from sea containers*** *is considered to be* ***moderate***

The likelihood of ***exposure from air containers*** *is considered to be* ***low***

4.5.3 Fresh produce and cut flowers

Adult *H. halys* are highly mobile, and adults and nymphs are easily disturbed. Routine handling will disturb these lifestages and cause them to seek new host plants. It is the location in which they leave the infested commodity which will determine the likelihood of exposure to the New Zealand environment. If disturbed off the commodity in a closed environment such as a warehouse or supermarket the opportunities of finding a new host plant are greatly reduced. However, as *H. halys* commonly overwinter in indoor environments adults may be able to leave an indoor environment and locate a suitable host plant.

The majority of discarded produce or cut flowers will be sent to land-fill with limited opportunity for exposure. In a study by Hogg *et al.* (2010) it was reported that New Zealanders discard around 400,000 tonnes of kitchen waste each year; of this 67% is sent to landfill, 12.5% of this is composted, another 12.5% discarded in an in-sink disposal and 7% is collected by councils for composting.

Compost bins are likely to be in a garden setting in close proximity to suitable host plants. *Halyomorpha halys* is highly polyphagous, feeding on plants in 45 different families, many of which are common in New Zealand; therefore suitable host plants are likely to be present in a home garden environment. Adults and nymphs are easily disturbed and adults can fly some distance, therefore if they are disturbed they may well find a host plant.

Egg masses associated with leafy vegetables or cut flowers may be transported anywhere in the country. Eggs of *H. halys* hatch within 5 days therefore any eggs deposited on the commodity prior to export will either have hatched or be non-viable before reaching the consumer.

Given that:

- adults are highly mobile and adults and nymphs may be easily disturbed off host material;
- any adults or nymphs on imported fresh produce or cut flowers are likely to leave the commodity inside a building;
- adults may be able to leave an indoor environment and locate a suitable host plant;
- the majority of discarded produce will be sent to landfill;
- some discarded produce will be composted;
- egg masses on leafy produce or cut flowers are likely to have hatched before they are disposed of in the New Zealand environment;

*The likelihood of **exposure from fresh produce and cut flowers** is considered to be **moderate***

4.5.4 Personal luggage

Personal effects such as baggage may also be transported anywhere in the country; however, these items are likely to remain indoors reducing the opportunity for exposure to a host plant. As *H. halys* commonly overwinter in indoor environments it is not unlikely that they will be able to leave an indoor environment and locate a suitable host plant.

Given that:

- personal luggage may be transported anywhere in the country;
- personal luggage is likely to remain in an indoor environment;

*The likelihood of **exposure from personal luggage** is considered to be **low***

4.5.5 Vehicles and machinery

New and used vehicles and machinery may travel anywhere in the country and may come in close proximity to suitable hosts. Adults will fly when disturbed and most imported vehicles and machinery will travel through, or end up, in suitable environments. Border clearance of vehicles and machinery may occur some time after arrival in New Zealand and any *H. halys* arriving on these items may escape and find a host plant prior to biosecurity clearance. Therefore, even if an individual or an aggregation were detected at the border the highly mobile nature of this pest will increase the likelihood of exposure unless it is in a confined environment.

Given that:

- vehicles and machinery may travel anywhere in the country;
- adults are highly mobile and easily disturbed;

*The likelihood of **exposure from vehicles and machinery** is considered to be **high***

4.5.6 Vessels and aircraft

Vessels and aircraft present a more limited likelihood of exposure to suitable hosts. Vessels may anchor offshore or in ports with limited host plants in the vicinity. Aircraft may be present for short durations in environments with limited host plants. However; *H. halys* are highly mobile and may fly some distance to a suitable host plant if the opportunity occurs.

Given that:

- vessels and aircraft will be present in New Zealand only for limited periods;
- vessels and aircraft will be present only in environments with limited host plants;
- exiting a vessel or aircraft hold is likely to be difficult;

The likelihood of ***exposure from vessels and aircraft*** *is considered to be* ***very low***

4.5.7 Wood packaging

Wood packaging may be transported anywhere in the country and provide an ideal refuge for overwintering aggregations. Both the packaging itself and items within it may provide suitable sites for aggregations. Additionally, wood packaging is likely to be stored outdoors. Wood packaging is the suspected mechanism of introduction of *H. halys* into the USA.

Given that:

- wood packaging may be transported anywhere in the country;
- wood packaging is likely to be stored outdoors;
- wood packaging is considered to be the means of introduction into the USA;

The likelihood of ***exposure from wood packaging*** *is considered to be* ***high***

4.6 ESTABLISHMENT AND SPREAD ASSESSMENT

In order for *H. halys* to be become established in New Zealand it will be necessary for individuals to reproduce. The likelihood of mating and subsequent establishment is considered to be higher for gregarious insects than for solitary species (Yamamura and Katsumata, 1999). *Halyomorpha halys* may enter New Zealand either as part of an overwintering aggregation or as an isolated individual or egg mass.

Successful establishment of *H. halys* may be more likely to result from the entry of an aggregated population, than from individuals. Overwintering populations are most likely to enter New Zealand during our late spring, summer and early autumn periods and therefore will encounter temperatures suitable for establishment (developmental thresholds of between 15 °C and 35 °C with an optimum temperature of 25 °C (Nielsen *et al.* 2008a)).

Reproduction in *H. halys* is sexual, which requires several individuals of both sexes establishing in the same environment. This is most likely to result from bugs that enter as aggregations, rather than as individuals; however, a single mated female is capable of starting a population if she were exposed to a suitable host plant for egg deposition. Additionally, an egg mass, provided it were deposited in an environment conducive to successful hatching, may be capable of starting a population.

It had been suggested that the introduction of *H. halys* into the USA was of an aggregated population rather than individuals (Aldrich *et al*. 2009). However, recent mtDNA analysis (COI and COII genes) (Nielsen, 2011) indicates that there is a single haplotype in the USA (as of 2004). To identify the source country, material was collected from the native range. The US haplotype is found in China and Korea but not in Japan. These results indicate that the US incursion resulted from just one single mated female or egg mass from China or Korea, probably in shipping containers (Nielsen pers. comm. 2011). These results validate the possibility of a single introduction initiating a population; although, the overall likelihood of establishment is considered to be greater if an aggregation were introduced.

Overwintering aggregations, food finding and mate finding behaviours are thought to be mediated in part by pheromones. While the specific pheromone produced by *H. halys* has not yet been identified there is experimental evidence to suggest that such a pheromone exists. Traps baited with live males attracted conspecific females, males and nymphs (Aldrich *et al*. 2009). Therefore, if several individuals are present in the same environment the opportunity for mate finding may be mediated by pheromones.

No information was found in the literature to indicate a minimum population level needed for successful establishment.

Halyomorpha halys only forms aggregations during the overwintering stage and during the first nymphal stage (however, nymphal aggregations occur only on host plants, rather than on inanimate objects). A larger number of individuals arriving together as an aggregated population will increase the likelihood of successful mate finding.

Adults never copulate in an overwintering area (Kawada and Kitamura 1983). Mating and egg deposition occurs about two weeks after the majority of adults have emerged from overwintering sites (Hoebeke and Carter 2003). Sexual development is dependent on temperature and nutrition (Funayama 2004). The threshold temperature for ovarian development is reported to be 16.3 °C (*in* Funayama 2004) and *H. halys* exhibits host switching behaviour based on plant phenology and will feed at critical stages of fruit development to obtain the optimum nutrients for gonad development and again before reproductive diapause to increase fat bodies (Nielsen and Hamilton 2009a). Adults taken from overwintering sites at the beginning of their reproductive diapause (in late autumn) and reared in conditions simulating summer, with longer day length, warmer temperatures and suitable nutrition, will become sexually mature within 14 - 15 days (Kawada and Kitamura 1983).

Developmental data and the existing distribution of this species suggest that most places in New Zealand will be suitable for establishment of *H. halys*. Lower developmental thresholds have been calculated and the lowest reported is 15 °C (Nielsen *et al*. 2008a). Species with similar or higher developmental thresholds have been able to establish in many areas in New Zealand and become pests *e.g. Nezara viridula* (green stink bug)[6] and *Sitophilus oryzae* (lesser grain weevil)[7] (both 15 °C) (NAPPFAST Insect Development Database).

[6] Found throughout most of the North Island and in the Nelson and Marlborough regions (Allan 1998)
[7] Widespread throughout New Zealand (Archibald and Chalmers 1983)

A wide range of documented fruiting hosts are common throughout New Zealand in commercial and backyard situations (*e.g. Citrus* spp. *Malus domestica* (apple), *Phaseolus vulgaris* (common bean), *Pisum sativum* (pea) and *Zea mays* (corn)). Additionally a number of other plants (*e.g. Arctium* spp. (burdock) *Buddleia davidii* (butterfly bush), and *Solanum nigrum* (black nightshade)), present in New Zealand as weed species, may serve as alternate hosts. *Halyomorpha halys* has been recorded from host plants belonging to 49 different families making it extremely likely that suitable host plants will be available in New Zealand.

In the 15 years since 1996, when *H. halys* was first detected in one town in the USA, it has undergone rapid range expansion and now populations have been detected in 35 states indicating its potential as a successful invasive species. *Halyomorpha halys* is a highly mobile species capable of migrating between hosts as well as hitchhiking on a wide range of inanimate items. *Halyomorpha halys* has a high reproductive potential and survival is favoured by the ability to overwinter in protected sites. Suitable host plants and temperatures occur over much of New Zealand increasing the likelihood of successful establishment and spread throughout the country.

Given that:

- aggregations may be more likely to establish than individuals;
- however the US population is thought to have been derived from a single mated female or egg mass;
- reproduction is sexual;
- mate finding may be mediated by pheromones;
- adults require two weeks to become sexually mature after the end of reproductive diapause and activity in the field is established;
- adults are highly mobile;
- host plants are common throughout New Zealand;
- the New Zealand climate is likely to be suitable for establishment;

The likelihood of ***establishment*** *throughout much of New Zealand is considered to be* ***high for aggregated populations*** *and* ***moderate for individuals****.*

The likelihood of ***spread*** *following establishment is considered to be* ***high***

4.7 CONSEQUENCE ASSESSMENT

4.7.1 Economic consequences

Halyomorpha halys attacks intact developing and ripe fruit and has a range of hosts that are economically important in New Zealand. Infestations can reduce marketable yields; reports of economic damage from its native and introduced ranges are summarised in Table 3.

Importing countries that do not currently have *H. halys* might impose additional biosecurity measures on commodities imported from New Zealand. However, given that the risk of entry and exposure on the fresh produce pathway has been assessed as being low overall by other international organisations (e.g. AQIS 2009; USDA-APHIS-PPQ 2006; AQIS 1998), additional measures may not be needed to meet export requirements.

Damage is seasonally dependant; *H. halys* switches hosts depending on timing of reproductive diapause. For example *H. halys* are significant pests of apples in Japan. Apples are poor hosts but may contribute to maturation of ovaries as the fruit is present on trees at a time when overwintering adults are emerging from reproductive diapause and little other fruit is available (Funayama 2004).

Feeding early in the fruiting season results in grooves or distorted brown lines on the surface of the fruit (Welty *et al*. 2008) while feeding later in the fruiting season results in pitting or flesh which is soft or spongy (Hoebeke and Carter 2003). Damage may also be compounded by secondary infections (Welty *et al*. 2008).

Table 3: *Halyomorpha halys* – Summary of reported impacts on selected crops

Crop	Reported impacts/damage
Apple (*Malus domestica*)	• Adults feed on fruit at its earliest stage (fruit set) and young fruit resulting in fruit abortion or deformed fruit, and on mature fruit reducing market value • Feeding results in around 47 – 89% of fruit with damage in lightly controlled orchards and a minimum of 25% in controlled orchards (Nielsen and Hamilton 2009)
Peach (*Prunus persica*)	• Adults feed on fruit at its earliest stage (shuck split) and young fruit resulting in fruit abortion or cat-facing, and on mature fruit reducing market value • Feeding damage is from 16 - 54% in controlled orchards (Nielsen and Hamilton 2009)
Pear (*Pyrus* spp.)	• Adults feed on fruit at its earliest stage (fruit set) and young fruit resulting in fruit abortion or deformed fruit, and on mature fruit reducing market value • Feeding results in around 25 – 65% of fruit with damage in uncontrolled orchards and from 18 – 39% in controlled orchards (Nielsen and Hamilton 2009)
Persimmon (*Diospyros* spp.)	• Adults feed on fruit reducing market value • In Korea fruit damage as high as 34 – 44% has been reported with damage between 6 and 10% even in intensively controlled orchards (Son *et al.* 2009)
Soybean (*Glycine max*)	• Damage includes deformed seeds, delayed maturity and reduction in both yield and oil content (Nielsen *et al.* 2011) • Feeding damage occurs on around 34% of pods and 9% of seeds (Kang *et al.* 2003)

Based on reported impacts on crops from other countries, if *H. halys* were to establish in New Zealand direct losses would be likely to the following crops in New Zealand: apples, cherries, corn, grapes, peaches, pears, peas and persimmons.

- Around 263 million kilograms of apples and pears were exported in 2010 with an export value of $346 million[8]. Infestation could significantly impact these markets as feeding damage reduces market values.
- Significant impacts could be expected on cherry and to a lesser extent peach and plum production (cherries are the most important summerfruit export by value worth $21.9 million in 2009[9]). Seventy percent of all summerfruit produced in New Zealand is consumed within the domestic market. The export market takes a further 25% with Taiwan, Australia and the USA being the predominant markets[10]
- Processed peas had an export value of around $85 million and processed sweet corn was worth around $45 million in 2009[7]

[8] Source: Situation and Outlook for New Zealand Agriculture and Forestry, 2010
[9] Source: HortResearch Fresh Facts 2009 (http://www.freshfacts.co.nz/file/fresh-facts-2009.pdf)
[10] Source: Summerfruit New Zealand (http://www.summerfruitnz.co.nz)

Infestations have the potential to impact the wine industry. *Vitis vinifera* is a host plant of *H. halys* and feeding damage can cause premature rot of grapes. Additionally, adults, if harvested with grapes for winemaking, have the potential to taint the wine. As few as 10 individuals in 12 kilograms of grapes are enough to produce a detectable taint (Leskey and Hamilton 2010).

Laboratory results suggest that *H. halys* may be effectively controlled by pyrethroid insecticides, although the short residual and secondary pest outbreaks associated with pyrethroid applications complicate control efforts (Nielsen *et al.* 2008b). Attractant lures and traps are currently available in the US (Khrimian *et al.* 2007). A major concern with the attractant is that it is only attractive late in the season after populations have already completed a generation (Nielsen *et al.* 2011).

A combination of control methods is needed to reduce yield losses in commercial production; however, they will also raise production costs to an unknown extent. Control based on the regular application of broad spectrum insecticides has the potential to affect integrated pest management programs[11] and allow currently manageable pests to increase in importance.

Invasion of *H. halys* in the eastern USA has disrupted the integrated pest management system previously used in stone and pome fruit orchards requiring growers to use broad spectrum insecticides to control populations of *H. halys*. An increase in the use of broad spectrum insecticides has caused an increase in outbreaks of secondary pests such as mites, wooly apple aphids and scale insects. Despite control methods, growers are still reporting 10 – 15% fruit damage as a result of feeding by *H. halys* (Krawczyk *et al.* 2012).

In Asia *H. halys* is a vector of a phytoplasma disease (witches' broom) of *Paulownia tomentosa* (princess tree). Infection with this phytoplasma reduces growth and vigour causing severe decline and premature death (Hoebeke and Carter 2003). The phytoplasma causing rose witches' broom in China is the same phytoplasma causing witches' broom in *Paulownia* (*in* Jones and Lambdin 2009). The status of *H. halys* as a vector of other phytoplasmas is unknown; however, there exists the possibility it could transmit other phytoplasmas infecting a wider range of plants. Given the polyphagous habits of *H. halys* and the lack of host specificity of some phytoplasmas, disease transmission between plants may be an additional impact of establishment of this pest.

Currently, a serious issue in vegetable production in the USA is that feeding by *H. halys* introduces or provides entry for adventious pathogens and fruit rots. This phenomenon is common for stink bug feeding but appears to be a serious issue with *H. halys* (Nielsen pers. comm. 2011).

Given that:

- *Halyomorpha halys* has a broad host range;
- feeding damage will reduce market value in mature fruits and may cause fruit abortion in young fruits;
- additional control methods will likely increase production costs and adversely affect the marketability of exported fruit;

[11] *e.g.*: http://fruitgrowersnews.com/index.php/news/release/12583/

- The use of broad spectrum insecticides will adversely affect existing IPM programmes;
- *Halyomorpha halys* is a vector of phytoplasma, but the likely impacts associated with transmission of phytoplasmas is not known;
- feeding damage provides opportunity for pathogen entry;
- additional biosecurity measures may be imposed by countries free of *H. halys*;

The potential ***economic consequences*** *of establishment are considered to be* ***moderate to high***

4.7.2 Environmental consequences

Halyomorpha halys has been recorded from plants belonging to 49 different families (detailed in Appendix 1), of which Rosaceae contains the most hosts (10 genera). The only New Zealand species within Rosaceae with a threatened status is *Acaena rorida* (nationally critical, New Zealand Plant Conservation Network 2010). *Halyomorpha halys* infests wild *Rubus* and *Sophora* species so may attack New Zealand's native *Rubus* and *Sophora* species. There are five native species of *Rubus* in New Zealand but none is considered threatened. In addition there are seven native species of *Sophora* and while three of these are considered naturally uncommon, none are considered threatened (New Zealand Plant Conservation Network 2010).

Feeding activities on flowers and young fruits by nymphs and adults may cause fruit abortion, and thereby reduce reproductive potential; these losses are unlikely to be significant to most plant populations. However, the effect of *H. halys* feeding on populations of native plant species, and consequent impacts on invertebrate and bird populations, is unknown.

Given that:

- the most commonly attacked family, Rosaceae, contains only one threatened species in New Zealand;
- fruit damage is unlikely to impair seed development;

The potential ***environmental consequences*** *of establishment are uncertain but considered to be* ***low***

4.7.3 Socio-cultural consequences

H. halys is a significant public nuisance. Adults aggregate in large numbers on the outside of buildings in the late autumn eventually entering structures to overwinter (Hamilton 2009) when disturbed they discharge an unpleasant and long lasting odour (EPPO 2010). Control options for overwintering aggregations are limited; the most commonly used methods are mechanical removal (such as vacuuming) and exclusion (installation of screens and sealing of cracks) as the effectiveness of chemical sprays is temporary (Gyeltshen *et al.* 2011).

Halyomorpha halys is likely to attack a wide range of crops. This may increase the price of commercially produced produce. Home gardeners would also be likely to endure losses and may have to pay for additional treatments to control infestations.

Given that:

- *Halyomorpha halys* is a significant public nuisance;

- *Halyomorpha halys* infests a wide range of commonly grown species;

The potential ***socio-cultural consequences*** *of establishment are considered to be* ***moderate***

4.7.4 Human health consequences

While *H. halys* produces an unpleasant and long lasting odour when disturbed there are no anticipated human health consequences of this behaviour. While there are no direct impacts on physical health the psychological impacts of overwintering aggregations of *H. halys* within homes may be considerable for some people.

The potential ***human health consequences*** *of establishment are considered to be* ***very low***

5 Risk estimation

Overwintering aggregations have the highest likelihood of becoming associated with an entry pathway. Individuals disturbed from an aggregation, or those associated with host plants, are less likely to become associated with an entry pathway but the opportunity still exists for association and subsequent entry.

Entry pathways have been assessed assuming that the management measures required by the relevant import health standards are applied effectively. Any failure of these measures will increase the likelihood of entry.

There are numerous potential pathways of introduction of *Halyomorpha halys* into New Zealand and each carries its own likelihood of entry and exposure; these likelihoods will vary depending on the lifestage present. The likelihood of entry is considered to range from negligible to moderate, depending on the pathway; and the likelihood of exposure is considered to range from very low to high. All likelihoods are detailed in Table 4.

The likelihood of establishment is independent of the pathway of entry. Establishment is considered to be more likely to occur for aggregated populations than for individuals. Once establishment has occurred the likelihood of spread is considered to be high. The potential economic consequences of establishment are considered moderate to high, and the potential environmental consequences are considered to be low. The socio-cultural consequences are considered to be moderate and the potential human health consequences negligible.

Table 4 Risk estimation for *H. halys*

		Considered to be: Negligible	Low	Moderate	High
Likelihood of entry of specific lifestages	Eggs		Extremely low		
	Nymphs		■		
	Adults			■	
Likelihood of entry on specific pathways	Containers (and items within)			■	
	Fresh produce & cut flowers		■		
	Nursery stock	■			
	Personal luggage		■		
	Vehicles and machinery			■	
	Vessels and aircraft		■		
Likelihood of exposure	Boxes and unaccompanied goods		■		
	Containers		Air	Sea	
	Fresh produce & cut flowers			■	
	Personal luggage		■		
	Vehicles and machinery				■
	Vessels and aircraft		Very low		
	Wood packaging				■
Likelihood of establishment	Aggregated populations				■
	Individual adults			■	
Likelihood of spread	Established populations				■
Likelihood of consequences	Economic			■	■
	Environmental		■		
	Socio-cultural			■	
	Human health		Very low		

6 Management options

6.1 GENERAL MANAGEMENT OPTIONS

Robust identification and recording of interceptions on all pathways will provide critical information for risk management. It would enable the most likely component pathways of entry to be identified and targeted for biosecurity risk management. Better recording and reporting of interception information would enable interceptions to be used in a predictive manner to reduce the likelihood of entry on pathways where other management options are limited, such as the sea container pathway.

All interceptions of Pentatomidae should be identified to species level and associated data such as location on the commodity, port and supplier of origin, and numbers present needs to be recorded. The presence of *H. halys* on transported items relates specifically to the conditions in which that item was used and stored prior to its arrival in New Zealand. Therefore, when one individual is found on a particular pathway there is an increased likelihood that others will be found on items from the same source. This information may help manage the risk from some pathways. However, it will be difficult to implement for used vehicles because the location in which the vehicle was parked prior to being sold to the exporter is unlikely to be available.

Increased awareness of the identity and biology of *H. halys* by staff at transitional facilities and members of the public likely to receive goods from infested countries would help ensure detection of *H. halys* before it has an opportunity to establish and spread in New Zealand. This could be achieved by the provision of fact sheets and other awareness initiatives.

Factors for consideration in the development of risk management options are presented in Appendix 2.

6.2 MANAGEMENT OPTIONS BY PATHWAY

Overall, no practical risk management measures have been identified that can be implemented by reviewing or updating import health standards or by implementing non-targeted approaches, outside the standards development process, such as country-based risk management. The management options identified are largely “tactical” measures. These can be implemented within current import health standards, by identifying and targeting the areas of highest risk within each pathway.

6.2.1 Containers and items within

The most likely pathways of entry are containers (and their contents), and vehicles and machinery; on these pathways visual inspection may be the only available detection tool. However, given that *H. halys* hide in crevices visual inspection is unlikely to be an effective risk mitigation tool.

Halyomorpha halys have a tendency for nocturnal activity and will hide during the day therefore all crevices both internally and externally on containers could harbour individuals. Inspection of the insides of containers paying particular attention to corners and crevices could be a useful addition to the current inspection regime, but is only likely to be useful if targeted to a subset of the most likely containers (a possible targeting approach is outlined in Appendix 2).

A key issue is how likely *H. halys* is to aggregate on the underside of containers. Inspection of the underside of containers will considerably increase the costs and logistical difficulties and without further data may not be warranted as a risk mitigation measure.

6.2.2 Fresh produce and cut flowers

Fresh produce and cut flowers are covered by management measures specific to the commodity and country of origin and there is no concern with the current pathways. There are no practical additional management options on these pathways that are likely to reduce entry below current levels.

However, the risk of establishment of *H. halys* is significant enough to consider in future risk analyses in support of new import health standards for specific host commodities or countries, or if *H. halys* were to expand its current geographic range.

Compulsory identification of any Pentatomidae intercepted on fresh produce and cut flowers pathways would assist in determining whether these pathways are higher risk than is currently indicated by the data.

6.2.3 Personal luggage

Awareness of the identity and biology of *H. halys* by passengers from infested countries may reduce the likelihood of entry on personal luggage. This could be achieved by the provision of fact sheets detailing the identity and biology of *H. halys*. However, given that most people are likely to kill an insect in their luggage without prompting, the cost-benefit ratio of this option is unlikely to be viable.

6.2.4 Vehicles and machinery/Vessels and aircraft

Vehicles and machinery, and vessels and aircraft may be used as overwintering locations for aggregations of *H. halys*; however, in elevated temperatures *H. halys* becomes more active and aggregations may disperse. By such time as the conveyance or commodity has reached New Zealand what was initially an aggregation may not be as easily detectable and the contents of containers carrying the vehicles or the hold of the transport vessel may have become incidentally contaminated. Therefore the interception of a single individual may be indicative of others present and a more intensive inspection or mandatory treatment of the whole shipment may be warranted.

Visual inspections have limitations and it is not possible to see inside all the crevices without using a videoscope. Inspection using the videoscope typically takes around two minutes per vehicle depending on the experience of the inspector. This type of inspection may be a practical routine measure that could be used for inspection of certain shipments considered to be higher risk, or for classes of vehicle that are more difficult to inspect, such as damaged vehicles.

Under the current import health standard for vehicles and machinery, mandatory treatment is not required for most items unless biosecurity risk organisms are detected. However when treatment is required (if live contamination is detected) the options are either fumigation with methyl bromide or heat treatment and removal of gross contamination if present (MAFBNZ 2010e). Heat treatment and fumigation have the advantage of treating both internal and external contaminants and those that are not visible in standard visual inspection procedures. They are also relatively rapid processes.

7 References

Aldrich, J R; Khrimian, A; Chen, X; Camp, M J (2009) Semiochemically based monitoring of the invasion of the brown marmorated stink bug and unexpected attraction of the native green stink bug (Heteroptera: Pentatomidae) in Maryland. *The Florida Entomologist* 92(3): 483-491.

Allan; D. J. (1998) HortFACT - Green vegetable bug lifecycle http://www.hortnet.co.nz/publications/hortfacts/hf401017.htm, Accessed June 14 2011

AQIS (1998) Final import risk analysis of the importation of fruit of Fuji apple (*Malus pumila* Miller var. *domestica* Schneider) from Aomori Prefecture in Japan. Australian Quarantine and Inspection Service. Canberra, Australia.

AQIS (2009) Final import risk analysis report for fresh unshu mandarin fruit from Shizuoka Prefecture in Japan. Australian Quarantine and Inspection Service. Canberra, Australia.

AQIS/MAFBNZ (2010) Schedule of Aircraft Disinsection Procedures Spray Rates Listing. Australian Quarantine and Inspection Service. Canberra, Australia. MAFBNZ; Wellington New Zealand. Available online at: http://www.daff.gov.au/aqis/avm/aircraft/disinsection/procedures/aqismafbnz_schedule_of_aircraft_disinsection_procedures_spray_rates_listing

Archibald, R D; Chalmers, I (1983) Stored product Coleoptera in New Zealand. *New Zealand Entomologist* 7(4): 371-397.

AQSIQ (2007) *Technical information for the export of fresh Chinese pears.* Administration of Quality Supervision, Inspection and Quarantine of PRC.

Barron, M (2006) Effects of aggregation on the probability of detecting infestations in fresh produce consignments. New Zealand Plant Protection 59: 103–108.

CPC (2011) Crop Protection Compendium: datasheet for *Halyomorpha halys* (brown marmorated stink bug) http://www.cabicompendium.org/cpc/home.asp Accessed May 31 2011

EPPO (1995) *EPPO distribution list for Viteus vitifoliae.* EPPO; Paris.

EPPO (2010) *Halyomorpha halys* (Heteroptera: Pentatomidae) brown marmorated stink bug http://www.eppo.org/QUARANTINE/Alert_List/insects/halyomorpha_halys.htm Accessed 31 May 2011

Flora of China (2011) Zhengyi W and Raven P H (ed) http://www.efloras.org/flora_page.aspx?flora_id=2 Accessed 26 July 2011

Funayama, K (2004) Importance of apple fruits as food for the brown-marmorated stink bug, *Halyomorpha halys* (Stal) (Heteroptera: Pentatomidae). *Applied Entomology and Zoology* 39(4): 617-623.

Gordon, D P (ed) (2010) *New Zealand Inventory of Biodiversity.* Canterbury University Press; Christchurch, NZ.

Gyeltshen, J.; Bernon, G.; Hodges, A.; Stocks S.; Brambila, J. (2011) Featured Creatures - Brown Marmorated Stink Bug http://entomology.ifas.ufl.edu/creatures/veg/bean/brown_marmorated_stink_bug.htm Accessed June 7 2011

Hamilton, G C (2009) Brown marmorated stink bug. *American Entomologist* 55(1): 19-20.

Harris, A C (2010) *Halyomorpha halys* (Hemiptera: Pentatomidae) and *Protaetia brevitarsis* (Coleoptera: Scarabaeidae: Cetoniinae) intercepted in Dunedin. *The Weta* 40 42-44.

Hoebeke, E R; Carter, M E (2003) *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae): a polyphagous plant pest from Asia newly detected in North America. *Proceedings of the Entomological Society of Washington* 105(1): 225-237.

Hogg, D; Wilson, D; Gibbs, A; Holmes, A; Eve, L. (2010) *Household organic waste cost benefit analysis*. Report to Greenfingers Garden Bags/Earthcare Environmental Limited & Envirofert Limited Eunomia Research and Consulting Limited; Auckland, New Zealand

Jones, J R; Lambdin, P L (2009) New County and State Records for Tennessee of an Exotic Pest, *Halyomorpha halys* (Hemiptera: Pentatomidae), with Potential Economic and Ecological Implications. *Florida Entomologist* 92(1): 177-178.

Kang, C; Huh, H; Park, C (2003) Review on true bugs infesting tree fruits, upland crops, and weeds in Korea. *Korean Journal of Applied Entomology* 42(3): 269-277.

Kartesz, J T (2011) The Biota of North America Program (BONAP). *North American Plant Atlas* http://www.bonap.org Accessed 27 July 2011

Kawada, H; Kitamura, C (1983) The reproductive behavior of the brown marmorated stink bug, *Halyomorpha mista* Uhler (Heteroptera: Pentatomidae). 1. Observation of mating behavior and multiple copulation. *Applied Entomology and Zoology* 18(2): 234-242.

Khrimian, A; Shearer, P W; Zhang, A; Hamilton, G C; Aldrich, J R (2007) Field trapping of the invasive brown marmorated stink bug, *Halyomorpha halys*, with geometric isomers of methyl 2, 4, 6-decatrienoate. *Journal of Agricultural and Food Chemistry* 56(1): 197-203.

Kiritani, K (1997) The low development threshold temperature and the thermal constant in insects, mites and nematodes in Japan. *Miscellaneous Publication of the National Institute of Agro-Environmental Sciences (Japan)*

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

Krawczyk, G; Hull, L A; Biddinger, D J (2012) The impact of invasive brown marmorated stink bug, *Halyomorpha halys*, on IPM programmes in eastern US fruit orchards. Presentation S1007TU03 *International congress of Entomology* Daegu, Korea August 2012

Larivière, M; Larochelle, A (2004) *Heteroptera* (Insecta: Hemiptera): *catalogue*. Manaki Whenua Press; New Zealand.

Leskey, T C (2011) *Impact of the invasive brown marmorated stink bug in vineyards*. Presentation 0270, 59th Annual Meeting of the Entomological Society of America, November 13-16 2011

Leskey and Hamilton (2010) Brown Marmorated Stink Bug Working Group Meeting. Virginia Agriculture Experiment Station November 17 2010

MAF (2006) Biosecurity New Zealand risk analysis procedures. Ministry of Agriculture and Forestry, New Zealand, 201 pp. Available online at http://www.biosecurity.govt.nz/files/pests-diseases/surveillancereview/risk-analysis-procedures.pdf

MPI interception database (2011) Data retrieved by Anthea Craighead 31 May 2011

MAFBNZ (1998) Import Health Standard 152.07.01I Air containers from any country. MAFBNZ; Wellington New Zealand.

MAFBNZ (2007) Import Risk Analysis: Vehicle and Machinery. MAFBNZ; Wellington New Zealand.

MAFBNZ (2008a) Air Container Survey. Data Analysis and Survey Teams - Border Monitoring Report MAFBNZ; Wellington New Zealand.

MAFBNZ (2008b) Nursery Stock Survey. Data Analysis and Survey Teams - Border Monitoring Report MAFBNZ; Wellington New Zealand.

MAFBNZ (2009a) Import Risk Analysis: Pears (*Pyrus bretschneideri, Pyrus pyrifolia and Pyrus sp. nr. communis*) Fresh Fruit from China. MAFBNZ; Wellington New Zealand.

MAFBNZ (2009b) Break Bulk Survey. Data Analysis and Survey Teams MAFBNZ; Wellington New Zealand.

MAFBNZ (2009c) Guidance document in support of the import health standard for sea containers. MAFBNZ; Wellington New Zealand.

MAFBNZ (2009d) Import health standard for vehicles, machinery and tyres Guidance document. MAFBNZ; Wellington New Zealand.

MAFBNZ (2009e) Import health standard Wood packaging material from all countries. MAFBNZ; Wellington New Zealand.

MAFBNZ (2010a) New Vehicles Survey. Data Analysis and Survey Teams - Border Monitoring Report MAFBNZ; Wellington New Zealand.

MAFBNZ (2010b) Pathway Analysis Annual Report 2009-2010. Analysis and Profiling Group. MAFBNZ; Wellington New Zealand.

MAFBNZ (2010c) Standard 155.02.06 Importation of nursery stock. MAFBNZ; Wellington New Zealand.

MAFBNZ (2010d) Nursery Stock Exiting PEQ Survey. Data Analysis and Survey Teams - Border Monitoring Report MAFBNZ; Wellington New Zealand.

MAFBNZ (2010e) Approved Biosecurity Treatments BNZ-STD-ABTRT. MAFBNZ; Wellington New Zealand.

MAFBNZ (2011a) Border Systems Manual http://intranet.maf.govt.nz/intra/business/biosecurity/border-system-manual.pdf

MAFBNZ (2011b) MAF Biosecurity New Zealand standard 152.02 Importation and clearance of fresh fruit and vegetables into New Zealand. MAFBNZ; Wellington New Zealand.

New Zealand Plant Conservation Network (2010) *New Zealand indigenous vascular plant checklist.* New Zealand Plant Conservation Network; Wellington. http://www.nzpcn.org.nz/flora_search.asp?scfSubmit=1 accessed June 16 2011

Nielsen, A L (2008) Population ecology and biology of the invasive stink bug *Halyomorpha halys* (Hemiptera: Pentatomidae) in New Jersey and Pennsylvania. Unpublished PhD thesis. Rutgers University New Jersey

Nielsen, A L (2011) *Invasion biology and seasonality of BMSB in Pennsylvania and New Jersey*: Presentation 0020, 59th Annual Meeting of the Entomological Society of America, November 13-16 2011

Nielsen, A L; Hamilton, G C; Matadha, D (2008a) Developmental rate estimation and life table analysis for *Halyomorpha halys* (Hemiptera: Pentatomidae). *Environmental Entomology* 37(2): 348-355.

Nielsen, A L; Shearer, P W; Hamilton, G C; (2008b) Toxicity of insecticides to *Halyomorpha halys* (Hemiptera: Pentatomidae) using glass-vial bioassays Journal of Economic Entomology 101(4): 1439-1442

Nielsen, A L; Hamilton, G C (2009a) Life history of the invasive species *Halyomorpha halys* (Hemiptera: Pentatomidae) in Northeastern United States. *Annals of the Entomological Society of America* 102(4): 608-616.

Nielsen, A L; Hamilton, G C (2009b) Seasonal occurrence and impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) in tree fruit. *Journal of Economic Entomology* 102(3): 1133-1140.

Nielsen, A L; Hamilton, G C; Shearer, P W (2011) Seasonal phenology and monitoring of the non-native *Halyomorpha halys* (Hemiptera: Pentatomidae) in soybean. *Environmental Entomology* 40(2): 231-238.

Niva, C C; Takeda, M (2003) Effects of photoperiod, temperature and melatonin on nymphal development, polyphenism and reproduction in *Halyomorpha halys* (Heteroptera: Pentatomidae). *Zoological Science* 20(8): 963-970.

PPIN (2010) Plant Pest Information Network, MPI Database. Accessed 12 November 2010

QuanCargo (2011) MPI database accessed 22 June 2011

Rider, D A; Zheng, L Y; Kerzhner, I M (2002) Checklist and nomenclatural notes on the Chinese Pentatomidae (Heteroptera). II. Pentatominae. *Zoosystematica Rossica* 11(1): 135-153.

Rider, D A (2005) *Halyomorpha halys* Stål, 1855. North Dakota State University fact sheet. http://www.ndsu.nodak.edu/ndsu/rider/Pentatomoidea/Species_Cappaeini/Halyomorpha_halys.htm Accessed 27 June 2011

Son, J K; Yun, J E; Park, C G (2009) Insect pest problems of sweet persimmon in Korea. *Acta Horticulturae* 833 325-330.

Toyama, M; Ihara, F; Yaginuma, K (2006) Formation of aggregations in adults of the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae): The role of antennae in short-range locations. *Applied Entomology and Zoology* 41(2): 309-315.

Toyama, M; Ihara, F; Yaginuma, K (2011) Photo-response of the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae), and its role in the hiding behavior. *Applied Entomology and Zoology* 46(1): 1-4.

Toy, SJ; Newfield, MJ (2010) The accidental introduction of invasive animals as hitchhikers through inanimate pathways: a New Zealand perspective. *OIE Scientific and Technical Review* 29(1): 123-133.

USDA-APHIS-PPQ (2010) Qualitative analysis of the pest risk of the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), in the United States. United States Department of Agriculture

USDA-APHIS-PPQ (2006) A qualitative pest risk analysis for the importation of fresh unshu orange fruit (*Citrus reticulata* Blanco var. *unshu* Swingle) from the republic of Korea into Alaska. United States Department of Agriculture

USDA (2011) Natural resources conservation service – Plants Database http://plants.usda.gov/java/ accessed 27 July 2011

Venette, R C; Moon, R D; Hutchison, W D (2002) Strategies and statistics of sampling for rare individuals. Annual Review of Entomology 47: 143–174.

Weintraub, P G; Beanland, L A (2006) Insect vectors of phytoplasmas. *Annual Review of Entomology* 51 91-111

Welty, C; Shetlar, D; Hammond, R; Jones, S; Bloetscher, B; Nielsen, A (2008) *Brown Marmorated Stink Bug.* Ohio State University Data Sheet;

Wermelinger, B; Wyniger, D; Forster, B (2008) First records of an invasive bug in Europe: *Halyomorpha halys* Stal (Heteroptera: Pentatomidae), a new pest on woody ornamentals and fruit trees? *Mitteilungen-Schweizerische Entomologische Gesellschaft* 81(1/2): 1-8.

Work, T T; McCullough, D G; Cavey, J F; Komsa, R (2005) Arrival rates of nonindigenous insect species into the United States through foreign trade. Biological Invasions 7 (2): 323–332.

Yamamura, K; Katsumata, H (1999) Estimation of the probability of insect pest introduction through imported commodities. *Researches on population ecology* 41(3): 275-282

Yu, G; Zhang, J (2007) The Brown-marmorated Stink Bug, *Halyomorpha halys* (Heteroptera: Pentatomidae) in PR China. In Wu, Y; Wang, X Y (ed) *International Workshop on Biological Control of Invasive Species of Forests, Beijing P.R. China, September 20-25.* USDA Forest Service; West Virginia USA; pp 58-63.

Zhu, G; Bu, W; Gao, Y; Liu, G (2012) Potential geographic distribution of brown marmorated stink bug invasion (*Halyomorpha halys*). *PLoS ONE* 7(2): e31246.

8 Appendix 1: *Halyomorpha halys* host plant list

Family	Host name	Common name	Reference
Adoxaceae	*Sambucus spp.*	Elder	USDA-APHIS-PPQ 2010
	Viburnum opulus	American cranberry	Nielsen 2008
	Viburnum spp.		USDA-APHIS-PPQ 2010
Altingiaceae	*Liquidambar spp.*	Sweet gum	Nielsen 2008
Amaranthaceae	*Celosia argentea*	Celosia	Gyeltshen *et al.* 2011; USDA-APHIS-PPQ 2010; Hoebeke and Carter 2003
Anacardiaceae	*Rhus spp.*	Sumac	USDA-APHIS-PPQ 2010, Yu and Zhang 2007
Aquifoliaceae	*Ilex spp.*	Holly	USDA-APHIS-PPQ 2010
Araliaceae	*Aralia elata*	Japanese angelica tree	Wermelinger *et al*. 2008
Asparagaceae	*Asparagus officinalis*	Asparagus	EPPO 2010; Wermelinger *et al*. 2008
Asteraceae	*Arctium spp.*	Burdock	EPPO 2010; USDA-APHIS-PPQ 2010; Hoebeke and Carter 2003
	Artemisia argyi	Ai ye	Yu and Zhang 2007
	Chrysanthemum morifolium	Chrysanthemum	Yu and Zhang 2007
	Helianthus spp.	Sunflower	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
Basellaceae	*Basella rubra*	Indian spinach	Gyeltshen *et al.* 2011; USDA-APHIS-PPQ 2010; Hoebeke and Carter 2003
Betulaceae	*Betula spp.*	Birch	USDA-APHIS-PPQ 2010
	Corylus colurna	Turkish filbert	USDA-APHIS-PPQ 2010
Bignoniaceae	*Catalpa spp.*	Catalpa	USDA-APHIS-PPQ 2010
Boraginaceae	*Symphytum spp.*	Comfrey	USDA-APHIS-PPQ 2010
Cannabaceae	*Celtis occidentalis*	Hackberry	USDA-APHIS-PPQ 2010
	Humulus scandens	Japanese hop	Yu and Zhang 2007
Caprifoliaceae	*Abelia spp.*		EPPO 2010; USDA-APHIS-PPQ 2010
	Lonicera spp.	Honeysuckle	EPPO 2010; Nielsen 2008
Celastraceae	*Celastrus spp.*	Bittersweet	USDA-APHIS-PPQ 2010
	Euonymus spp.	Euonymus	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
Chenopodiaceae	*Beta vulgaris*	Beetroot	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
Cleomaceae	*Cleome spp.*	Cleome	USDA-APHIS-PPQ 2010
Cornaceae	*Cornus spp.*	Dogwood	USDA-APHIS-PPQ 2010
Cucurbitaceae	*Cucumis sativus*	Cucumber	USDA-APHIS-PPQ 2010
	Sicyos angulatus	Burcucumber	USDA-APHIS-PPQ 2010
Cupressaceae	*Cryptomeria spp.*		EPPO 2010; USDA-APHIS-PPQ 2010
	Cupressus spp.	Cypress	EPPO 2010; USDA-APHIS-PPQ 2010
	Platycladus orientalis	Chinese arborvitae	Yu and Zhang 2007

Ebenaceae	*Diospyros spp.*	Persimmon	CPC 2011; Gyeltshen *et al.* 2011; EPPO 2010; Hoebeke and Carter 2003
Elaeagnaceae	*Elaeagnus angustifolia*	Russian olive	Nielsen 2008
Fabaceae	*Caragana arborescens*	Siberian pea shrub	Nielsen 2008
	Cercis canadensis	Redbud	USDA-APHIS-PPQ 2010
	Glycine max	Soybean	CPC 2011; Gyeltshen *et al.* 2011; EPPO 2010; Hoebeke and Carter 2003; Kang et al. 2003
	Phaseolus lunatus	Lima bean	USDA-APHIS-PPQ 2010
	Phaseolus vulgaris	Common bean	EPPO 2010; USDA-APHIS-PPQ 2010
	Pisum sativum	Pea	CPC 2011; USDA-APHIS-PPQ 2010
	Robinia pseudoacacia	Black locust	Yu and Zhang 2007
	Sophora japonica	Pagoda tree	Yu and Zhang 2007
	Wisteria sinesis	Chinese wisteria	Yu and Zhang 2007
	Vigna spp.	Chinese long bean	USDA-APHIS-PPQ 2010
Juglandaceae	*Carya spp.*	Pecan	USDA-APHIS-PPQ 2010
	Juglans nigra	Walnut	USDA-APHIS-PPQ 2010
Lamiaceae	*Vitex negundo*	Five-leaved chaste tree	Yu and Zhang 2007
Lardizabalaceae	*Decaisnea fargesii*		Wermelinger *et al.* 2008
Lauraceae	*Cinnamomum camphora*	Camphor tree	Yu and Zhang 2007
Lythraceae	*Punica granatum*	Pomegranate	Yu and Zhang 2007
Magnoliaceae	*Magnolia stellata*	Star magnolia	USDA-APHIS-PPQ 2010
Malvaceae	*Althaea rosea*	Common hollyhock	Yu and Zhang 2007
	Gossypium spp.	Cotton	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
	Hibiscus spp.		Gyeltshen *et al.* 2011; EPPO 2010; USDA-APHIS-PPQ 2010; Hoebeke and Carter 2003
	Firmiana platanifolia	Chinese parasol tree	Yu and Zhang 2007
	Tilia americana	Linden	USDA-APHIS-PPQ 2010
	Tilia spp.	Basswood	USDA-APHIS-PPQ 2010
Moraceae	*Ficus spp.*	Fig	Gyeltshen *et al.* 2011; USDA-APHIS-PPQ 2010
	Morus spp.	Mulberry	Gyeltshen *et al.* 2011; Funayama 2004; Hoebeke and Carter 2003
Oleaceae	*Fraxinus americana*	White ash	Nielsen 2008
	Ligustrum spp.	Privet	USDA-APHIS-PPQ 2010
	Syringa spp.	Lilac	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
Orchidaceae	*Brassia spp.*	Orchid	Yu and Zhang 2007
Paulowniaceae	*Paulownia tomentosa*	Princess tree	EPPO 2010; Nielsen 2008; Funayama 2004; Hoebeke and Carter 2003
Pinaceae	*Tsuga canadensis*	Eastern hemlock	Nielsen 2008

Platanaceae	*Platanus occidentalis*	Sycamore	USDA-APHIS-PPQ 2010
Poaceae	*Triticum aestivum*	Wheat	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
	Zea mays	Corn	EPPO 2010; USDA-APHIS-PPQ 2010; Yu and Zhang 2007
Rhamnaceae	*Rhamnus spp.*	Buckthorn	USDA-APHIS-PPQ 2010
	Zizyphus jujuba	Red date	Yu and Zhang 2007
	Zizyphus sativa	Chinese date	CPC 2011
Rosaceae	*Crataegus spp.*	Hawthorn	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
	Malus domestica	Apple	CPC 2011; EPPO 2010; Nielsen and Hamilton 2009; Funayama 2004; Hoebeke and Carter 2003
	Prunus apetala	Japanese flowering cherry	Funayama 2004
	Prunus armeniaca	Apricot	EPPO 2010; USDA-APHIS-PPQ 2010; Yu and Zhang 2007
	Prunus avium	Cherry	CPC 2011; Gyeltshen *et al.* 2011; EPPO 2010; USDA-APHIS-PPQ 2010; Hoebeke and Carter 2003
	Prunus domestica	Plum	EPPO 2010; USDA-APHIS-PPQ 2010; Yu and Zhang 2007
	Prunus grayana	Japanese bird cherry	USDA-APHIS-PPQ 2010; Funayama 2004
	Prunus mume	Japanese apricot	Gyeltshen *et al.* 2011; Hoebeke and Carter 2003,
	Prunus persica	Peach	CPC 2011; Gyeltshen *et al* 2011; EPPO 2010; USDA-APHIS-PPQ 2010; Nielsen and Hamilton 2009; Hoebeke and Carter 2003
	Pyracantha coccinea	Firethorn	USDA-APHIS-PPQ 2010
	Pyrus communis	European pear	EPPO 2010; USDA-APHIS-PPQ 2010; Nielsen 2008
	Pyrus prifolia	Japanese pear	USDA-APHIS-PPQ 2010
	Pyrus pyrifolia	Asian pear	Gyeltshen *et al.* 2011; Nielsen 2008; Hoebeke and Carter 2003
	Rhodotypos scandens	Jetbead	USDA-APHIS-PPQ 2010
	Rosa rugosa	Japanese rose	EPPO 2010; Nielsen 2008; USDA-APHIS-PPQ 2010
	Rosa spp.	Rose	USDA-APHIS-PPQ 2010
	Rubus spp.	Raspberry	EPPO 2010; USDA-APHIS-PPQ 2010; Nielsen 2008
	Sorbus spp.	Mountainash	USDA-APHIS-PPQ 2010
	Spiraea spp.	Spirea	USDA-APHIS-PPQ 2010
Rutaceae	*Citrus junos*	Yuzu	CPC 2011; EPPO 2010; Kang *et al.* 2003
	Citrus spp.		Gyeltshen *et al.* 2011; EPPO 2010; Hoebeke and Carter 2003; Kang *et al.*

			2003
Salicaceae	*Populus tomentosa*	Chinese white poplar	Yu and Zhang 2007
	Salix spp.	Willow	EPPO 2010; USDA-APHIS-PPQ 2010
Sapindaceae	*Acer spp.*	Maple	EPPO 2010; Wermelinger *et al.* 2008
	Koelreuteria spp.	Goldenrain tree	USDA-APHIS-PPQ 2010
Scrophulariaceae	*Buddleja davidii*	Butterfly bush	EPPO 2010, Wermelinger *et al.* 2008
Solanaceae	*Capsicum annuum*	Capsicum	USDA-APHIS-PPQ 2010
	Lycium barbarum	goji berry	Yu and Zhang 2007
	Lycopersicon spp.	Tomato	USDA-APHIS-PPQ 2010
	Nicotiana alata	Winged tobacco	Yu and Zhang 2007
	Solanum nigrum	Black nightshade	Gyeltshen *et al.* 2011; USDA-APHIS-PPQ 2010; Hoebeke and Carter 2003
	Solanum spp.		USDA-APHIS-PPQ 2010
Spiraeoideae	*Amelanchier spp.*	Shadbush	Wermelinger *et al.* 2008
Theaceae	*Camellia oleifera*	Tea-oil camellia	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
	Camellia sinesis		Yu and Zhang 2007
	Stewartia pseudocamellia	Deciduous camellia	Wermelinger *et al.* 2008
Tropaeolaceae	*Tropaeolum majus*	Nasturtium	Wermelinger *et al.* 2008
Ulmaceae	*Ulmus spp.*	Elm	USDA-APHIS-PPQ 2010; Yu and Zhang 2007
Vitaceae	*Cayratia japonica*	Bushkiller	Yu and Zhang 2007
	Vitis vinifera	Grapevine	EPPO 2010; USDA-APHIS-PPQ 2010; Yu and Zhang 2007

9 Appendix 2: Factors to consider in risk management

9.1 GENERAL RISK FACTORS

There are general risk factors which increase the likelihood of *H. halys* becoming associated with a consignment. *Halyomorpha halys* has a wide host range (see Appendix 1) and adults are strong fliers. Host plants in the environment surrounding the port may harbour populations. *Halyomorpha halys* overwinters preferentially on man-made structures, and the times of year when overwintering aggregations build up vary depending on country. Containers, wood packaging, and vehicles and machinery stored in an outdoor environment prior to shipping may provide overwintering sites for aggregations of *H. halys.*

9.2 PATHWAYS

The most likely pathways for entry of *H. halys* are considered to be containers, wood packaging, and vehicles and machinery. These pathways provide opportunity to transport overwintering aggregations. Containers, wood packaging, and vehicles and machinery may be in an outdoor environment for some time before being transported. This will increase the likelihood of aggregations.

9.3 COMMODITIES

The commodities transported within containers and wood packaging will not influence the likelihood of presence of *H. halys*. It is the containers and wood packaging themselves that increase the likelihood of entry.

9.4 COUNTRIES

There is increased likelihood of entry from those countries with widespread established populations (see Table 1 for details). *Halyomorpha halys* is widespread throughout its native range in Japan, Korea, China and Taiwan; there are outbreak conditions with established populations in some states in the USA and few records from Switzerland. The likelihood of entry will be lower from those countries with records of presence but where populations are not widespread or known to be established. Additionally, populations may fluctuate within these countries increasing or decreasing the likelihood of entry depending on the status of outbreaks. It would be advisable to monitor these local conditions before implementing intensive treatment or inspection regimes.

Table 1 Current geographic distribution of *H. halys*

Region	Country	State/Areas
Asia	China	Widespread in: Anhui, Fujian, Guandong, Guangxi, Guizhou, Heibei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Nei Menggu, Shaanxi, Sichuan, Tibet, Yunnan and Zhejiang
	Japan	Widespread
	Korea	Widespread
	Taiwan	Widespread
North America	USA	Established populations in: New Jersey, Oregon and Pennsylvania, Records of presence from: Alabama, Arizona, California, Colorado, Connecticut, Delaware, District of Columbia, Florida, Georgia, Illinois, Indiana, Iowa, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Nebraska, New Hampshire, New York, North Carolina, Ohio, Rhode Island, South Carolina, Tennessee, Vermont, Virginia, Washington, West Virginia and Wisconsin
Europe	Switzerland	Only a few records from Zurich

9.5 TRANS-SHIPMENT

Interceptions have been recorded on consignments from Australia and Hong Kong, neither location has *H. halys*, therefore the last port of call is not a reliable indicator of the potential for infestation. Rather, previous ports should be recorded.

9.6 LOCATION ON CARGO/CONVEYANCE

Halyomorpha halys has a tendency to hide in small spaces and therefore may not be readily apparent on initial inspection. Aggregations and individuals are likely to be concealed in crevices in the cargo or conveyance, either externally where there are joins or crevices, or internally in joins, corners and small spaces.

9.7 INTERCEPTIONS

In order for interception data to be used in a predictive manner it is important to record specific details of an interception.

Numbers

The number of individuals and not just the presence is an important factor. Multiple individuals may be present as an overwintering aggregation whereas single individuals may have been disturbed and sought shelter.

Dates

Overwintering aggregations will only be present during specific seasons and this will vary somewhat depending on the origin of the shipment. Therefore, dates and previous ports need to be accurately recorded.

Locations

The location of the interception on the commodity will be important in better informing future inspections.

9.8 MOST LIKELY RISK PERIODS

Overwintering dates are country specific; overwintering individuals aggregate at different times, for different durations throughout their range. Table 2 indicates the months and corresponding southern hemisphere seasons when *H. halys* is most likely to be intercepted.

Table 2 Months/seasons when *H. halys* is most likely to be intercepted from various countries

Southern Hemisphere Season/Month									
	Winter	Spring			Summer			Autumn	
	August	September	October	November	December	January	February	March	April
Japan									
USA									
Korea									
Northern China									
Southern China									