Ministry for Primary Industries
Manatū Ahu Matua

Technical Review – Proposed Treatments for BMSB (*Halyomorpha halys* (Stål); Pentatomidae)

MPI Technical Paper

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Growing and Protecting New Zealand

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Approval

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(*Halyomorpha halys* (Stål); Pentatomidae)

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Approved for Distribution

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1. Purpose of document:

The draft Import Health Standard for Vehicles, Machinery and Tyres (MPI 2015a) contains changes to the measures required to manage the biosecurity risks of Brown Marmorated Stink Bug (BMSB) (*Halyomorpha halys* (Stål); Hemiptera: Pentatomidae). This document is a review of the science underpinning these changes. More specifically the purpose of this document is to:

- Estimate the level of efficacy required for a treatment for BMSB on any given pathway based on the propagule pressure from BMSB and the likely volume of imports;
- Describe the level of efficacy provided by published or reported treatment research;
- Provide information to enable lab-determined treatment schedules to be converted into operational schedules;
- Provide background/references on the effect of the treatments on other pests to illustrate relativity to BMSB.

2. Executive Summary

This technical advice provides quantitative estimates of the efficacy of two treatment options as measured against a baseline estimate of risk of BMSB to New Zealand.

The quantitative models used in the analysis relied upon a number of underlying assumptions in response both to incomplete data and the need to future-proof the model outputs. The most significant assumptions included the use of border interception data as indicators of the levels of pathway infestation, and the extrapolation of interception information from goods imported from the USA to future infestation rates for goods imported from Europe and the Mediterranean region. Other assumptions include estimates related to the biological characteristics of BMSB, most notably number of aggregated individuals required to establish a population in a new area (the founder population size).

In all cases the assumptions made were tested with suitably informed experts to ensure they were within the expected range of what was likely. The parameters used in estimating infestation rates and the relative sensitivity in the model were as follows:

Input Parameter	Model sensitivity
Volume of imported goods	Volume data extracted from actual border records for 2015-16. Volumes can vary by 5-10% annually depending on economic activity. Model not considered particularly sensitive to variations in trade volumes.
Level of inspection	The level of inspection (proportion of goods inspected) were determined for the period the data were collected (2015-16) from border inspection records and regulatory standards. This data is considered accurate.
Efficacy of inspection	The efficacy of inspection (ability of an inspection to detect a BMSB adult) was determined by expert elicitation and informed by border inspection data. Due to the significant uncertainty related to this parameter, a sensitivity analysis was undertaken through running the model using an efficacy inspection at half the expected level. The changes in model outputs were not found to be significant with this degree of variation in inspection efficacy, providing some confidence that the model outputs are sufficiently robust to account for the extent of uncertainty inherent in this parameter.

Another area of uncertainty relates to the levels of efficacy demonstrated by the proposed treatment options; namely Methyl bromide or Sulfuryl fluoride fumigation. In both cases the empirical evidence supporting efficacy was incomplete, and wider evidence of efficacy against insect pests was used to support the potential use of these treatments. In the latter period of the analysis the author became aware that the evidence of efficacy was based on tests against non-diapausing adults. Small scale testing of Methyl bromide and Sulfuryl fluoride fumigation against diapausing adults, which are more likely to be associated with goods in trade, has indicated that as much as twice the dose may be required to achieve the same levels of mortality as that achieved against non-diapausing adults. MPI is currently undertaking research to confirm the relative tolerance levels non-diapausing and diapausing adult BMSB against Methyl bromide and Sulfuryl fluoride fumigation.

3. Technical Summary

Analysis of the biology of BMSB, trading patterns with New Zealand, and records of BMSB association with import pathways identified the following:

- The most likely pathways of entry into New Zealand are new and used vehicles from North America. BMSB adults have been intercepted on other pathways and on vehicles from East Asia and Europe; however, the estimated levels of infestation are too low to be significant.
- The number of adult BMSB recorded as entering New Zealand on inspection of imported goods is greatest during most of the New Zealand spring-summer-autumn period (September to April).
- Auckland receives the greatest number of BMSB adults and as such is the most likely place BMSB will establish in New Zealand.
- Modelling the number of adult BMSB accumulating in Auckland over a year based on trade patterns, interceptions, treatments and biological information of BMSB indicates the following:
    - The majority of BMSB arrive in Auckland between September and April. With no measures applied to the main pathways of entry for BMSB, the number of adult BMSB accumulating in the Auckland region is unlikely to exceed seventy five. The likelihood should be considered low to moderate that seventy five adult BMSB in the entire Auckland region would result in two adult BMSBs of opposite sex being in close enough proximity to enable breeding and subsequent introduction;
    - The number of adult BMSB accumulating in the Auckland region is unlikely to exceed two with the inclusion of a pre-border treatment on the vehicle pathway from North America over the New Zealand spring-summer-autumn (September to April) period, that ensures no more than one adult BMSB in 1,000 survive (efficacy of 99.9%),. The likelihood should be considered very low that two adult BMSB in the entire Auckland region would result in two adult BMSBs of opposite sex being in close enough proximity to enable breeding and subsequent introduction;
    - The number of adult BMSB accumulating in the Auckland region is unlikely to exceed four if the efficacy of inspection is halved (half as effective) while including a pre-border treatment on the vehicle pathway from North America over the New Zealand spring-summer-autumn (September to April) period, that ensures no more than one adult BMSB in 1,000 survive (efficacy of 99.9%). While this number is twice that stated in (b) above, the likelihood should also be considered very low that four adult BMSB in the entire Auckland region would result in two adult BMSBs of opposite sex being in close enough proximity to enable breeding and subsequent introduction.
- The analysis in this paper concludes that reduced treatment rates will achieve the following levels of efficacy:
    - a reduced methyl bromide fumigation rate of >140 g.h/m^3 at >10°C and >120 g.h/m^3 at >15°C, applied over a 12-24 hour period, should ensure (at the 95% level of confidence) no more than one BMSB adult survives in 1,000 exposed individuals.

- A reduced sulfuryl fluoride fumigation rate of >135 g.h/m^3 for treatments at >10°C, applied over a >12 hour period at a minimum concentration of 8 g/m^3, should ensure (at the 95% level of confidence) no more than one (non-diapausing) BMSB adult survives in 290 exposed individuals.
- A heat treatment of 56°C for 30 minutes or 60°C for 1 minute, at the coldest location BMSB could be found on any treated vehicle, should ensure (at the 95% level of confidence) no more than one BMSB adult survives in 1,000 exposed individuals.

4. Background

In December 2014 an aggregation of BMSB was found in a new vehicle from the USA at the Auckland port and an urgent amendment was made to the Import Health Standard to require all vehicles and machinery from the USA to be treated.

In December 2015 an increased inspection regime was implemented for the high risk New Zealand summer period for cargo from Italy after the interception of BSMB in a container.

a. Current treatment requirements for BMSB

The current pre-export treatment rates for BMSB on vehicles entering New Zealand from the USA[a] are as follows:

- Methyl bromide fumigation at 48 g/m^3 for 24 hours at 10-15°C; or
- Methyl bromide fumigation at 40 g/m^3 for 24 hours at 15-21°C; or
- Sulfuryl fluoride fumigation at 40 g/m^3 for 24 hours at 16-20°C; or
- Sulfuryl fluoride fumigation at 32 g/m^3 for 24 hours at 21-25°C; or
- Heat treatment at 60°C for 10 minutes for vehicles weighing <3,000kg and 60°C for 20 minutes for vehicles weighing >3,000kg in the coldest location[b].

Using recent international standards for specifying treatment schedules to more accurately delimit the critical treatment parameters, and assuming these treatment fumigations are completed under tarpaulin or in shipping containers, these treatments would be described as follows:

- Methyl bromide fumigation at >10°C to achieve a minimum CT of 475 g.h/m^3 over 24 hours and a minimum concentration of 14 g/m^3 (guidance indicates a starting dose of >48 g/m^3); or
- Methyl bromide fumigation at >15°C to achieve a minimum CT of 400 g.h/m^3 over 24 hours and a minimum concentration of 12 g/m^3 (guidance indicates a starting dose of >40 g/m^3); or
- Sulfuryl fluoride fumigation at >16°C to achieve a minimum CT of 520 g.h/m^3 over 24 hours and a minimum concentration of 10 g/m^3 (guidance indicates a starting dose of >40 g/m^3); or
- Sulfuryl fluoride fumigation at >21°C to achieve a minimum CT of 415 g.h/m^3 over 24 hours and a minimum concentration of 8 g/m^3 (guidance indicates a starting dose of >32 g/m^3).

It has been proposed to introduce new treatment schedules into the import health standard for vehicles[c] that require a reduced application of fumigant. These new schedules include:

[a] http://www.mpi.govt.nz/document-vault/1189

[b] The heat treatment schedule as it is stated is unusual, as the exposure period of the target pest should not vary (pests are not more tolerant to heat when on larger vehicles). The increased heating time for larger vehicles likely reflects the greater difficulty in heating all parts (e.g. the coldest parts) of these vehicles. A more suitable treatment description would state the target treatment dose (e.g. 60°C for 10 minutes), and provide operational guidance (or requirements) on how to ensure that dose is achieved in the coldest parts of all vehicles (big or small).

[c] http://www.mpi.govt.nz/document-vault/1189

- Methyl bromide fumigation at >15°C to achieve a minimum CT of 128 g.h/m^3 over 12 hours and a minimum concentration of 8 g/m^3 (guidance indicates a starting dose of >16 g/m^3); or
- Sulfuryl fluoride fumigation at >10°C to achieve a minimum CT of 135 g.h/m^3 over 12 hours and a minimum concentration of 8 g/m^3 (guidance indicates a starting dose of >16 g/m^3); or
- Heat treatment at 50°C for 20 minutes for vehicles weighing <3,000kg and 50°C for 30 minutes for vehicles weighing >3,000kg in the coldest location.

A review of the efficacy of the proposed additional treatments schedules, and an estimation of the level of treatment efficacy required to manage the likelihood of BMSB establishing in New Zealand, has been provided below.

b. Description of BMSB biology

The biology of the BMSB has been described in detail in Aldrich (1988), Wermelinger *et al.* (2008), Nielsen (2008 and *et al.* 2009), Niva & Takeda (2003) and Duthie (2015). An edited version is provided here to highlight the biological characteristics that are significant to this analysis.

BMSB is a polyphagous stink bug native to China, Japan, Korea, and Taiwan, with +300 reported host plants, including many agricultural crops, particularly fruits and vegetables important for fresh market sales (Hoffman 1931, Hoebeck & Carter 2003, Rice *et al*. 2016). Since being introduced into North America in 1996, BMSB has spread across the US and Canada, and more recently (2007) into Europe (Rice *et al*. 2016).

BMSB overwinters from the onset of winter as adults in reproductive diapause, aggregating naturally in tree bark but within urbanised areas commonly in artificial structures (Nielsen *et al*. 2009). The agriculture–urban interface may drive populations, with urban settings providing overwintering habitat and increased overwintering survival, while agricultural crops provide resources for development and population increase (Rice *et al*. 2016).

Adults do not mate before overwintering (Wermelinger *et al.* 2008). As daily temperatures and photoperiod increase, the adults or 'spring adults' emerge from these sites in spring. Females are reproductively immature at this stage, resulting in a delay before reproduction while they accumulate enough degree days (DD) to complete maturity (Nielsen *et al*. 2009). After maturation and a single mating, the spring females start to oviposit eggs on the underside of leaves in clusters containing 28 eggs, with an average of 244 eggs laid over the life span of a female (Nielsen 2008). Pentatomids including BMSB produce aggregation pheromones for either food or mate location or to identify overwintering habitats (Aldrich 1988). The nymphs undergo five stadia before reaching the adult stage, and feed on a wide variety of plant species. Fourth and fifth instars are sensitive to diapause induction, which is both temperature and photoperiod dependant (Niva & Takeda 2003).

The adults and nymphs usually feed on fruiting structures, but will also feed on stems, leaves and flowers (USDA 2010). In the United States, BMSB is recognized as an increasingly important economic pest complex in many crops, due to the replacement of broad-spectrum insecticides that have historically managed populations (Nielsen 2008). Nymphs and adults, like other stink bugs, are capable of dispersing to feed on susceptible hosts. If disturbed, both nymphs and adults drop off of host plants or escape to sheltered areas. Adults are also capable of long distance flight and on warm days may take flight if disturbed, but usually for only short distances. In flight-mill studies, tethered adults from wild populations flew an average of 2 km in 24 hours (Rice *et al*. 2016).

BMSB has a large developmental range and can successfully develop in areas with temperatures as low as 17°C or as high as 33°C (Nielsen *et al*. 2008). In warmer climates such as southern China, BMSB is multivoltine with four to six generations per year, while in more temperate climates such as the mid-Atlantic United States (and New Zealand) it has (or is likely to have) only one to two generations per year. Colder winters will result in greater BMSB mortality in the overwintering population during diapause (Wermelinger *et al*. 2008). Warmer winters are likely to reduce winter mortality by an estimated 13% with every centigrade of warming (Kiritani 2006; Kiritani 2007).

Haye *et al*. (2014) investigated aspects of the phenology of BMSB in Europe. They collected recently overwintered adult BMSB and held them in sealed containers outdoors to measure rates of mortality. Measurements from these studies found that the rate of adult mortality was not constant over the life of the adult, with the highest rate occurring between 14 and 21 weeks post-overwintering (see ***Figure 1***). As the adults may enter the New Zealand environment at an uncertain period post-overwintering and would be subject to predation that would be expected to increase mortality (Morrison *et al*. 2016), it was considered appropriate to use an average rate of mortality over the life of the adults. This average rate of weekly mortality was calculated to be around 7.7% or around 30% per month (Kiritani 2006). When plotted against the data from Haye *et al*. (2014) (see ***Figure 1***), the modelled mortality rate provides an overestimate for weeks 1 to 14, an underestimate for weeks 14 to 21, and is a close approximation for weeks 21 to 31. For the purposes of this paper the monthly overwintered-adult mortality rate for BMSB was estimated at a more conservative 26% for September through April, and 50% for May through August when the adults would normally be in diapause and protected from the elements (see ***Appendix 1***).

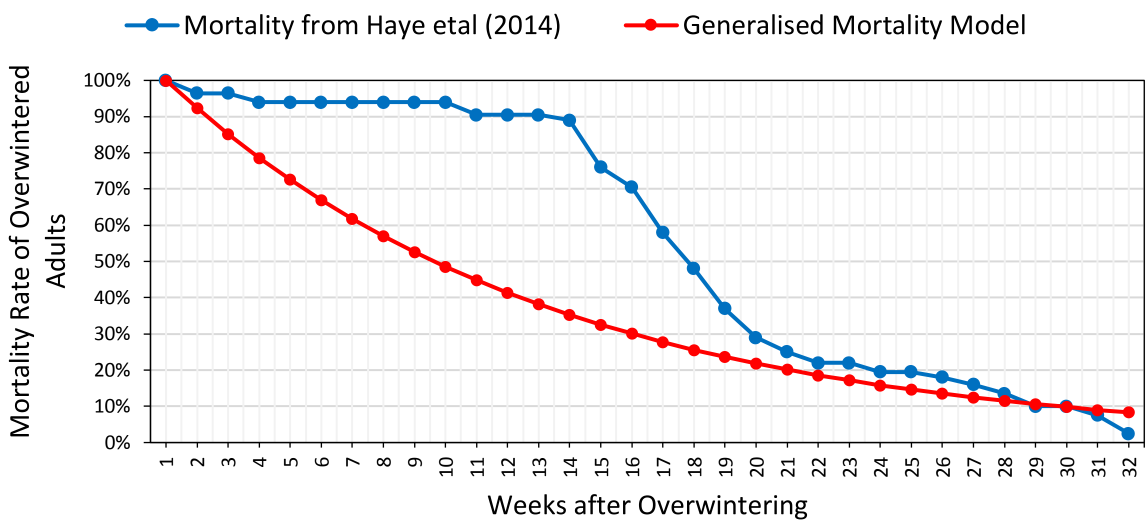

Figure 1: Mortality rates of overwintered adult BMSB measured by and modelled from Haye *et al*. (2014).

There is no information currently reported in the literature that indicates the minimum population level needed for successful establishment of BMSB into a new area (USDA 2010). It has however been suggested based on genomic analyses that the introduction of BMSB into the United States and subsequent spread to Oregon was of an aggregated population and not individuals (Aldrich *et al*. 2009). Given the lack of any known mating pheromone in BMSB, and the ability of adults and some juvenile stages to be highly mobile, for the purposes of this paper the number of adult BMSB required in a confined area (2 km radius) to provide a 50% likelihood of a population establishing in an area per month will be assumed to be 10 (5 males and 5 females). This translates into a 7% monthly establishment rate per adult BSMB above 2 (as you need at least 2 adults to have a male and female for mating). As the likelihood of a population of BMSB establishing during colder climatic periods is reduced (Duthie 2015), the monthly rate of establishment is reduced from April to November (see Appendix 1). The following figure (***Figure 2***) provides monthly establishment rates for BMSB populations assuming per adult establishment rates of 7%, 4%, 3%, 2% and 1% as provided in Appendix 1.

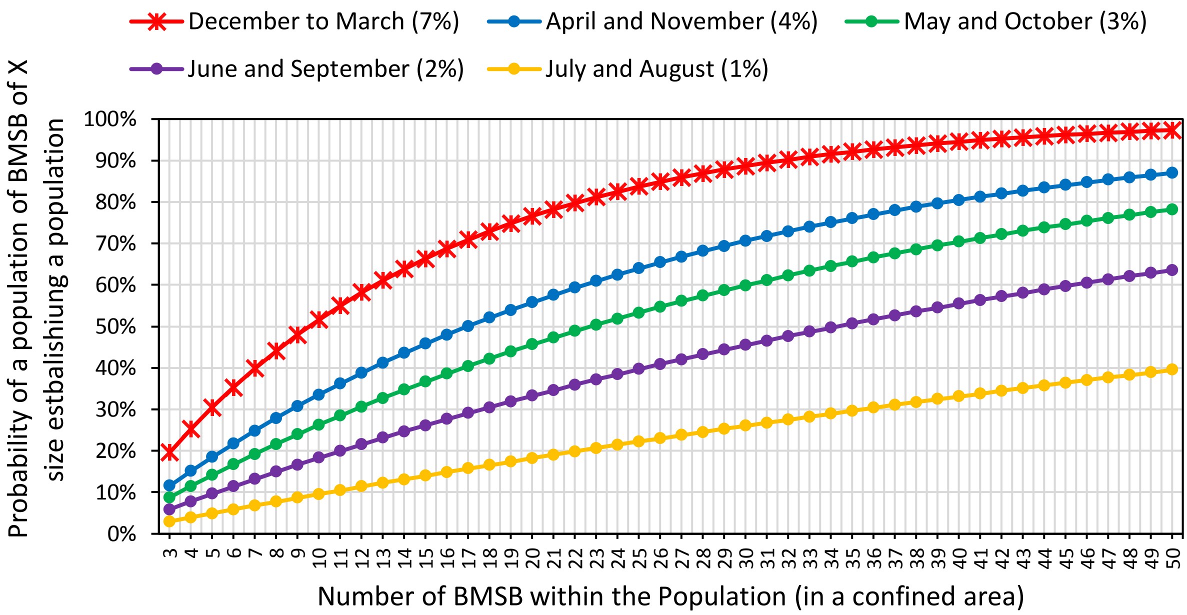

Figure 2: Estimated probabilities of establishment of an aggregated population of BMSB at different periods of the year (in Auckland).

5. Determining the required level of treatment efficacy

The required level of treatment efficacy can be thought of as the level of treatment outcome (e.g. mortality) required to reduce to an acceptable level the likelihood that a breeding population of the target pest will establish in the area of concern (the Pest Risk Assessment (PRA) area). This efficacy level is usually expressed as a percentage and reflects both the biology of the pest and the nature of the pathway of entry into the area.

Therefore in order to determine the level of treatment efficacy required, an estimate of the number of BMSB arriving in New Zealand at any location over the most likely survival period of adults is needed. This requires the following information:

- The international distribution of BMSB.
- Pathways of entry to BMSB into New Zealand.
- The level at which those goods or conveyances are infested (and the level of aggregation).
- Where those goods or conveyances end up in New Zealand

Underpinning all of this trade-related information is information on the biological characteristics of BMSB, such as its likely distance of spread and adult longevity. This information has been collected and provided in the appendices (1-4) and in the text below.

a. The international distribution of BMSB

BMSB is now considered to be established or endemic in a number of regions and countries (CABI 2016) (see ***Table 1***).

Table 1: Regions and countries that have indigenous or established populations of BMSB

Region	Countries	Notes

North America	USA and Canada	As of May 2016 it is still spreading in North America and expected to become more prevalent
Europe	Italy, France, Switzerland, Germany, Greece, Hungary, Liechtenstein, Romania	Currently isolated populations but expected to spread throughout Europe and become more prevalent
East Asia	China, North and South Korea, Japan, Hong Kong[d], Taiwan	Considered endemic to this region, and likely also found in surrounding countries in low numbers

New Zealand imports numerous commodities from all of these areas (for further information see ***Appendix 3***).

b. Pathways of entry of BMSB into New Zealand

A review of New Zealand border (arrival) interception data since 2012 identified a large range of commodities or pathways of entry for BMSB (see ***Table 2***). Data was also sourced from Australia to develop a more accurate picture of the range of goods that BMSB may be associated with. As only a few interceptions of BMSB have occurred on the mail pathway, and the low infestation levels of vessels are not considered likely to contribute to establishment, these two pathways were not included further in the assessment of propagule pressure.

Table 2: Goods or conveyances in or on which BMSB were found when entering New Zealand or Australia

Commodity/Pathway	Description
Car/machinery parts	Containerised spare parts for vehicles or machinery
Consumer goods	Manufactured goods in containers, such as tiles, furniture, glass etc.
Fresh fruit (hosts)	Fresh fruit in containers (usually boxed or bagged)
Mail	Posted mail including packages
New vehicles	New (unused) cars, trucks or machinery e.g. tractors, trains
Used vehicles	Used cars, trucks or machinery e.g. tractors, trains
Passenger baggage	Baggage arriving with passengers at airports
Personal effects	Household goods in containers
Sawn timber	Wood arriving in containers or as break bulk
Sea containers	The inside of a sea container which is either empty, or BMSB were not associated with the goods therein.
Vessels	A ship or boat arriving independently (not as cargo)

[d] While BMSB is not known from Hong Kong, many of the goods exported to New Zealand from areas infested with BMSB are recorded as originating from this region.

c. The level of infestation of imported goods or conveyances

Assessment of New Zealand's BMSB interception data (alive and dead) over the last full calendar year (2015) indicate that interception rates are uneven; more interception events involving greater numbers of BMSB adults occur over much of New Zealand's summer and autumn months (September to April) (see ***Figure 3***).

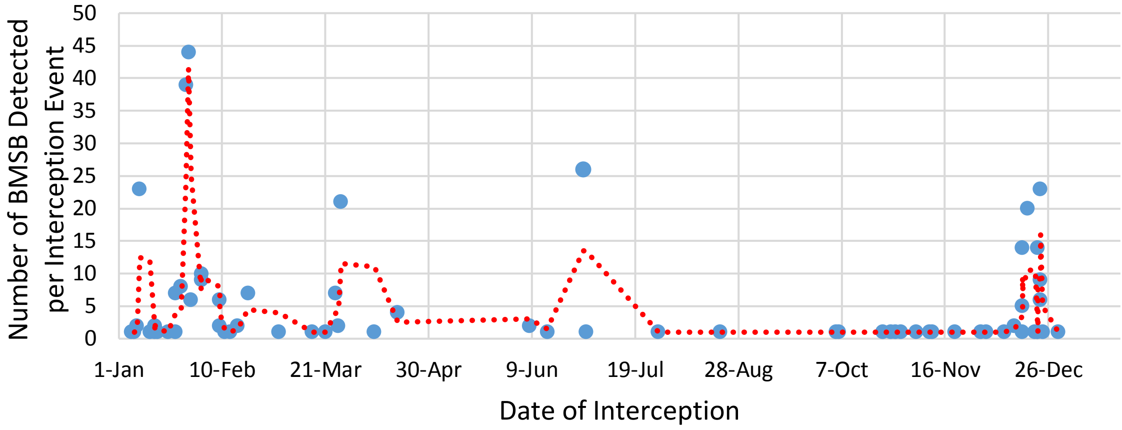

Figure 3: Recorded BMSB adults (dead or alive) found on inspection of goods imported into New Zealand (red dotted line is the moving average of the interception records (blue dots))

One notable exception to this seasonal trend is a single event in June on an imported (used) vehicle from the USA. While this vintage vehicle imported for restoration was found to have 29 adult BMSB present, all had clearly been dead for an extended period. An investigation of that vehicle's history found that it had been in pre-export storage for up to 6 months during the northern hemisphere winter aggregation period. Given that this infestation occurred in a prior aggregation season, and could have arrived at any time unrelated to the infestation date, it should be considered an outlier event. Any such infestation is unlikely to contain live adults on arrival in New Zealand and as such this outlier was removed from the analysis.

The level of BMSB infestation at source (pre-export) is able to be estimated from interception data if the likely efficacy of detection at the New Zealand border is known. Information required for this estimation therefore is as follows:

- The volume of potentially infested goods or units entering New Zealand in 2015. This data is captured by the New Zealand government in a number of databases, including those of MPI, Statistics New Zealand, and Customs;
- The level of inspection of those goods by MPI or associated personnel.
- The likely efficacy of that inspection (note this includes the whole supply chain including post clearance finds). This estimate is generated by experts and considers all of the inspections that occur on the pathway on entry into New Zealand e.g. MPI inspectors, approved persons, vehicle compliance officers, car yard mechanics etc.; and
- The number of BMSB found during any of the inspections on the pathway (alive or dead).

To ensure the results of this analysis will remain applicable for the immediate future, the pre-export infestation rates for Europe (a region only relatively recently invaded by BMSB) were estimated based on the calculated pre-export infestation rates for North America (a region currently affected by a large outbreak of BMSB). This information for each of the pathways is provided in **Appendix 2**.

From an analysis of this information it is clear that the most likely pathways of entry into New Zealand are vehicles (new and used) (see ***Figure 4***).

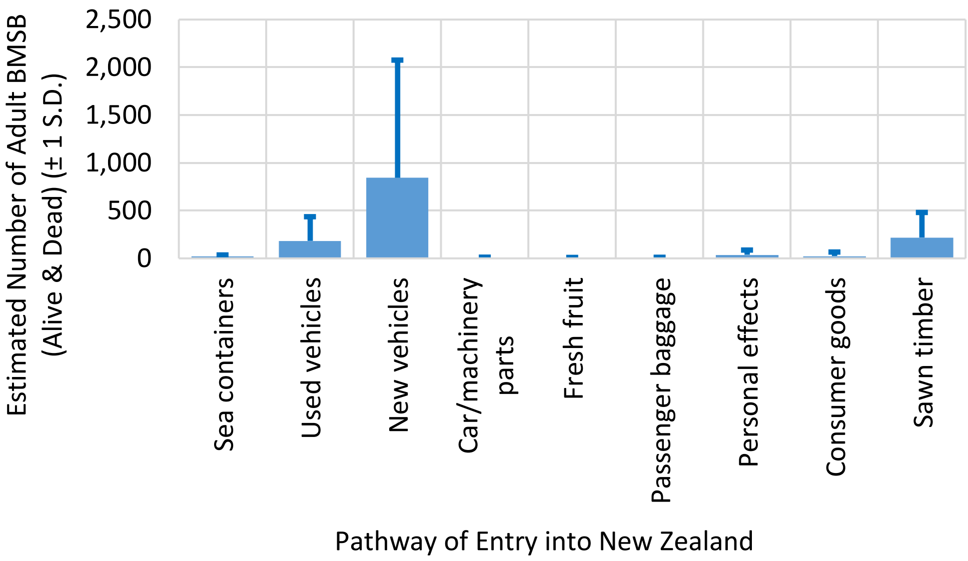

Figure 4: The estimated number of BMSB adults (alive & dead) entering New Zealand over a full year on each of the recorded pathways of entry based on an analysis of 2015 interception records.

The interceptions detected on the sawn timber pathway occurred over a short period only and originated from one location. As mitigation efforts at the location have resulted in no further finds on that pathway, for the purposes of this analysis the pathway will be considered to have a very low level of infestation and as such will not be considered further.

Analysis of the infestation rates of new and used vehicles imported from each of the main regions (North America, East Asia and Western Europe) indicates that the most likely pathways of entry into New Zealand are vehicles (new and used) from areas invaded by BMSB and from which relatively high volumes are imported (e.g. North America) (see ***Figure 5***). While BMSB adults have been intercepted on other high-volume pathways such as vehicles from East Asia, the estimated levels of infestation are too low to be significant. Most notably all BMSB detections on vehicles from East Asia have been single dead BMSB with no aggregations found.

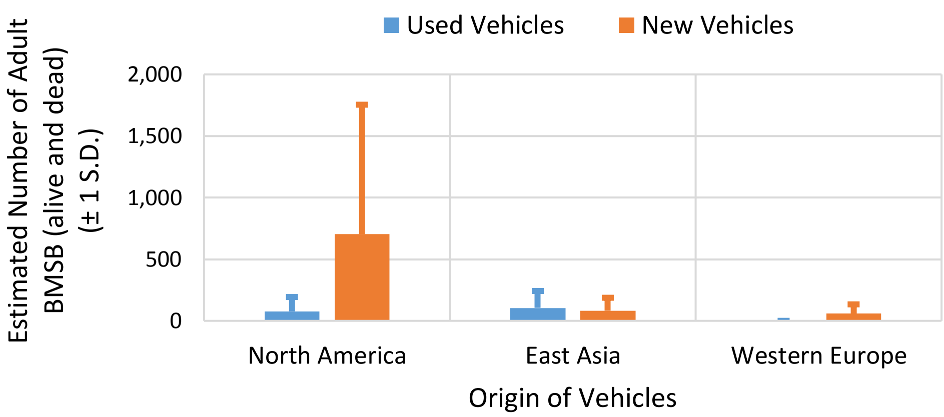

Figure 5: The estimated number of live BMSB adults entering New Zealand on new and used vehicles from BMSB areas based on an analysis of 2015 interception records

Focusing only on the most likely pathways of entry into New Zealand (vehicles from North America), the number of adult BMSB entering New Zealand is greatest during most of the New Zealand spring-summer-autumn period (September to April) (see ***Figure 6***).

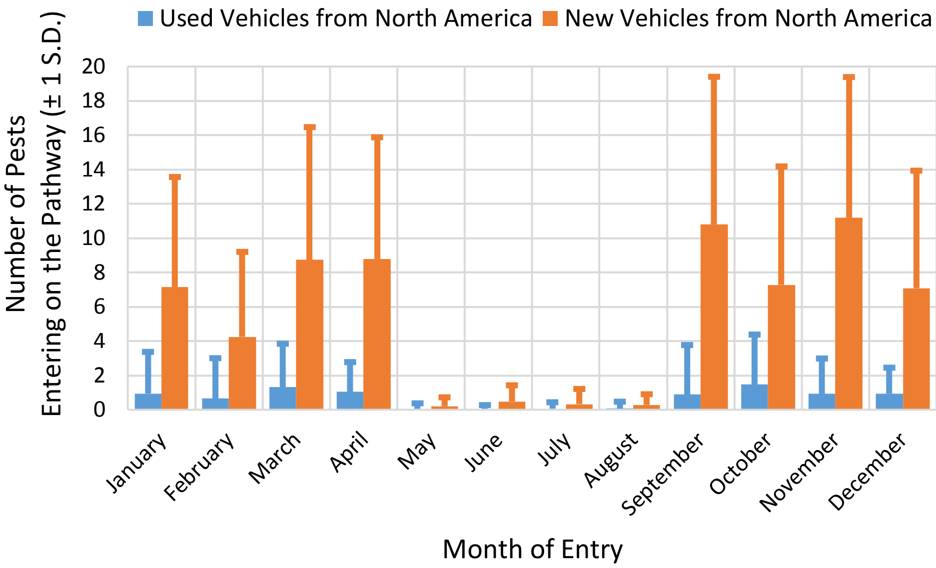

Figure 6: The estimated number of live BMSB adults entering New Zealand on new and used vehicles from North America based on an analysis of 2015 interception records.

d. Destination of goods and conveyances infested with BMSB

Analysis of interception data for each port of first arrival (PoFA) and each month of the year (see ***Appendices 3-4***) indicates that Auckland is the region that receives the greatest number of BMSB adults and as such based on propagule pressure (and assuming climate suitability) is the most likely place BMSB will establish in New Zealand (see ***Figure 7***).

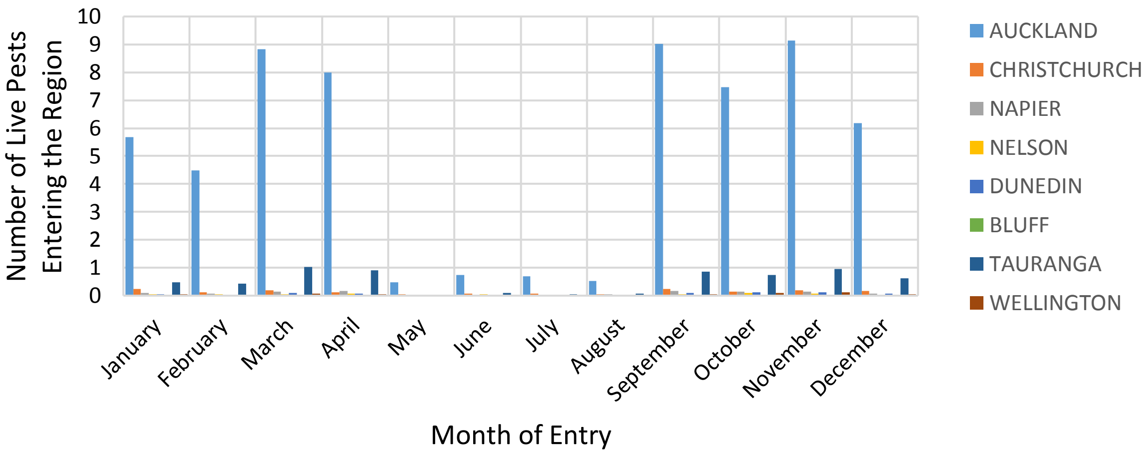

Figure 7: The estimated number of live BMSB adults entering each place of first arrival (PoFA) based on an analysis of 2015 interception records and trade data

6. Estimating the likelihood of establishment

The likelihood that a breeding population of BMSB will establish increases as the propagule pressure (or the number of adult bugs arriving in New Zealand) increases (Hufbauer *et al*. 2013). Additionally, establishment is much more likely from aggregations that arrive on a single pathway over a single lifetime, than from individual BMSB arriving at different times and/or in different locations. While studies from the USA indicate that a population can establish from a founder population consisting of very few individuals (Aldrich *et al*. 2009), these individuals would need to arrive on the same pathway and within a single lifetime and then remain in proximity to each other for mate finding and subsequent establishment to occur.

The likelihood of establishment of BMSB in New Zealand from northern hemisphere overwintering populations is higher than summer populations. This is because these bugs arrive in aggregated adult populations and, on arrival in New Zealand, will encounter the environmental conditions (warmer temperatures and longer day lengths) that signal the end of diapause and initiate reproductive maturation (Niva & Takeda 2003). While actively feeding, the production of an aggregation pheromone serves to keep the population in close proximity (Weber *et al.* 2014) therefore mate finding is more likely (Duthie 2015). This contrasts with northern hemisphere summer populations which will encounter colder conditions with shorter days on arrival in New Zealand thereby lacking the cues for reproduction; additionally, there is likely to be a limited range of food suitable for complete nutrition (Duthie 2015).

a. Risk estimation model

To aid in the analysis of the considerable volumes of data on pathways of entry, infestation levels and trading patterns of phytosanitary pests and their host commodities, a Bayesian Network (BN) model was built using the GeNIe Bayesian network tool[e]. A model support tool was also developed, and implemented in java, utilising the GeNIe Application Programming Interface, allowing the user to specify the inputs in to the model, i.e., spatial resolutions and input distributions, using excel spread sheets (Jamieson *et al*. 2016).

The model was designed to run in combination with a Geographical Information System (GIS) tool with two passes. The first pass runs the 'Pathway' sub-models for all pest entry ports, determining the expected percentage of infected units arriving from the pathway to any infection point it supplies. The second pass runs the 'Location' and 'Consequences' sub-models for all infection points, taking output on pest densities from the first pass using the entry pathways as the input (Jamieson *et al*. 2016).

A conceptual diagram is provided in ***Figure 8*** to describe the variables that may influence the level of biosecurity risk on a generic import pathway of any risk organism that might impact plant production in New Zealand, including the likelihood of entry, exposure, establishment and consequences.

The model has a number of sub-models (from Jamieson *et al*. 2016):

- Pathways, which model the infected units coming from any pathway feeding the locations;
- Exposure Pests, which model the number of pests entering and transferring from the commodity or pathway to a suitable host or environment (exposure of pest to location);
- Locations, which models the pests arriving at a location; and
- Consequences, which model expected costs of establishment and spread at the location.

The 'Month' variable is used as a switch; to select the monthly specific input values, such as number of units arriving and likely establishment rates.

[e] https://dslpitt.org/genie/

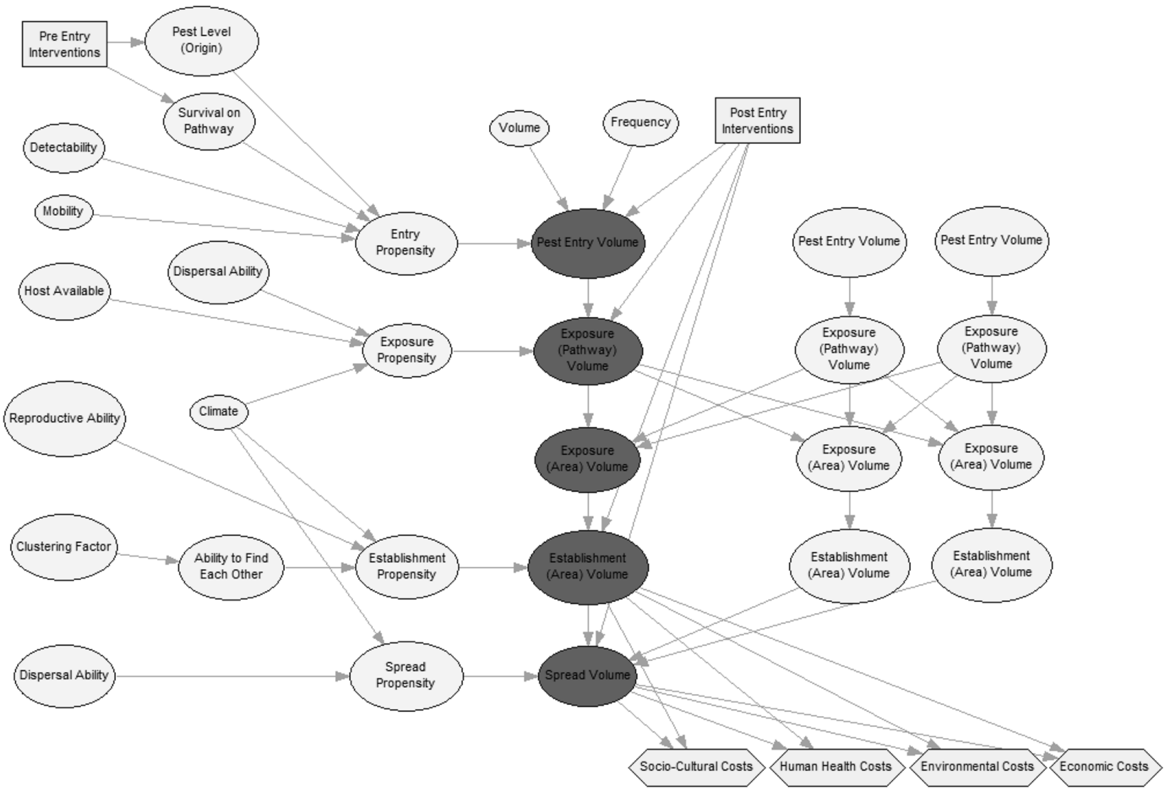

Figure 8: Conceptual diagram of the variables (or nodes) influencing biosecurity risks on import pathways. Rectangle nodes are the interventions (pre-border, at border and/or post border). Shaded oval nodes are the main pathway nodes (Vol = volume, Amt = amount). Rhomboid nodes are the impacts (from Jamieson *et al*. 2016).

A description of the variables (or nodes) of the high level generic biosecurity risk assessment model is shown in **Table *3***.

Table 3: Main upper level generic biosecurity risk assessment model for imports. Description of the variables and their relationship to one another (from Jamieson *et al*. 2016).

Node/Sub-model	Description	Units	Parent nodes	Relationship
Month	Month of the current model run. Value is entered as an integer representing the month.	Enumerated Month (e.g., Jan=1, Feb=2, …)	NA	NA
Pathway 1, 2, …	Determines the ratio of units infected coming from an entry pathway.	NA	Month	Switches month specific inputs
Location 1, 2, …	Determines the chance of an establishment and/or spread event for an infection point.	NA	Pathway 1, 2, …	For each potential infection pathway, ratio of units infested taken as input.
			Month	Month switches between month specific inputs
Location 1, 2, … Consequences	Determines the consequences of establishment and spread events at the location	NA	Location 1, 2, …	For each location, takes the chances of establishment and spread.

Data to populate the model was collected on regional trade patterns (MPI and other sources) and aspects of BMSB epidemiology (Nielsen 2008) (see text above and ***Appendices 1-4***) and run through the risk estimation model (Jameson *et al.* 2016). The model was run twice:

1. With no pre-border treatment;
2. With a pre-border treatment included on selected pathways (vehicles from Europe and North America) during the New Zealand spring-summer-autumn period (September to April) only.

In both cases it was assumed that all pathways received the current levels of on-arrival inspections and, when a treatment was applied, the expected level of treatment efficacy was achieved.

To investigate a more conservative scenario the model was run a second time under scenario 2 while assuming half of the current estimated efficacy level of on-arrival inspection.

b. Results of applying the model

The results from the risk estimation model indicate the following:

a. Analysis of the BMSB entry data for Auckland indicates that with no measures applied to the main pathways of entry for BMSB, the number of adult BMSB accumulating in the Auckland region is unlikely to exceed seventy five (see **Figure *9***). The likelihood should be considered low to moderate that seventy five adult BMSB in the entire Auckland region would result in two adult BMSB of opposite sex being in close enough proximity to enable breeding etc.

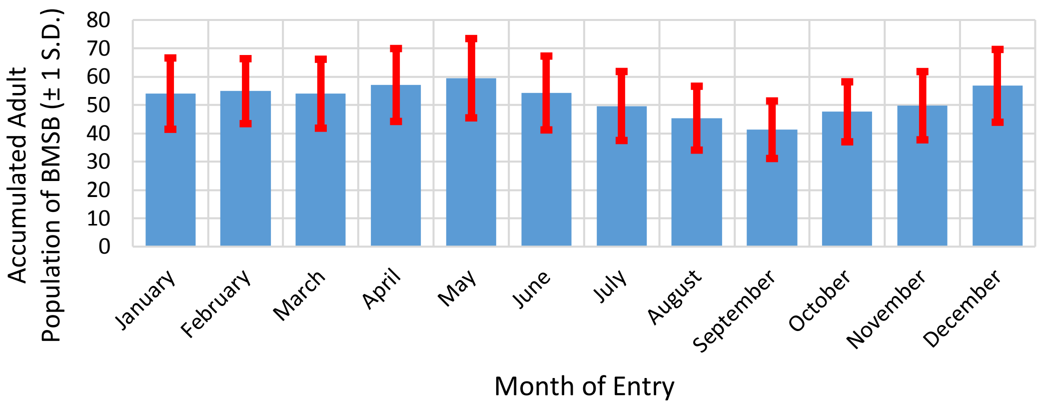

Figure 9: The estimated monthly accumulated adult population of BMSB in the Auckland urban area (showing one standard deviation) with no measures applied to entry pathways.

b. With the inclusion of a pre-border treatment on the vehicle pathway from North America over the New Zealand spring-summer-autumn (September to April) period, that ensures no more than one adult BMSB in 1,000 survive (efficacy of 99.9%), the number of adult BMSB accumulating in the Auckland region is unlikely to exceed two (see ***Figure 10***). The likelihood should be considered very low that two adult BMSB in the entire Auckland region would result in two adult BMSB of opposite sex being in close enough proximity to enable breeding etc.

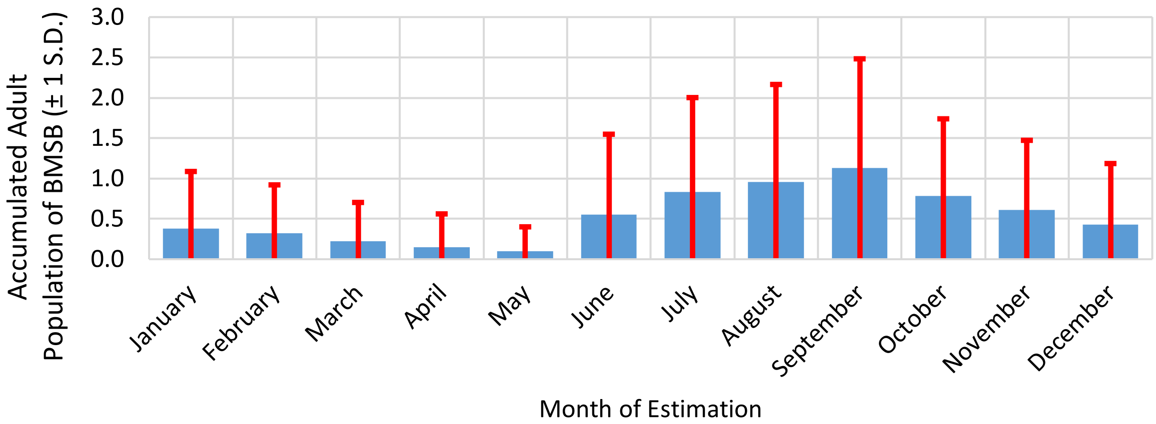

Figure 10: The estimated monthly accumulated adult population of BMSB in the Auckland urban area (showing one standard deviation). The pathway of entry for the adult BMSB was on imported vehicles from North America that were treated from September to April to achieve 99.9% mortality of exposed BMSB adults.

To confirm these results are supported under an even more conservative scenario, the model was run once more. The efficacy of inspection (or the ability of an inspector to detect an adult BMSB on inspection – see ***Appendix 2***) was estimated by subject experts within MPI. In reality however there has been little research into the ability of visual inspection to detect vehicles infested with BMSB or other such insect contaminants. To account for a potential over-estimation of the efficacy of inspection by experts, the estimates provided in ***Appendix 2*** were halved, effectively doubling the estimated pathway infestation levels. This model was also run using estimated infestation rates for Europe assuming the BMSB outbreak in Europe develops to the extent it has in North America. Using these adjusted estimates in the model the outputs indicate that:

c. Halving the efficacy of inspection while including a pre-border treatment on the vehicle pathway from North America over the New Zealand spring-summer-autumn (September to April) period, that ensures no more than one adult BMSB in 1,000 survive (efficacy of 99.9%), the number of adult BMSB accumulating in the Auckland region is unlikely to exceed four (see ***Figure 11***). While this number is twice that stated in (b) above, the likelihood should also be considered very low that four adult BMSB in the entire Auckland region would result in two adult BMSB of opposite sex being in close enough proximity to enable breeding etc.

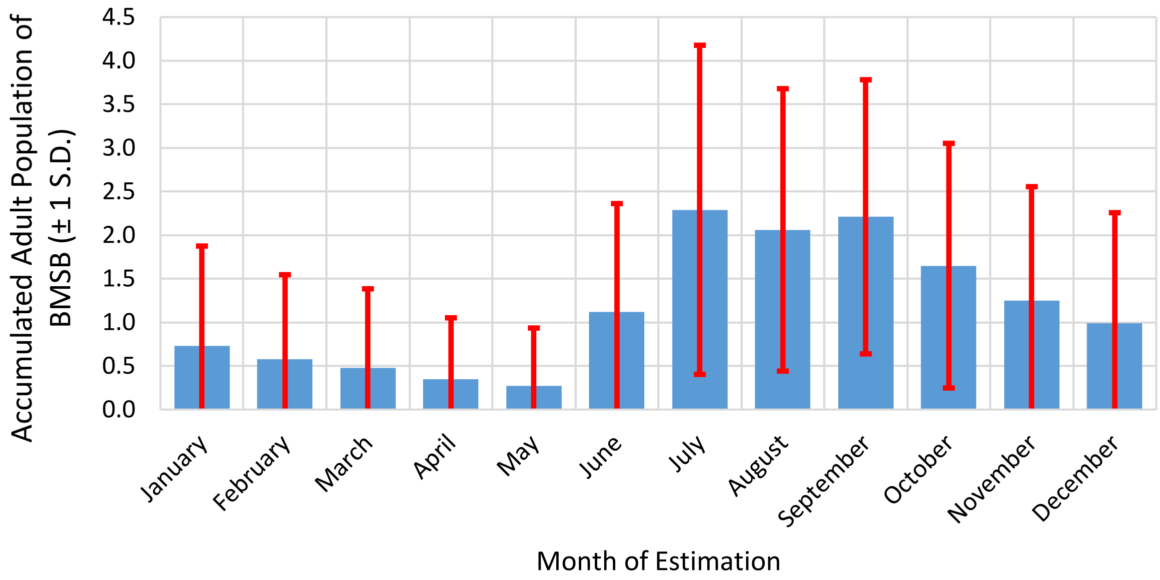

Figure 11: The estimated monthly accumulated adult population of BMSB in the Auckland urban area (showing one standard deviation). The pathway of entry for the adult BMSB was on imported vehicles from North America and assumed half the estimated level of inspection efficacy on the pathway as well as the application of a treatment from September to April to achieve 99.9% mortality of exposed BMSB adults.

7. Determining the level of treatment efficacy

Treatment efficacy can be described in a number of ways, but the more recently accepted method is to say that (in this case) the treatment achieves 99.9% mortality of adult BMSB at the 95% level of confidence (FAO 2015). It should also be noted that:

- The required end point of the treatment (in this example 'mortality') may differ depending on the treatment type and the nature of the particular risk e.g. adult sterility may be considered a suitable treatment endpoint in some cases;
- The percentage (%) level [end point] refers to the portion of the population where the desired outcome has been demonstrated to have been achieved (based on supporting research);

The level of confidence (95%) describes the degree of trust we have in this level of efficacy e.g. a treatment with a 99% level of efficacy at the 95% level of confidence could also be described as having a 99.99% level of efficacy at the 4% level of confidence. Clearly a 4% level of confidence is not satisfactory, therefore internationally it is accepted that the confidence level should be 95% for treatment efficacy.

The level of efficacy of a treatment can be demonstrated in a number of ways, but two main ways have been used extensively: confirmatory trials or regression analysis. Confirmatory trials expose large numbers of the target pest to the required treatment schedule while regression analysis trials involve exposing smaller numbers of pests to a range of related treatment schedules. Both methods require statistical analyses to calculate the level of efficacy at the 95% level of confidence. Confirmatory trails suffer from the need to have large numbers of test organisms but can demonstrate the effectiveness of treatment schedules that are close to the minimum required. Regression analyses require fewer test organisms but usually over-estimate the treatment dose required (to achieve the 95% level of confidence) (Schortemeyer *et al*. 2011). Both of these methods are considered in this technical review.

a. Converting lab schedules into operational schedules

It is a generally accepted practice that treatment schedules developed in the laboratory are 'proven' through confirmatory trials using the most resistant life stage to the particular treatment being tested. These confirmatory trials apply treatment schedules under operational or near-operational conditions. Exceptions to this rule can be accepted where it has previously been shown that results from the laboratory can be used to predict the confirmatory results. Exceptions can also be accepted where the particular treatment parameters can be confirmed with ease under operational conditions e.g. wood core temperatures.

Treatments using fumigants or heat/cold can be developed under laboratory conditions only where the target insects are not naturally covered or protected by the commodity e.g. the treatment has unrestricted access to the target organism. In these cases laboratory conditions should duplicate as far as possible the range of environmental conditions likely to be found in operations, such as humidity, starting atmosphere or commodity temperature, and levels of oxygen or carbon dioxide. Where gas concentrations or temperatures are likely to vary across the commodity, operational trials need to be completed just to confirm the critical treatment parameters are delivered across the entire commodity or consignment under operational conditions. With BMSB only adult insects will be present on the commodity or conveyance, and these adults will likely be in or recently emerged from diapause and found on the surface albeit potentially hiding in crevasses or under coverings.

b. The efficacy of Methyl bromide on BMSB

Methyl bromide is a general purpose fumigant that at relatively low doses provides a high level of mortality against a very wide range of pest species[f]. Methyl bromide is a gas at room temperature but a liquid at temperatures below around 4°C. As the gas begins to condense at temperatures approaching 4°C, it is generally accepted that effective fumigation (pest mortality) can only be achieved consistently at temperatures at or exceeding 10°C. Methyl bromide gas penetrates substrates such as wood reasonably well, but penetration is limited by higher moisture content.

Examples from a review of the literature on the effectiveness of methyl bromide fumigation on insects found on or near the surface of commodities are provided in ***Appendix 5***. It is apparent from numerous studies that methyl bromide is generally effective on direct application to exposed insects at C/T levels of <140 g.h/m^3 and temperatures >10°C (or 120 g.h/m^3 at > 15°C). Higher doses are required when the insects are partially or completely imbedded in the commodity. For vehicle fumigations the question of fumigant penetration into the vehicle is as important as the level of efficacy of the fumigant on the target pest.

The current fumigation standard requires C/T values of 475 or 400 g.h/m^3 over 24 hrs (10 and 15°C respectively). The reported (but not sighted) results of research completed by USDA-ARS, indicating a suitable level of methyl bromide efficacy on the most methyl bromide-tolerant life stages (2nd & 3rd instar) of non-diapausing BMSB at 16°C, suggested the following C/T exposure values for 99% and 99.99683% mortalities, respectively: 40.494 g.h/m^3 (confidence limits of 31.571 to 59.887) and 90.033 g.h/m^3 (confidence limits of 60.675 to 179.997). To provide a 95% level of confidence that the desired treatment outcome is achieved (BMSB mortality), the results could be interpreted to indicate that at 16°C: 60 g.h/m^3 is required to achieve 99% mortality compared to 180 g.h/m^3 to achieve 99.99683% mortality. These unsighted results would indicate that Methyl

[f] Methyl bromide fumigation is an internationally approved treatment against a wide range of insects of concern in the international movement of wood packaging material (FAO 2009).

bromide achieves equivalent levels of mortality on non-diapausing BMSB to many other insect species. It should be noted, however, that preliminary results from exposing diapausing adult BMSBs to methyl bromide fumigation found that around twice the dose was required to achieve the same levels of mortality.

Based on the unsighted data from USDA-ARS, and the efficacy results presented in ***Appendix 5***, to achieve an efficacy of 99.9% (no survivors in 1,000) a reduced methyl bromide fumigation rate of >140 g.h/m^3 for treatments at >10°C may be acceptable if evidence is provided that C/T values of >140 g.h/m^3 are achieved throughout the vehicle where BMSB could be found. At higher temperatures (>15°C) a reduced rate of >120 g.h/m^3 may be acceptable providing C/T values of >120 g.h/m^3 are achieved throughout the vehicle where BMSB could be found. These results would support the use of the new proposed Methyl bromide schedule:

- Methyl bromide fumigation at >15°C to achieve a minimum C/T of 128 g.h/m^3 over 12 hrs and a minimum concentration of 9 g/m^3 (guidance indicates a starting dose of >16 g/m^3).

As indicated above, a schedule at >10°C would need to achieve a C/T value of >140 g.h/m^3.

- Methyl bromide fumigation at >10°C to achieve a minimum C/T of 140 g.h/m^3 over 12 hrs and a minimum concentration of 11 g/m^3 (guidance indicates a starting dose of >16 g/m^3).

Given the extended fumigation periods used when treating vehicles (12-24 hours) are equivalent to those used for treating wood, methyl bromide penetration into the vehicle types found on this pathway should not be an issue as long as reasonable steps are taken to ensure compartments within the vehicle are unsealed (opened) during fumigation.

c. The efficacy of sulfuryl fluoride on BMSB

While not yet available (not registered) in New Zealand, sulfuryl fluoride is the preferred gas by vehicle manufacturers in the USA and Europe as methyl bromide is not widely available (not registered in Europe) and some manufacturers have concerns over the effect of methyl bromide gas on some vehicle components.

As is the case with methyl bromide fumigation, the question of fumigant penetration into the vehicle is as important as the level of efficacy of sulfuryl fluoride fumigation on the target pest (BMSB). As a general insect fumigant, sulfuryl fluoride is more effective against adult insects and less effective against insect eggs. Dose rates required for effective control of the egg stages can be 29 times more than that required for adults (Jagadeesan *et al*. 2015). As it is only the adult life stage of the BMSB that needs to be controlled on pathways of entry into New Zealand, lower dose sulfuryl fluoride fumigation may be acceptable. Unlike methyl bromide, dose levels required for equivalent levels of sulfuryl fluoride efficacy against different insect species can vary significantly, and no generally effective dose on exposed insects is available (see ***Appendix 6***).

As is the case with methyl bromide, a sulfuryl fluoride fumigation schedule involving an extended period of exposure (>12 hours) has been shown to effectively penetrate wood to treat insects (Ren *et al*. 2010). Therefore any sulfuryl fluoride schedule applied over periods >12 hours should be expected to adequately penetrate the vehicle types found on this pathway as long as reasonable steps are taken to ensure compartments within the vehicle are unsealed (opened) during fumigation.

Efficacy data from laboratory studies

The data provided by Walse (2015) for sulfuryl fluoride fumigation of non-diapausing adult BMSB indicates that C/T values of 990 g.h/m^3 over 2 hours or 275 g.h/m^3 over 12 hours (all at >10°C) may be sufficient to achieve a suitable level of mortality on exposed insects (at the 95% level of confidence). Walse (pers. comm.) calculated that a C/T value of 89.821 g.h/m^3 with 95% confidence limits of 76.029 to 128.884 are required to achieve mortality levels of 99% (no survivors in 100), and a C/T value of 142.816 g.h/m^3 with 95% confidence limits of 106.868 to 274.871 to achieve mortality levels of 99.99683% (no survivors in ~30,000). It is normal practice to take the higher estimated doses, however the analysis used low numbers of exposed insects and replicates at each dose. As a result the level of error in extrapolation to higher doses (above those tested) renders the estimates uninformative (there is no (or little) significant difference in results for 99% and 99.9963% efficacy).

Taking the exposed numbers without extrapolation, the research results indicate that a treatment dose (C/T value) of 144 g.h/m^3 over 12 hours provides 97.1% efficacy at the 95% level of confidence (no survivors in 34) or 384 g.h/m^3 over 12 hours provides 99% efficacy at the 95% level of confidence (no survivors in 100). Further research and/or analysis of results may be required to obtain a suitable (95%) level of confidence that the sulfuryl fluoride dose applied to exposed insects will achieve a 99.9% level of efficacy (no survivors in 1,000).

Based on preliminary studies on non-diapausing BMSB exposure and extensive evidence against insects in general, a reduced sulfuryl fluoride fumigation rate of >384 g.h/m^3 for treatments at >10°C, applied over >12 hour period, should be expected to ensure no more than one BMSB adult survives in 100 exposed individuals. As was found with exposure to methyl bromide fumigation, effective sulfuryl fluoride rates are likely to higher when treating diapausing adult BMSB.

Efficacy data from use in trade

Another potential source of efficacy data is from the use of a particular treatment schedule in trade. There are a number of limitations in using such data to provide suitable levels of confidence in a stated efficacy, and these limitations were described in a paper presented to the International Plant Protection Convention Standards Committee in 2015 (IPPC 2015). The identified limitations that would relate to BMSB trade data included:

1. The condition of target regulated article may vary over the period the data was collected in a way that could be critical to treatment effectiveness e.g. the pre-conditioning process of the regulated article or particulars of a systems approach to managing the risk;
2. The life state (e.g. dormancy) of the target organism varied over the period the data was collected in a way that could be critical to treatment effectiveness;
3. Environmental parameters critical to treatment efficacy varied over the period the data was collected e.g. exposure to lower temperatures in transit, changes in packaging created hypoxic conditions after treatment;
4. The number of living target organisms infesting the regulated articles at the time of treatment application was unknown or unable to be estimated accurately;
5. The number of surviving target organisms after treatment was not determined;
6. The data record is incomplete or inaccurate.

From July 2015, Australia approved the use of a reduced sulfuryl fluoride fumigation rate for BMSB on the 15 July 2015 (DA 2015). The approved rates were lowered to 48 g/m^3 for 6 hours or 16 g/m^3 for 12 hours with an end point reading of at least 50% of the approved rate at temperatures of 10°C or higher. The calculated C/T values for these two schedules are 235 g.h/m^3 and 135 g.h/m^3 respectively. Australia requires the treatment for BMSB of used vehicles imported from the USA that are shipped between from 1st September and the 30th April, and new vehicles manufactured between 1st September and the 1st December. Since the reduced fumigation rates were introduced it is roughly estimated based on New Zealand import volumes that around 20,000 new and used vehicles were treated in the USA and imported into Australia. It is further estimated that the majority (an estimated 80% or more) of which would have been fumigated with Sulphuryl fluoride at the rate achieving a C/T of 135 g.h/m^3. It has been reported (pers. comm.) that over that period no live BMSB were detected in those vehicles on arrival in Australia.

In September 2015, MPI also approved the use of a reduced sulfuryl fluoride fumigation rate for BMSB for use for one year from the 15th October 2015 (MPI 2015b). The approved rate was lowered to 16 g/m^3 for 12 hours, with an end point reading of at least 50% of the approved rate at temperatures of 10°C or higher. The calculated C/T value for this schedule is 135 g.h/m^3. From New Zealand border clearance records between 1st October 2015 and 30th November 2016, New Zealand imported around 7,800 treated vehicles, of which around 5,150 arrived during the summer months and 2,650 during the winter months. As was the case with Australia, during this period no live BMSB were detected on these vehicles and the majority of the vehicles (an estimated 80% or more) would have been fumigated using sulfuryl fluoride.

Taking the Australian and New Zealand export volumes together, we can say that around 80% of 25,150 vehicles (20,120 vehicles) treated at the reduced sulfuryl fluoride fumigation rate achieving a C/T of 135 g.h/m^3 were imported during the summer, and around 2,120 vehicles (80% of 2,650) during the winter. Using the estimated infestation rates provided in Appendix 2 for new and used vehicles exported from the USA over the summer and winter period, the estimated number of BMSB adults associated with the pathway that were treated by the reduced sulfuryl fluoride fumigation rate achieving a C/T of 135 g.h/m^3 was 766 (see calculations in ***Table 4***).

Table 4: Estimated BMSB infestation rates new and used vehicles treated with 135 g.h/m^3 of sulfuryl fluoride and exported from the USA to New Zealand and Australia

Vehicle Pathway (as cargo)	Approximate Number of SF Treated Vehicles	Infestation Rate (from Appendix 2)	Estimated Number of Adults (live and dead)
USA exported **used** vehicles to New Zealand (Summer)	832	2.1408%	18
USA exported **used** vehicles to New Zealand (Winter)	380	0.2175%	1
USA exported **new** vehicles to New Zealand (Summer)	3,288	4.2816%	141
USA exported **new** vehicles to New Zealand (Winter)	1,740	0.4350%	7
USA exported **used** vehicles to Australia (Summer)	4,000	2.1408%	85
USA exported **new** vehicles to Australia (Summer)	12,000	4.2816%	514
Total =	22,240	**Total =**	**766**

Combining this total with the number treated by Walse (2015) at a similar rate (103 non-diapausing adults) gives a total exposed adult population with no survivors of 869, or an efficacy level of 99.65% (no survivors in 290) at the 95% level of confidence using a reduced sulfuryl fluoride fumigation rate achieving a C/T of >135 g.h/m^3 over a 12 hour period.

As discussed above, the use of trade data in this way has a number of limitations. The greatest weaknesses in the assumptions made are the estimates of vehicle contamination rate and proportion of vehicles treated at the lower SF rate (C/T of around 140 g.h/m^3). Over the treatment period used in this analysis, no individual BMSB, alive or dead, were detected on arrival in New Zealand on new or used vehicles imported from the USA. This could have resulted from the loss of adult BMSB from the treated vehicles during or after treatment, or could reflected a lower-than-expected vehicle infestation rate over this period. Australia and New Zealand both offer alternative treatment options to the low SF rate, and the relative proportions of the different options applied was not measured in a systematic way. It should therefore be recognised that these results are only indicative at best.

d. The efficacy of heat on BMSB

It is generally accepted that insect pest species (as opposed to insects that are adapted to high temperature environments and are generally not considered pests) are relatively intolerant to heat (NAPPO 2014). Exposing insects to temperatures exceeding 50°C for an extended period (>24 hours) will result in levels of mortality suitable for trade. Achieving a suitable level of efficacy over shorter treatment periods may necessitate an increase in treatment temperature. As with the fumigation treatments above, the question of heat penetration into the vehicle is as important as the level of efficacy of heat on the target pest (BMSB).

Heat treatment work on wood pests has identified an insect pest (emerald ash borer (*Agrilus planipennis*)) that requires temperatures of 60°C for 20 minutes to achieve a suitable level of efficacy (McCullough *et al.* 2007). All other tested insect pests of wood are suitably managed by treatments equalling or exceeding 56°C for 30 minutes (NAPPO 2014).

For tephritid fruit flies (Diptera: Tephritidae), research on heat treatment schedules on perishable commodities (e.g. fresh fruit) have demonstrated high levels of efficacy (e.g. no survivors from >30,000 pests) at temperatures of around 47-48°C for 1-4 hours.

Aigner & Kuhar (2016) exposed small numbers (~40) of adult BMSB to increasing temperatures and exposure times. They found that none survived temperatures of 45°C for more than an hour or 50°C for more than 15 minutes. These results indicate that, like many other insect pests, BMSB is likely to undergo high levels of mortality (e.g. no survivors in >10,000 adults) under the ISPM 15 (FAO 2009) heat treatment schedules of 56°C for 30 minutes or 60°C for 1 minute, and may be suitably managed by even lower temperatures and/or shorter treatment times.

As mentioned above for fumigation, research is required to ensure the appropriate heat exposures are achieved throughout the treated vehicle where BMSB could be found. Tests on heat penetration of a vehicle (a small car) using a large kiln (container-sized fan driven heating units) were completed in New Zealand (MPI 2001). The target temperature was measured in various potential cold-spots throughout the vehicle, with the vehicle in a number of different configurations (windows or boots open or closed) (see **Figure 12**).

Figure 12: A vehicle undergoing heat penetration trials.

The results from these trials indicated that a pre-treatment heat up period of as little as 10 minutes is sufficient to ensure all parts of the vehicle achieve the target temperature as long as doors and windows remain open during heating.

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

8. Reviewers of this technical advice

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- Ken Glassey (Senior Adviser – Biosecurity and Environment)
- Dr Andrew Robinson (Reader & Associate Professor in Applied Statistics, School of Mathematics and Statistics, & Director, CEBRA, School of BioSciences, University of Melbourne, Australia)

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Appendix 1: Exposure, establishment and mortality rates for BMSB

The following estimates of rates of mortality, exposure and establishment for BMSB adults were made based on the information provided in section 3.1 above. The base establishment rate is adjusted (reduced) as climate conditions become less suitable for BMSB over colder periods. Mortality rates of adult BMSB were also increased (doubled) over these less-favourable climatic periods. Natural mortality on the pathway and the rate of exposure on arrival were not altered during the year as these are not influenced by local environmental conditions.

Month of Year	Rate of Establishment (per month)	Mortality Rate (per month)
January	7%	26%
February	7%	26%
March	7%	26%
April	4%	26%
May	3%	50%
June	2%	50%
July	1%	50%
August	1%	50%
September	2%	26%
October	3%	26%
November	4%	26%
December	7%	26%
	Natural Mortality on Pathway of Entry =	30%
	Rate of Exposure on Arrival =	50%

Appendix 2: Information on goods or conveyances in or on which BMSB were found when entering New Zealand and Australia

Commodity/Pathway	Infested Area	Volume Imported from BMSB Areas	Level of Inspection	Efficacy of Inspection	Number of BMSB Detected (lines)		Number of BMSB per Detection (Mean ± SE)		Estimated Level of Infestation	
					Summer*	Winter*	Summer*	Winter*	Summer*	Winter*
Sea containers	USA	39,981	100%	98%	11 (4)	2 (1)	4.07 ± 4.18	2 ± 0	0.0030%	0.0009%
	Asia	151,250	100%	98%					0.0030%	0.0009%
	Europe	16,253	100%	98%					0.0030%	0.0009%
Used vehicles	USA	1,111	100%	20%	113 (22)	6 (5)	4.69 ± 7.11	1.2 ± 0.45	2.1408%	0.2175%
	Asia	149,408	100%	20%					0.0184%	0.0342%
	Europe	37	100%	20%					0.0749%	0.1541%
New vehicles	USA	5,392	50%	20%					4.2816%	0.4350%
	Asia	59,713	50%	20%					0.0368%	0.0683%
	Europe	9,884	50%	20%					0.1498%	0.3083%
Car/machinery parts (units/boxes)	USA	31,173	100%	50%	1 (1)	0	2.75 ± 3.5	0	0.0022%	0.0047%
	Asia	102,755	100%	50%					0.0022%	0.0047%
	Europe	359	100%	50%					0.0022%	0.0047%
Fresh fruit (boxes)	USA	1,947,152	100%	45%	3 (2)	0	1.5 ± 0.71	0	0.0002%	0.0004%
	Asia	149,631	100%	45%					0.0002%	0.0004%
	Europe	385,401	100%	45%					0.0002%	0.0004%
Passenger baggage	USA	309,024	100%	98%	8 (8)	0	1.09 ± 0.3	0	0.0011%	0.0003%
	Asia	579,904	100%	98%					0.0011%	0.0003%
	Europe	197,280	100%	98%					0.0011%	0.0003%
Personal effects (containers)	USA	1,472	79.22%	80%	24 (2)	0	12 ± 15.56	0	0.1449%	0.1538%
	Asia	1,125	39.42%	80%					0.1449%	0.1538%
	Europe	607	60.36%	80%					0.1449%	0.1538%
Consumer goods (containers)	USA	3,949	100%	70%	26 (7)	0	2.41 ± 4.23	0	0.1023%	0.0225%
	Asia	11,071	100%	70%					0.1023%	0.0225%
	Europe	1,100	100%	70%					0.1023%	0.0225%
Sawn timber (packs)	USA	21,790	100%	45%	98 (6)	0	16.33 ± 19.71	0	0.0921%	0.0274%
	Asia	80	100%	45%					0.0921%	0.0274%
	Europe	731	100%	45%					0.0921%	0.0274%

* The "summer" season was take as being between the 1st September and the 30th April of the following year. The remaining months are considered to be "winter".

Appendix 3: The volume of potentially BMSB infested goods arriving at each place of first arrival (PoFA) in New Zealand during 2015

Key to the graphs provided below.

Arrivals from North America in 2015 (Canada and USA).

Arrivals from East Asia in 2015 (China, Japan, South Korea, Taiwan, Hong Kong).

Arrivals from Europe in 2015 (Italy, Spain, Germany, France, Switzerland, Austria, Netherlands)

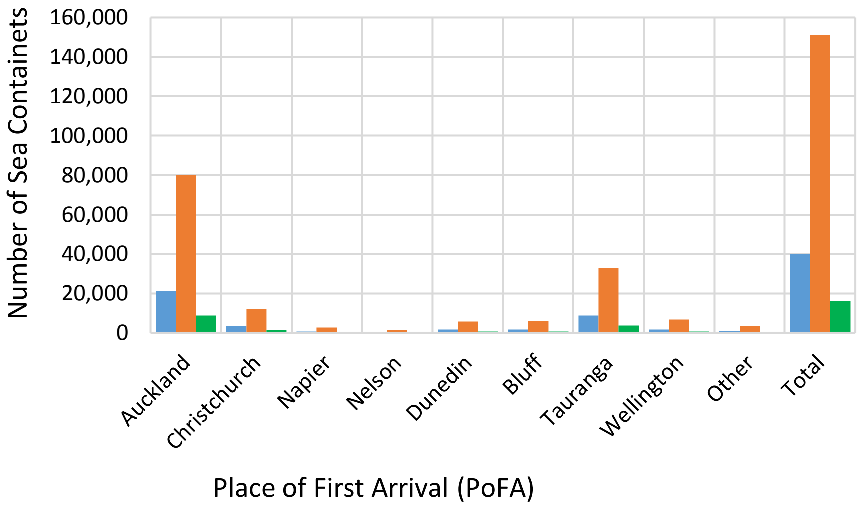


Figure 13: The number of sea containers arriving per PoFA in 2015

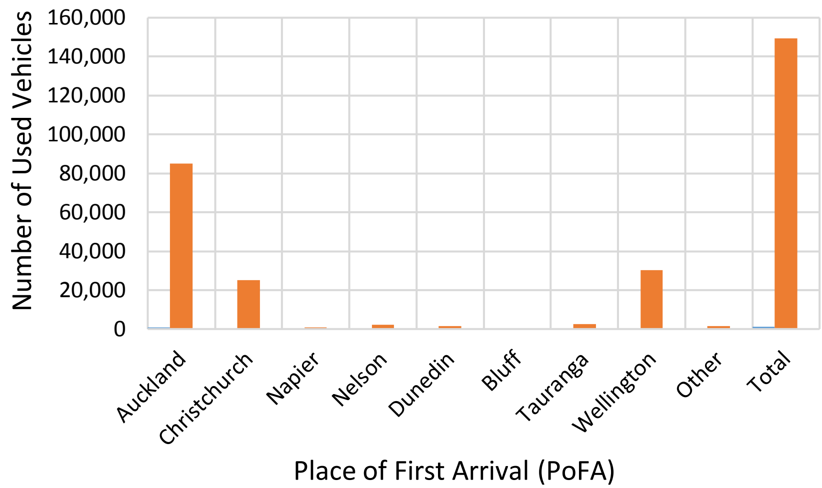


Figure 14: The number of used vehicles arriving per PoFA in 2015

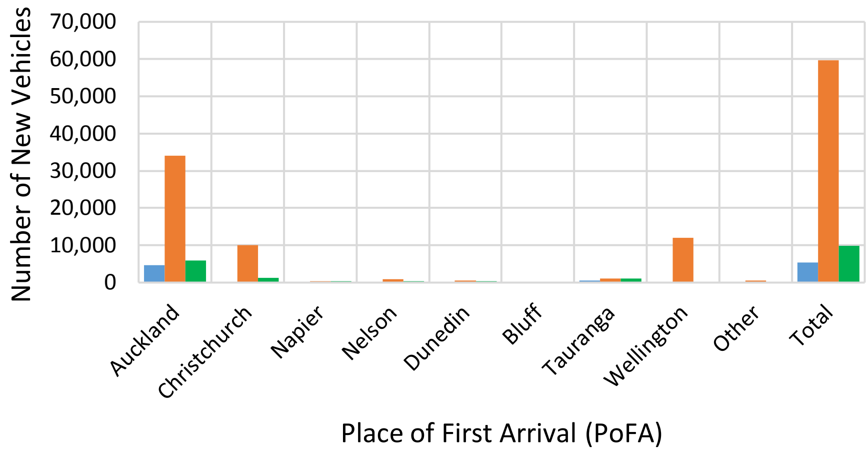


Figure 15: The number of new vehicles arriving per PoFA in 2015

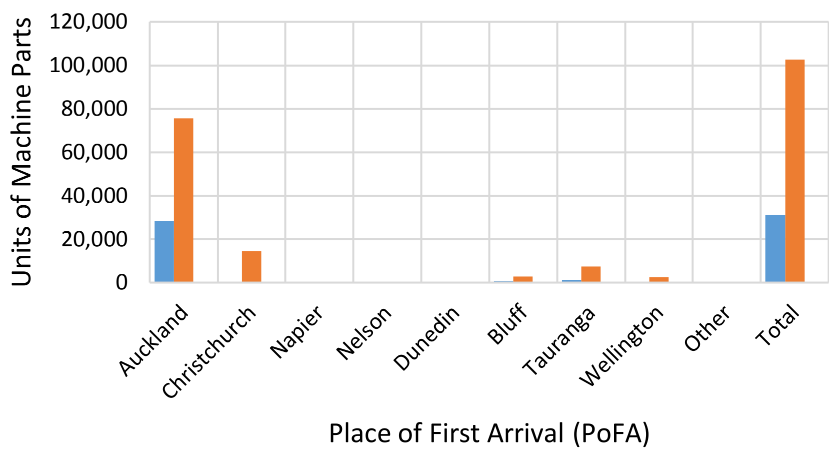


Figure 16: The number of units of machinery parts arriving per PoFA in 2015

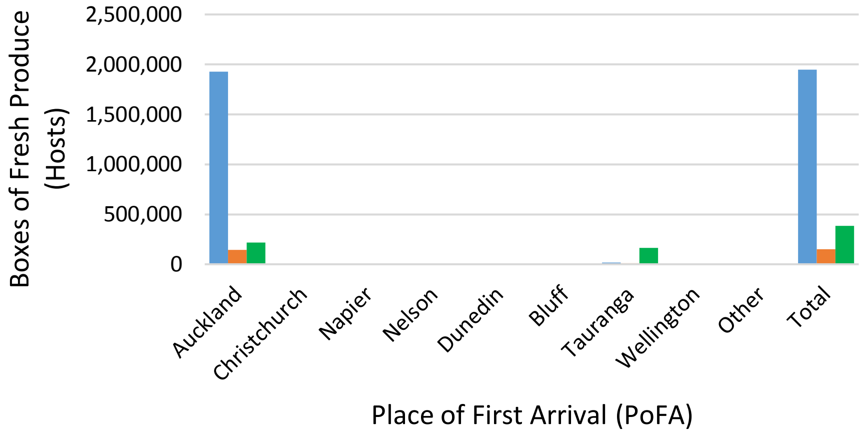


Figure 17: The number of boxes of host fresh fruit arriving per PoFA in 2015

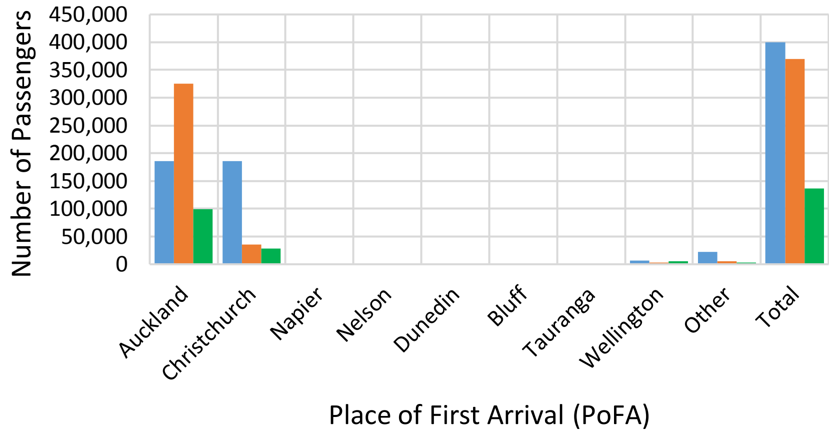


Figure 18: The number of passengers arriving per PoFA in 2015

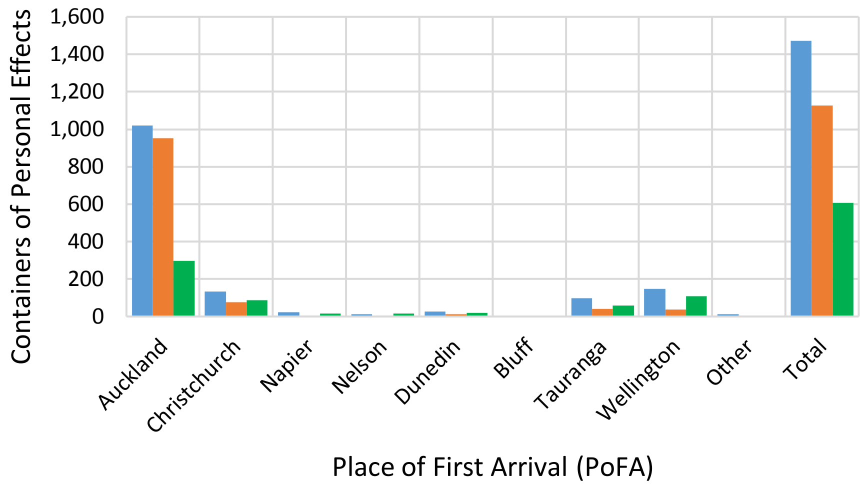


Figure 19: The number of containers of personal effects arriving per PoFA in 2015

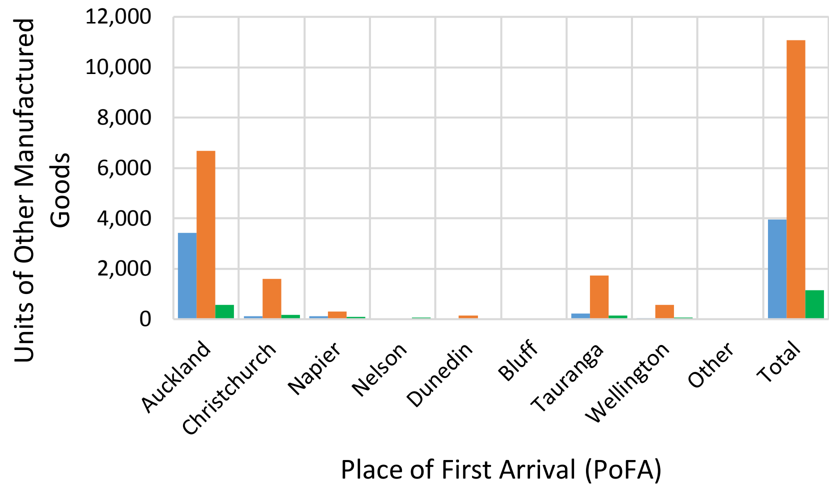


Figure 20: The number of units of manufactured goods arriving per PoFA in 2015

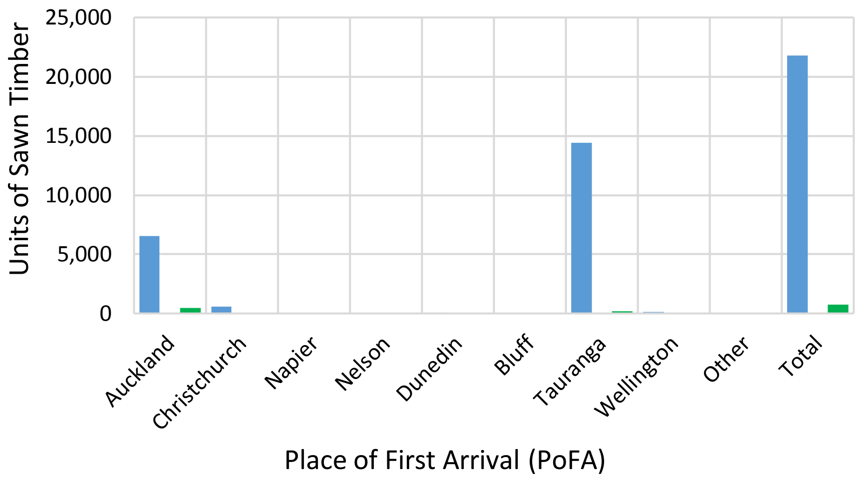


Figure 21: The number of units of sawn timber arriving per PoFA in 2015

Appendix 4: The volume of potentially BMSB infested goods arriving each month in New Zealand during 2015

Key to the graphs provided below.

Arrivals from North America in 2015 (Canada and USA).

Arrivals from East Asia in 2015 (China, Japan, South Korea, Taiwan, Hong Kong).

Arrivals from Europe in 2015 (Italy, Spain, Germany, France, Switzerland, Austria, Netherlands).

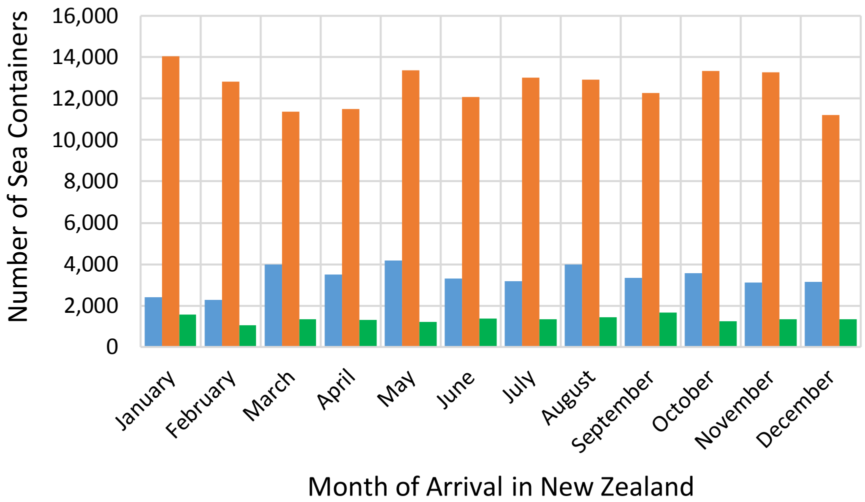


Figure 22: The number of sea containers arriving per month in 2015

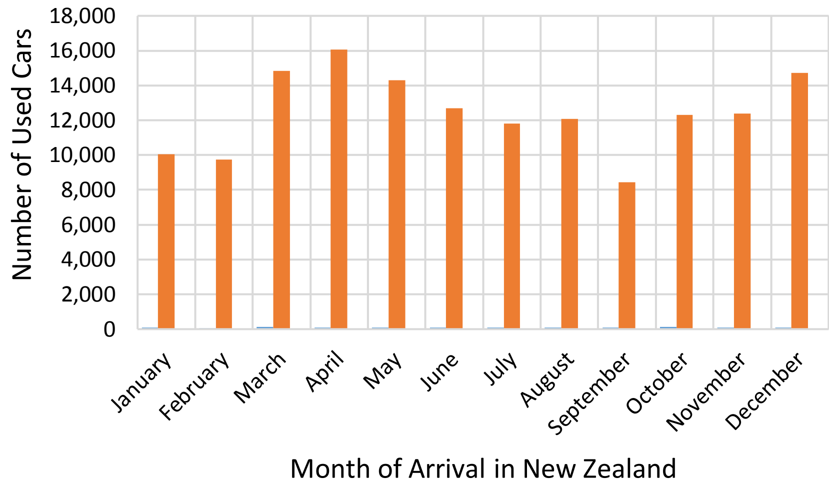


Figure 23: The number of used vehicles arriving per month in 2015

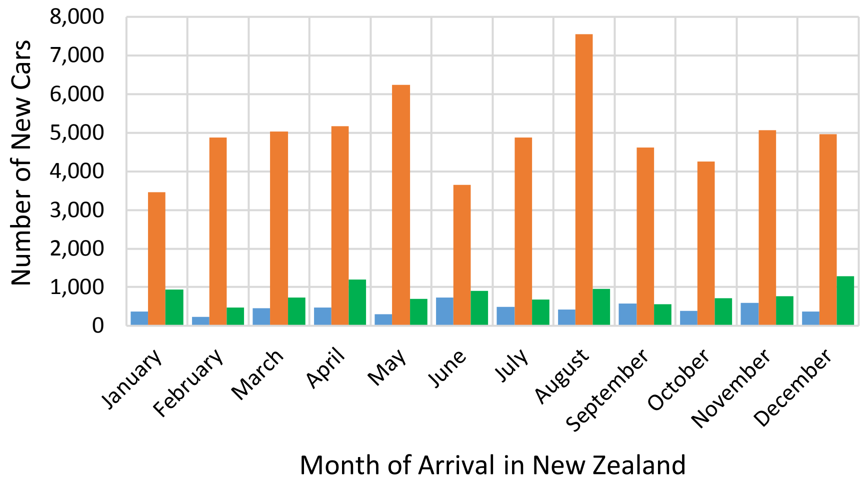


Figure 24: The number of new vehicles arriving per month in 2015

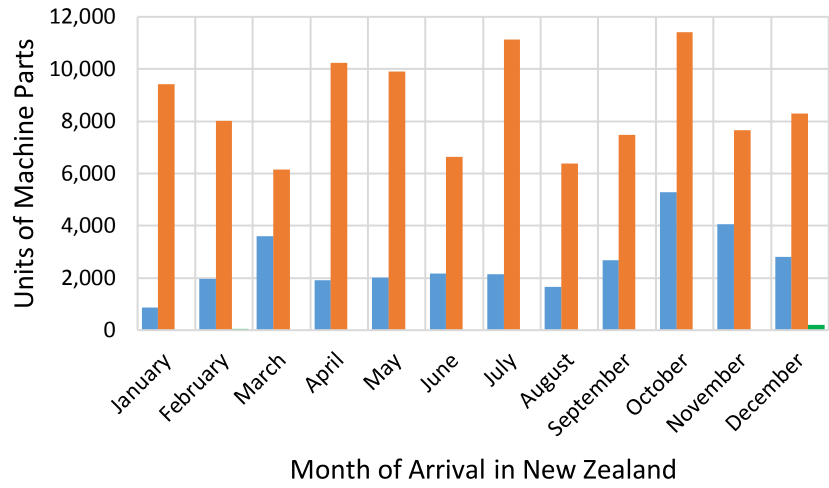


Figure 25: The number of units of machine parts arriving per month in 2015

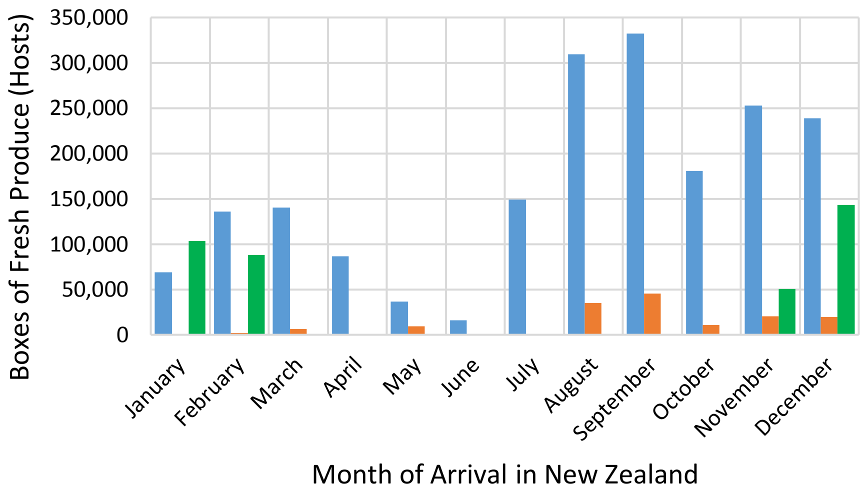


Figure 26: The number of boxes of fresh produce arriving per month in 2015

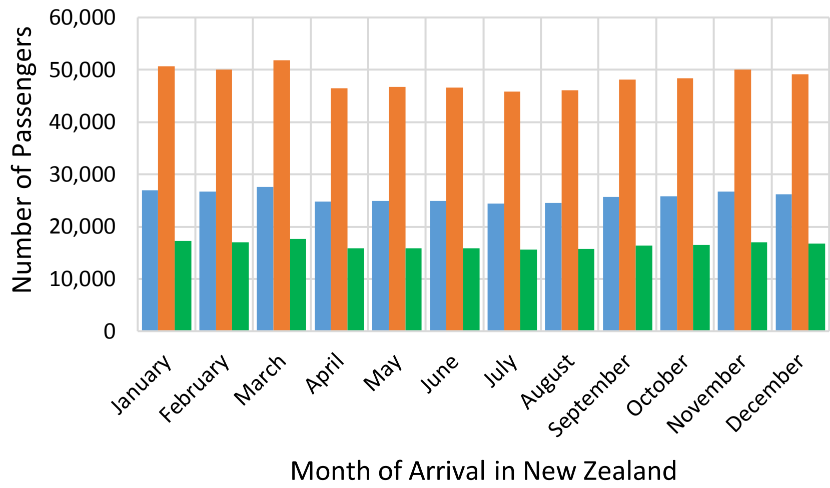
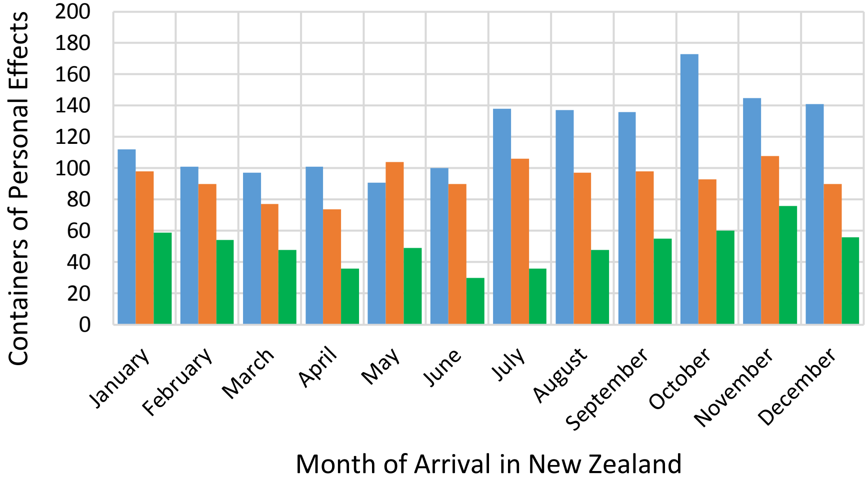


Figure 27: The number of passengers arriving per month in 2015



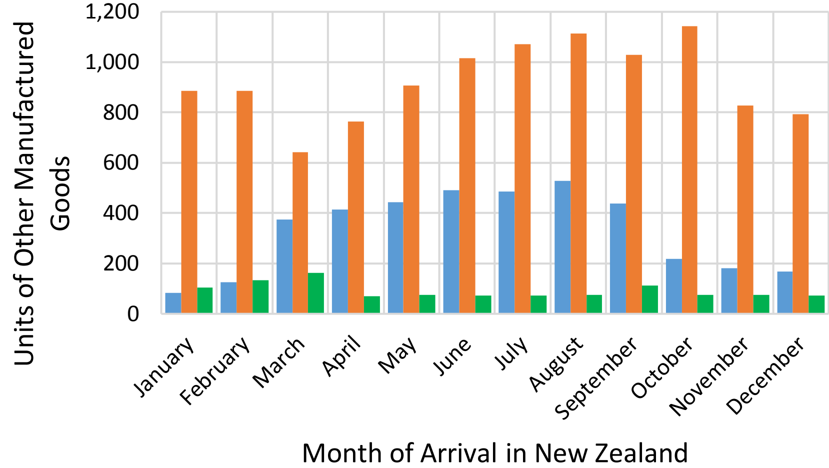


Figure 28: The number of containers of personal effects arriving per month in 2015

Figure 29: The number of units of manufactured goods arriving per month in 2015

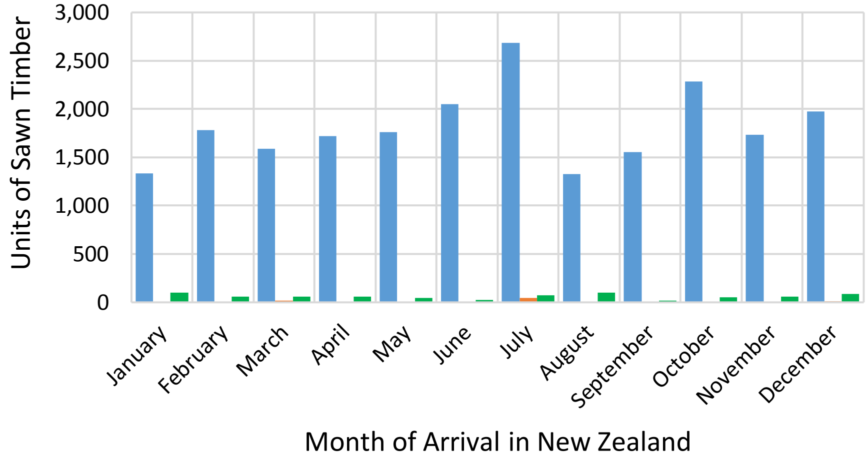


Figure 30: The number of units of sawn timber arriving per PoFA in 2015

Appendix 5: Efficacy data for Methyl bromide on direct exposure to insect species

Treated Insect Name (Common and Scientific)	Treated Insect Family	Treatment Schedule	C/T dose (g.h/m^3)	Efficacy (% mortality) (95% LoC)	Reference
Pink hibiscus mealybug (*Maconellicoccus hirsutus*)	Pseudococcidae	48 g/m^3 for 2 hours at >15°C	90 at 15°C	99.9783% (1 in 4,610) (15°C)	Zettler *et al.* (2002)
Burnt pine longhorn beetle (*Arhopalus ferus*); Golden-haired bark beetle (*Hylurgus ligniperda*); Black pine bark beetle (*Hylastes ater*)	Cerambycidae Scolytidae	59 g/m^3 for 4 hours at >10°C 28 g/m^3 for 4 hours at >20°C	90 at 10°C 90 at 20°C	99% (1 in 100)	Pranamornkith *et al.* (2014)
Melon thrips (*Thrips palmi*); Western flower thrips (*Frankliniella occidentalis*); Flower thrips (*Frankliniella intonsa*)	Thripidae	35 g/m^3 for 3 hours at >10°C 26.5 g/m^3 for 3 hours at >15°C	93 at 10°C 71 at 15°C	99.469% (1 in 188) (10°C) 99.6269% (1 in 268) (15°C)	Misumi *et al.* (2009)
Cowpea aphid (*Aphis craccivora*); Potato aphid (*Macrosiphum euphorbiae*); Green peach aphid (*Myzus persicae*); Cotton aphid (*Aphis gossypii*)	Aphididae	35 g/m^3 for 3 hours at >10°C 26.5 g/m^3 for 3 hours at >15°C	93 at 10°C 71 at 15°C	99.8325% (1 in 597) (10°C) 99.8956% (1 in 744) (15°C)	Misumi *et al.* (2009)
Oriental leafworm moth (*Spodoptera litura*); Cotton bollworm (*Helicoverpa armigera*)	Noctuidae	35 g/m^3 for 3 hours at >10°C 26.5 g/m^3 for 3 hours at >15°C	93 at 10°C 71 at 15°C	99.8442% (1 in 642) (10°C) 99.8227% (1 in 564) (15°C)	Misumi *et al.* (2009)
American serpentine leafminers (*Liriomyza trifolii*); Vegetable leafminer (*Liriomyza sativae*)	Agromyzidae	46 g/m^3 for 3 hours at >10°C 40 g/m^3 for 3 hours at >15°C	123 at 10°C 107 at 15°C	99.6341% (1 in 273) (10°C) 99.7186% (1 in 355) (15°C)	Misumi *et al.* (2009)
Tephritid fruit flies	Tephritidae	48 g/m^3 for 4.5 hours at >10°C 40 g/m^3 for 4 hours at >15°C	141 at 10°C 108 at 15°C	Min 99.99% (1 in 10,000)	Willink *et al.* (2007) Jessup (1994)
Kanzawa spider mite (*Tetranychus kanzawai*); Six-spotted mite (*Eoetranychus sexmaculatus*)	Tetranychidae	48 g/m^3 for 2 hours at >15°C	97 at 15°C	99.9915% (1 in 11,734) (15°C)	Katayama *et al.* (2001)
Tropical citrus aphid (*Toxoptera citricida*)	Aphididae	48 g/m^3 for 2 hours at >15°C	91 at 15°C	99.6939% (1 in 327) (15°C)	Katayama *et al.* (2001)
Citrus psyllid (*Diaphorina citri*)	Psyllidae	48 g/m^3 for 2 hours at >15°C	88 at 15°C	99.9740% (1 in 3,842) (15°C)	Katayama *et al.* (2001)

Appendix 6: Efficacy data for Sulfuryl fluoride on direct exposure to insect species

Treated Insect Name (Common and Scientific)	Treated Insect Family	Treatment Schedule	C/T dose (g.h/m³)	Efficacy (% mortality) (95% LoC)	Reference
Anobiid beetle (*Euvrilletta peltata*)	Anobiidae	30 g/m³ for 18 hours at >22°C	470 at 15°C	~99% (1 in 100) (22°C)	William *et al.* (1990)
Powderpost beetle (*Lyctus brunneus*)	Lyctidae	60 g/m³ for 18 hours at >22°C	1,120 at 15°C	~99% (1 in 100) (22°C)	William *et al.* (1990)
Emerald ash borer (*Agrilus planipennis*)	Buprestidae	60 g/m³ for 24 hours at >15°C 60 g/m³ for 24 hours at >21°C	3,723 at 15.6°C 3,172 at 21°C	98.89% (1 in 90) (15.6°C) 99.88% (1 in 819) (21°C)	Barak *et al.* (2010)
Cryptomeria bark borer (*Semanotus japonicus*)	Cerambycidae	102 g/m³ for 48 hours at >15°C	4,120 at 15°C	95% (1 in 20) (15°C)	Soma *et al.* (1996); Soma *et al.* (1997)
Small cedar longicorn beetle (*Callidiellum rufipenne*)	Cerambycidae	102 g/m³ for 48 hours at >15°C	4,120 at 15°C	95% (1 in 20) (15°C)	Soma *et al.* (1996); Soma *et al.* (1997)
Japanese pine sawyer (*Monochamus alternatus*)	Cerambycidae	102 g/m³ for 48 hours at >15°C	4,120 at 15°C	95% (1 in 20) (15°C)	Soma *et al.* (1996); Soma *et al.* (1997)
Larch ips (*Ips cembrae*)	Curculionidae	102 g/m³ for 48 hours at >15°C	4,120 at 15°C	95% (1 in 20) (15°C)	Soma *et al.* (1996); Soma *et al.* (1997)
Small pine bark beetle (*Cryphalus fulvus*)	Scolytidae	102 g/m³ for 48 hours at >15°C	4,120 at 15°C	95% (1 in 20) (15°C)	Soma *et al.* (1996); Soma *et al.* (1997)
Thuja bark beetle (*Phloeosinus perlatus*)	Scolytidae	102 g/m³ for 48 hours at >15°C	4,120 at 15°C	95% (1 in 20) (15°C)	Soma *et al.* (1996); Soma *et al.* (1997)
Burnt pine longhorn beetle (*Arhopalus tristis*)	Scolytidae	120 g/m³ for 24 hours at >15°C	2,720 at 15°C	94% (1 in 17) (15°C)	Zhang (2006)
Ambrosia beetle (*Xylosandrus germanus*)	Scolytidae	50 g/m³ for 48 hours at >15°C	2,080 at 15°C	20% (8 in 10) (15°C)	Mizobuchi *et al.* (1996); Soma *et al.* (1997)
Ambrosia beetle (*Xyleborus validus*)	Scolytidae	50 g/m³ for 48 hours at >15°C	2,080 at 15°C	20% (8 in 10) (15°C)	Mizobuchi *et al.* (1996); Soma *et al.* (1997)
Ambrosia beetle (*Xyleborus pfeili*)	Scolytidae	50 g/m³ for 48 hours at >15°C	2,080 at 15°C	20% (8 in 10) (15°C)	Mizobuchi *et al.* (1996); Soma *et al.* (1997)
Ambrosia beetle (*Platypus calamus*)	Platypodidae	50 g/m³ for 48 hours at >15°C	2,080 at 15°C	20% (8 in 10) (15°C)	Mizobuchi *et al.* (1996); Soma *et al.* (1997)
Ambrosia beetle (*Platypus quercivorus*)	Platypodidae	50 g/m³ for 48 hours at >15°C	2,080 at 15°C	20% (8 in 10) (15°C)	Mizobuchi *et al.* (1996); Soma *et al.* (1997)

Treated Insect Name (Common and Scientific)	Treated Insect Family	Treatment Schedule	C/T dose (g.h/m³)	Efficacy (% mortality) (95% LoC)	Reference
Termite (*Cryptotermes cavifrons*)	Kalotermitidae	22 hours at >27°C	40.3 at 27°C	99% (1 in 100) (27°C)	Osbrink *et al.* (1987)
Termite (*Kalotermes approximates*)	Kalotermitidae	22 hours at >27°C	65.1 at 27°C	99% (1 in 100) (27°C)	Osbrink *et al.* (1987)
Termite (*Incisitermes minor*)	Kalotermitidae	22 hours at >27°C	66.2 at 27°C	99% (1 in 100) (27°C)	Osbrink *et al.* (1987)
Termite (*Incisitermes snyderi*)	Kalotermitidae	22 hours at >27°C	55.2 at 27°C	99% (1 in 100) (27°C)	Osbrink *et al.* (1987)
Termite (*Neotermes jouteli*)	Kalotermitidae	22 hours at >27°C	43 at 27°C	99% (1 in 100) (27°C)	Osbrink *et al.* (1987)
Termite (*Coptotermes formosanus*)	Rhinotermitidae	22 hours at >27°C	42.5 at 27°C	99% (1 in 100) (27°C)	Osbrink *et al.* (1987)
Termite (*Coptotermes formosanus*)	Rhinotermitidae	2 hours at >??°C	60 at ??°C	99% (1 in 100) (??°C)	Su *et al.* (1989)
Lesser grain borer (*Rhyzopertha dominica*)	Bostrichidae	20 hours at >20°C 20 hours at >25°C 20 hours at >30°C	912 at 20°C 656 at 25°C 415 at 30°C	>99% (1 in 100)	Bell *et al.* (2006)
Foreign grain beetle (*Ahasverus advena*)	Silvanidae	40 hours at >20°C	4,656 at 20°C	>99% (1 in 100)	Bell *et al.* (2006)
Bean weevil (*Acanthoscelides obtectus*)	Bruchidae	24 hours at >20°C 24 hours at >25°C 24 hours at >30°C	1,070 at 20°C 763 at 25°C 480 at 30°C	>99% (1 in 100)	Bell *et al.* (2006)
Red flour beetle (*Tribolium castaneum*)	Tenebrionidae	67.25 g/m³ for 48 hours at >25°C	1,720 at 25°C	99.9% (1 in 1,000) (25°C)	Jagadeesan *et al.* (2015)
Khapra beetle (*Trogoderma granarium*)	Dermestidae	28.7 g/m³ for 3 hours at >17.5°C	88 at 17.5°C	50% (1 in 2) (17.5°C)	Hatyang & Shaozhr (1999)
Red-legged beetle (*Necrobia rufipes*)	Cleridae	24 g/m³ for 48 hours at >23°C	1,000 at 23°C	50% (1 in 2) (23°C)	Phillips *et al.* (2008)
Warehouse moth (*Ephestia elutella*)	Pyralidae	23 g/m³ for 48 hours at >20°C	1,022 at 20°C	94% (1 in 17) (20°C)	Baltaci *et al.* (2009)