Australian Government
Department of Agriculture and Water Resources

cebra
Centre of Excellence for Biosecurity Risk Analysis

Ministry for Primary Industries
Manatū Ahu Matua

CEBRA Report Cover Page

Title, ID, & Output #	*Scoping the value and performance of interventions across the NZ Biosecurity system. 1606E*			
Project Type	*Standard*			
Project Sponsor	*Steve Hathaway*	**DAWR Project Leader/s**	*NA*	
CEBRA Project Leader	*Andrew Robinson*	**NZ MPI Project Leader/s**	*Christine Reed*	
Project Objectives	*The project objectives are:* • *Identify an approach and high-level framework to assess the proportional contribution of biosecurity layers to New Zealand's biosecurity performance, including one or more metrics of value.* • *In two or more case studies, develop estimates of the proportional contribution using the framework and any available data.* • *Identify any ancillary benefits from analysis of end-to-end biosecurity regulation data.*			
Outputs				
CEBRA Workplan Budget	**Year 2016-17**			
	$81,000			
Project Changes	*Nil.*			
Research Outcomes	*This interim report provides a rapid prototype of a draft modelling approach that can be used to try to assess the impact of different activities undertaken by MPI and other parties upon the biosecurity risk presented by identified pests. The modelling approach is applied to two pests, namely brown marmorated stink bug and Queensland fruit fly. It is not intended to be read as a definitive analysis of either pest.* *The project applies a simple model structure to the biosecurity risk presented by each pest and estimates the individual and collective impact of activities that are undertaken by MPI and other parties upon the exposure to biosecurity risk presented by the pests. Estimation of the various factors is done by a combination of reference to MPI data holdings and expert elicitation.* *The progress to date on the exercise suggests that reasonable generalizations about the performance of the system can be made from a simple model and expert elicitation, although further work is required for the case studies documented herein before they could be used to guide robust discussions about the system.*			
Recommendations	*1. That MPI should note the progress of this project and provide feedback on the general direction and the specific outcomes.* *2. That the project should develop means for handling and reporting uncertainty and information source, as proposed in the 1606E project extension.* *3. That the project should develop means of handling multiple pests simultaneously, and aggregating across pests, as proposed in the 1606E project extension.* *4. That the project should critically assess the structure and representation of post-border activities before assessing their contribution to impacts.*			
Related Documents	*Nil*			
Report Complete				

CEBRA Use only	Received by:	Date:
	CEBRA / SRC Approval	Date:
	DAWR/MPI Endorsement ( ) Yes ( ) No	Date:
	Report published	Date:

CEBRA Project 1606E:

Scoping the value and performance of interventions across the NZ Biosecurity system

Final Report

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18 June 2018

Executive Summary

This interim report provides a rapid prototype of a draft modelling approach that can be used to try to assess the impact of different activities undertaken by MPI and other parties upon the biosecurity risk presented by identified pests. The modelling approach is applied to two pests, namely brown marmorated stink bug and Queensland fruit fly. It is not intended to be read as a definitive analysis of either pest.

The project applies a simple model structure to the biosecurity risk presented by each pest and estimates the individual and collective impact of activities that are undertaken by MPI and other parties upon the exposure to biosecurity risk presented by the pests. Estimation of the various factors is done by a combination of reference to MPI data holdings and expert elicitation.

The progress to date on the exercise suggests that reasonable generalizations about the performance of the system can be made from a simple model and expert elicitation, although further work is required for the case studies documented herein before they could be used to guide robust discussions about the system.

Recommendations

1. That MPI should note the progress of this project and provide feedback on the general direction and the specific outcomes.
2. That the project should develop means for handling and reporting uncertainty and information source, as proposed in the 1606E project extension.
3. That the project should develop means of handling multiple pests simultaneously, and aggregating across pests, as proposed in the 1606E project extension.
4. That the project should critically assess the structure and representation of post-border activities before assessing their contribution to impacts.

Acknowledgements

The authors are grateful to the subject-matter experts who contributed their time to the elicitation exercise, namely Jo Berry, George Gill, Barney Stephenson, Dave Voice (all from MPI); Lloyd Stringer (Plant and Food); and Bernie Dominiak (NSW DPI). We also appreciate very thoughtful review comments from Ken Glassey (MPI) and two anonymous reviewers.

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Introduction

The Ministry for Primary Industries (MPI) describes New Zealand's biosecurity system as comprising actions that may be classified into seven layers, namely:

1) International plant and animal health standard development;
2) Trade agreements and Bilateral Agreements;
3) Risk assessments and Import Health Standard development;
4) Border interventions;
5) Surveillance;
6) Readiness and response; and
7) Pest management.

We will split the sixth layer into two (Readiness *and* Response) for a total of eight layers. A detailed description is provided below. The biosecurity system faces increasing pressure from significant increases in goods and passengers, changing pathways and types of goods. With this increasing pressure, all layers of the system need to work together cost-effectively to maximise the reduction of biosecurity risk to New Zealand under sharply constrained resources.

In order to strategically increase the efficiency of biosecurity investment and to identify opportunities for substantial improvement, MPI would need to determine the contribution of each layer towards biosecurity effectiveness. Presently, there is no framework or process available to evaluate the value of biosecurity activities implemented at intersecting sites across the biosecurity system matrix. Without comparative knowledge on the likely effectiveness and costs of activities and control measures, risk management decisions on measures and allocation of resources at different "nodes" cannot be systematically evaluated.

This project seeks to identify a high-level framework or approach that would significantly improve risk management decisions and resource allocation throughout the biosecurity system (from pre-border to pest management) by applying a systematic risk / return approach and evidence-based analysis. The project focuses on estimating the proportional value of biosecurity activities in two case studies, brown marmorated stink bug and Queensland fruit flies and, in order to support the scoping exercise.

A particular challenge when modelling a complex and large system such as a biosecurity system is obtaining data of sufficient breadth, depth, and quality, to inform the model. Even the best possible biosecurity system will not have all the needed information; collecting and curating a sufficient data resource is well beyond the remit of a regulatory body. Two choices remain: first, to limit the model so that it only needs readily available and trusted data, and second: to blend data with carefully elicited opinions of experts.

The project leverages the considerable detailed information that is available within MPI, such as interception, incursion and surveillance data, to help build feedback on system performance back into the higher-level risk return framework. However, due to input data insufficiency, we augmented them using expert opinion.

Methodology

The approach we take is straightforward but exhaustive. The steps are as follows.

1) Considering a pest, we identify all the pathways by which the pest might enter New Zealand, for example, air passengers, mail, or certain kinds of cargo. We may do this by examining interception records or by asking experts.
2) For each pathway, we identify the unit of intervention, which is defined as the level at which biosecurity decisions are typically made. For example, in used motor vehicles the unit is a car or motorbike. For cut flowers the unit is a consignment.
3) We determine the number of units of intervention arriving at the border per unit of time, typically using Customs databases.
4) We then identify all the measures that are in place that may affect the exposure of the pathway to the pest – for example, the imposition of pest-free areas, border inspection, and so on. We may need to stratify the pathway by measures – for example, international passengers experience different measures depending on the country that issued their passport.
5) We estimate the multiplicative impact each measure has upon the exposure on the pathway – the impact is a number from 0 (no impact) to 1 (completely stops all exposure). We typically use expert elicitation for this estimation, and elicit uncertainties.
6) Then for the pest we define a minimal propagable unit, which is the minimum number of the pest at a given life stage that is required for a successful incursion.
7) We estimate the raw, baseline contamination of each pathway to the pest, that is, the rate per unit at which a propagable unit of the pest would arrive on that pathway if no measures were in place.
8) We compute the raw pathway *exposure* as the product of the baseline contamination and the number of units of intervention per unit time. This could also be considered a counterfactual or 'baseline' exposure.
9) Then to estimate the residual exposure of the pathway, we multiply the raw pathway exposure by each of the relevant measure impacts subtracted from 1. For example, if the raw pathway exposure were 0.9 and the impacts of two measures were 0.2 and 0.1, then the residual pathway exposure would be 0.9 * (1 – 0.2) * (1 – 0.1) = 0.648.

System Model

MPI uses a model framework comprising four pathways (namely, cargo, mail, passengers and vessels) and 23 sub-pathways. These are:

- Cargo
    - Animal Germplasm
    - Animal Products
    - Biological Products
    - Containers
    - Fresh Produce and Cut Flowers
    - Live Animals
    - Nursery Stock
    - Plant Products
    - Seed and Grain
    - Vehicles and Machinery
    - Wood and Wooden Products
- Mail
    - Articles
    - Bulk
    - Express
    - Letters
    - Parcels

- Passengers
    - Cruise, High Risk
    - Cruise, Low Risk
    - Air, High Risk
    - Air, Low Risk
- Vessels
    - Air, Fully Cleared
    - Air, Under Surveillance
    - Marine, Fully Cleared
    - Marine, Under Surveillance

According to MPI's "Biosecurity System description and key performance indicators" (MPI 2014), mitigatory actions that are undertaken on the pathways are categorise into eight 'layers' that comprise the biosecurity measures and activities of New Zealand's biosecurity system, including

- **International** Plant & Animal Health **Standards** ("International Agreements" in CEBRA report 1606E)
- **Trade Agreements & Bilateral Arrangements** ("Bilateral Agreements" in CEBRA report 1606E)
- **Risk Assessment & Import Health Standards** ("Import Health Standards" in CEBRA report 1606E)
- **Border Interventions** ("Border" in CEBRA report 1606E)
- **Surveillance** ("Surveillance" in CEBRA report 1606E)
- **Readiness** ("Readiness" in CEBRA report 1606E – NOTE: MPI (2014) considers Readiness & Response together as one layer)
- **Response** ("Response" in CEBRA report 1606E – NOTE: MPI (2014) considers Readiness & Response together as one layer)
- **Pest Management** ("Pest Management" – NOTE: MPI (2014) refers to "Pest & Disease Management" but IPPC 'pest' to include pathogens/disease)

Following we provide MPI's description of each 'layer' and an interpretation (by MPI and/or the authors of this report) of what actions it entails, as a 'glossary'.

1. **International** Plant & Animal Health **Standards**
   "Developing international standards and rules under the WTO SPS Agreement"

    - International Standards for Phytosanitary Measures (ISPMs, e.g., ISPM 15 "Regulation of wood packaging material in international trade")

2. **Trade Agreements & Bilateral Arrangements**
   "Negotiation, agreements and processes for future biosecurity cooperation and trade"

    - Agreements and arrangements between two countries (i.e., between New Zealand and a specific trading partner) that are in addition to or beyond any international agreements or general international trade, biosecurity and plant health agreements.

3. **Risk Assessment & Import Health Standards**
   "Identification of risk and specification of requirements for people and goods coming into NZ"

    - Risk assessment and risk analysis have been variously defined under different contexts, and in some cases are used synonymously. In this instance risk assessment is used as per ISO 31000 (2009), namely risk assessment includes risk identification, risk analysis, and risk evaluation.

- The meaning of ‘import health standard’ (IHS) is defined according to section 22 of the Biosecurity Act 1993. An import health standard (HIS) describes the “phytosanitary requirements that must be met for imported [goods] to be given biosecurity clearance into New Zealand.” IHS are “developed under the requirements of the [New Zealand] Biosecurity Act (1993) and in regard to New Zealand’s obligations under the International Plant Protection Convention (1997).” (representative text from MPI 2017, Import Health Standard: Sawn Wood from All Countries).

4. **Border Interventions**
   “Educating and auditing to encourage compliance. Inspecting to verify compliance and taking action to manage non-compliance”

   - Border interventions include measures and actions implemented by MPI or requested of importers by MPI. These may include inspection to verify freedom from unwanted organisms and for compliance with import health standards, etc., treatments (fumigation, heat treatment, etc.) at the border, and the application of any other interventions that are applicable at the border.

5. **Surveillance**
   “General and targeted programmes to detect harmful pests and diseases”

   - Surveillance includes (i) general ‘high-risk site surveillance’ in areas that receive higher volumes of imported goods and travellers by searching for unwanted organisms and symptoms, (ii) targeted surveillance using traps with lures specific for organisms such as gypsy moth and fruit flies, and (iii) general surveillance by industry staff and members of the public.

6. **Readiness**
   “Regular testing of the biosecurity system’s capability to respond”

   - Preparedness in terms of the availability of a plan and tools enabling effective responses to detections of incursions and newly established populations.

7. **Response**
   “Responding to detected harmful pests and diseases”

   - Incursion response with the aim of eradication or containment.

8. **Pest Management**
   “National, regional and industry actions to manage established pests and diseases”

   - The use of measures to mitigate and minimise pest damage, manage pest populations, and minimise the risk of pest presence on products for domestic consumption and especially for export. Measures include the use of pesticides, biological control, integrated pest management, and others.

Australia’s RRRA

The Department of Agriculture and Water Resources (DAWR) developed a Risk Return Resource Allocation model (RRRA) as a guiding mechanism for biosecurity investment. This effort can be used as an example of the kind of study that MPI envisions. The RRRA is a probabilistic model representation of a substantial portion of the biosecurity system, built using expert elicitation and Bayes nets (see below). RRRA covers 9 main pathways and about 60 sub-pathways, and 50 organisms or organism types. It has recently been used, for example, to forecast the likely effects on biosecurity risk of increases in pathway volumes over the next decade under different response scenarios.

The RRRA development process began before 2010 with a significant, two- to three-year Price Waterhouse Coopers (PWC) consulting project to identify the risks and capture them in a simple pathway model. Subsequently, the Department devoted considerable effort to reframing the problem, and adopted Bayes Nets as the key modelling approach. An ACERA review in 2012 recommended that the Department continue the Bayes Net development, and that expert elicitation workshops be used to obtain usable values for the many parameters required to run the model. These workshops were carried out by CEBRA on behalf of the Department in 2013 and 2014.

RRRA was launched in 2017 and so far has been used mainly for strategic scoping exercises, such as assessing the effect upon biosecurity risk of a forecast doubling of passenger arrival numbers. We are unaware of tactical applications of the RRRA model to date.

The investment into RRRA has been considerable by DAWR, involving an initial multiple million dollar project with PWC, a full-time team of 5-10 departmental people for at least five years subsequently, and numerous expert elicitation workshops provided by CEBRA. The response to the RRRA has been mixed. For example, the draft Inter-Governmental Agreement on Biosecurity Review (IGAB 2016) of Australia's biosecurity system recommended that RRRA be extended to include all jurisdictions and their investments, however, the submission from the West Australian Biosecurity Council commenting upon the IGAB review was critical of RRRA and its application.

Bayes Nets

Bayes nets are a special kind of model that are commonly represented by directed acyclic graphs, DAGs[1]. These graphs comprise nodes, which represent random variables (such as the number of contaminated consignments of oranges that arrive each year), and one-directional relationships between the nodes that report how the source node affects the receiving node. The graphs cannot include loops, and the relationships are always unidirectional, hence the 'directed acyclic' label.

Bayes nets are ideal for modelling the outcomes of certain kinds of complex and uncertain systems because they provide a representation for and means of handling uncertainty and natural variation and permit the modular division of large and complicated systems into smaller and simpler sub-systems. Bayes nets also provide an elegant way to blend real-world observations with opinion or guesses, that is, they provide a mechanism for probabilistic calibration of the opinions using measured data. Bayes nets have been applied successfully in modelling biosecurity systems (see, e.g., Jamieson et al. 2013, and Nicholson and Korb 2017).

Model Representation

The draft model representation for this project follows the RRRA approach in some regards, but at a substantially smaller scale in terms of the level of detail at which processes are captured. Our approach

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[1] An unfortunate acronym for Australian and New Zealand modelers.

is not formally a Bayes net, but uses an accountancy approach in which estimated relative raw risks are reduced by interventions or actions. We chose a model framework comprising four pathways (namely, cargo, mail, passengers and vessels) and 23 sub-pathways, based on a framework provided by MPI (see Figure 1.1). We identified the mitigatory actions that are undertaken on the pathways, and then classified these mitigatory actions in to one of eight 'layers' or types of actions that comprise New Zealand's biosecurity system, ranging from international agreements to pest management (namely International Plant and Animal Health Standards, Trade Agreements and Bilateral Agreements, Risk Assessments and Import Health Standards, Border Intervention, Surveillance, Readiness, Response, and Pest Management; Figure 1.1).

We developed representations of the impacts of these actions on the exposure to the pest along the pathway and aggregated them into the eight layers. Each action is represented by the relative amount of exposure that it impedes, ranging from 0 to 1. An action with effect 1 removes all of the exposure on the pathway. In this way, we can interpret the values as being probabilities, which provides a straightforward mechanism for aggregating across actions.

We assumed that the actions take effect independently, which is expedient but not true. For example, by reducing the pest load on a consignment, off-shore fumigation may make on-shore inspection less efficient, in that the same amount of on-shore inspection will result in interception of fewer pests or contaminated items. Furthermore, the effect of readiness for an incursion response is only possible if the response takes place; readiness without a response is much less valuable. Other combinations, such as the imposition of a pest-free area and mandatory on shore treatment, are a better match for this assumption. This assumption enabled us to easily roll up the effects of multiple actions into a single number.

We represented the raw, pest-specific exposure that each pathway presents by multiplying the pathway volume (the number of consignments) and the raw rate at which the consignments on the pathway carry enough of the pest to present at least a moderate threat of incursion. The raw rate is the assumed rate that the pest would arrive and invade, per consignment, if no controls or activities were imposed, that is, a baseline. The raw rate is not the same as the experienced rate, i.e., the rate at which consignments are detected as having the pest at the border. The difference is for two reasons: first, commonly, controls and activities are imposed, and second, the experienced rate is less because border inspections are not perfect, and pests may slip through the border. Making this distinction was particularly important during the subsequent expert elicitation exercise, as it is a reasonably unfamiliar way to think about the risk of pathway. Our intention was to be able to represent the effect of the measures and activities that are currently in place upon the exposure to develop a more complete picture of the pathway.

These pathways and actions rolled up to layers can be represented in a matrix, such as Figure 1.1. In this representation, the open nodes of the matrix represent the effect of the mitigating actions, ranging from 0 to 1 – the bigger the node, the larger the effect upon pest exposure. The left-most column of closed circles represents the relative raw pest-specific exposure of each sub-pathway – the baseline. On the right is another column of closed circles, which represents the net exposure of the pathway, after all mitigatory actions have been taken into account, again, the larger circles represent larger pest exposures. Finally, in the centre of the diagram is a column of solid dots representing the rolled-up post-border exposure. The scales for the three exposure columns are all relative to the highest raw exposure overall, and do not represent a particular time period. The scales for the other columns are absolute.

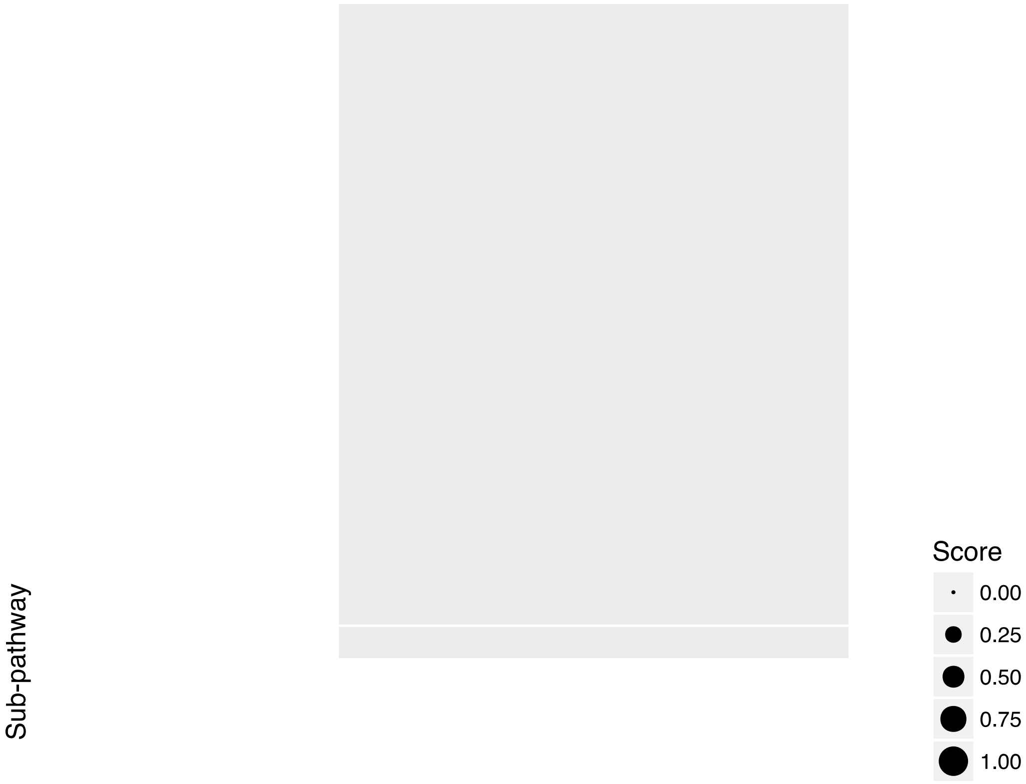

Figure 1.1: Example sub-pathway graph for an anonymous pest (brown marmorated stink bug). Each row represents a sub-pathway, gathered into blocks that represent pathways. The columns with solid symbols represent the raw approaching (left), post-border (centre), and residual (right) exposures by the size of the symbols (large is high, all relative to largest raw approaching exposure). The internal columns show the mitigating effects of the activities taken under each layer of the system to the relevant sub-pathway, using open symbols (large is high). The scales for the three exposure columns scales are all relative to the highest raw exposure overall, so do not represent a particular time period, whereas the scales are absolute for the other columns.

Choosing a hierarchical scale for an exercise like this is a trade-off between numerous factors, including utility, data availability, interpretability, and simplicity. There is no single correct solution; these in turn depend on the uses to which the model will be put, and the decision-maker's tolerance for ambiguity and uncertainty. We used two case studies to try to develop a sense of the inherent challenges for MPI's biosecurity system. An example of the trade-off is whether to divide the sub-pathways in Figure 1.1 into further, more detailed pathways. On the one hand, it is attractive to distinguish between fresh produce and cut flowers when assessing the risk of Queensland fruit fly, but on the other hand, dividing air passengers into pest-sensitive risk groups runs the risk of introducing substantial overhead that may not be useful. Case studies provide motivation and simple examples that can be used to test the quality of the model system.

Defining and Finding Parameters

Although they are simple in structure, the accounting models that we have described are quantitative models of the biosecurity system. These models comprise equations that are made up of parameters and rules that describe how to relate them. Briefly, our model says that for a given pest and pathway, the residual exposure is the product of the pathway volume, the raw infestation rate (per unit of volume), and the mitigatory effects of all the actions taken on the pathway.

$$RE_p = V_p I_p \prod_{i=1}^{7} L_{pi}$$

Each of these quantities listed is a parameter, for which we must have an estimate. Some of the parameters are conceptually straightforward and may even be measurable, for example, the volume of units on some pathways such as air passengers, and the effectiveness of treatments such as fumigation against a given pest. Others will be much trickier to grasp and infeasible to formally measure, for example, the impact of measures taken offshore upon the exposure of the pathway, such as the imposition of penalties for non-compliance upon air passengers, or the implementation of auditing under bilateral arrangements. Nonetheless, all are needed.

There are several points on the pathway where gross measures may be used to try to calibrate, even loosely, the parameter estimates, namely interceptions at the border, incursion records, and eradication outcomes. Bayes nets, as mentioned before, provide mechanisms for the seamless blending of opinion and data. However, it is unlikely to be worth a formal exercise of model fitting because the model is statistically over-parameterized, meaning that there are too many parameters relative to the pieces of information that area available. This is like saying that the model is ambiguous: there are too many potential causes for the observed patterns. That does not necessarily affect its operational utility.

Scope

We present the case studies as examples of the approach that we advocate for pathway analysis. The approach is modular, so if analysts prefer to include extra interventions, or to alter the assumptions we made, such alterations are easy to perform and compare.

Case Study 1: Brown Marmorated Stink Bug

Background

Halyomorpha halys Stål (Hemiptera: Pentatomidae), commonly known as the brown marmorated stink bug (BMSB), is native to northeast Asia and a successful invader in North America and several European countries (Rice et al. 2014). It has a very wide host range and damages a range of horticultural and agricultural and ornamental plants. BMSB is considered a serious pest, and damages to apple alone during an outbreak in the eastern USA in 2010 amounted to losses valued at US$37 million (American/Western Fruit Grower 2011). In addition, it is well-known as being a 'nuisance' because it enters homes and other buildings in the search for overwintering sites (Rice et al. 2014).

Because of the high profile of this successful invader and the damages it causes, and because introduction pathways are known to exist, its potential establishment in New Zealand is a concern. A risk analysis by MPI considers the likelihood of establishment and spread to be high, the economic consequences of establishment as 'likely to be moderate to high', with only low to moderate environmental and socio-cultural consequences are likely to be moderate (Duthie et al. 2012). From 2005 to January 2017, more than 1,000 BMSB specimens had been intercepted at New Zealand's borders and at transitional facilities, mainly with vehicles and machinery, timber, and, to a lesser extent, other pathways (MPI data, Catherine Duthie, pers. comm.). However, the effort to detect BMSB in imports has increased greatly in recent years.

BMSB was chosen for this case study because it has received considerable attention by MPI and, consequently, some information exists about its abundance in pathways, infestations of different commodities from various countries and the relative effectiveness of mitigation measures.

Approach

For this case study, we considered the occurrence of BMSB in the four pathways (namely: cargo, mail, passengers and vessels) and 23 sub-pathways based on a framework provided by MPI (see Figure 2.1). In order to estimate the occurrence upon pathways and the effects of mitigatory actions undertaken on the pathways, we used information from surveys, interception data and expert knowledge. We allocated each mitigatory action to one of nine 'layers' or types of actions inherent in New Zealand's biosecurity system, from risk assessment to pest management (Figure 1.1). The reference year we chose for this study was 2015, which were the data available at project inception. Therefore, where possible, we used data for 2015. Intervention changed in 2016, particularly around sea containers from USA and Italy, but these interceptions were incorporated (see below).

Interceptions of BMSB (obtained from Catherine Duthie, MPI, in January 2017) were summarised according to the higher-level pathways and the sub-pathway categories that were provided by MPI (Table 2.1). In several cases it was not clear whether interceptions occurred with containers as such or with the cargo in containers, and it was often not possible to ascertain this based on the notes and other information provided with the interception records. Therefore, we grouped all interceptions with containers into the containers sub-pathway unless interceptions were clearly associated with any of the other main sub-pathways including vehicles and machinery, wood and wooden products, and passengers. Furthermore, we did not distinguish between loaded and empty containers. With regard to BMSB, empty containers are not relevant at present because NZ imports empty containers mostly from the Pacific Islands but very few empty from the US and Europe and other locations where BMSB occurs.

The contrast between loaded and empty containers could be teased out further if this was of interest, but it would not affect infestation rates of containers from countries with BMSB.

The expanded QuanCargo data summary suggested that the total number of imported vehicles and machinery totalled 24,912 units (new and used vehicles and a variety of 'machinery' imports. A report from 2012 (Duthie et al. 2012) indicated that there were approximately 80,000 vehicles imported in that year. Consequently, we queried other data sources. The NZ Transport Agency (NZTA) publishes data on the number of vehicles registered each year. For 2015 the NZTA data of 151,258 vehicle registrations appeared to be more consistent with the 2012 records. Eventually we learnt about the availability of vehicle import data from New Zealand Customs, which we used for the final analysis.

Pathway volume and relevance of pathways. Pathways and sub-pathways were assessed regarding their potential relevance for international movements of BMSB that could lead to an introduction based on knowledge from interception data, survey finds, and other MPI information (see below). Furthermore, we considered the potential mechanism of association of BMSB with particular sub-pathways and transported commodities, given the insect's biology and behaviour. For details see the sheet "pathway volume" in the data file "BMSB template.xlsx". Pathway volumes were obtained from several sources including MPI's QuanCargo database, NZ Customs, Statistics NZ data, New Zealand motor vehicle registration statistics, and other sources, as explained in Table 2.2 below and in the "pathway volume" data sheet.

Exposure rates. To determine the potential number of BMSB moved on particular sub-pathways, 'infestation rates' of each relevant sub-pathway were calculated or estimated based on interception rates (MPI data, Table 2.1 below) and assumed slippage rates (based on MPI data and expert estimates). The exposure rates provided are 'raw', prior to the effects of any border biosecurity actions. We considered both overall (country-independent) and country-specific contamination rates, primarily based on information from interception data. For example, there were 242 and 225 BMSB interceptions with vehicle and machinery imports from Italy and the USA, respectively. However, because far more vehicles are imported from the USA (6503 vehicles in 2015 according to Customs NZ data) than from Italy (288 vehicles in 2015, which may have not included off-road vehicles such as tractors), the contamination rate for imported vehicles from Italy is considerably higher than for the USA. For details see the "contamination calculation" and "pathway contamination" sheets in the data file "BMSB template.xlsx" and Table 2.3.

In order to capture interceptions across all known pathways, we used all interception data available at the time when the analysis was completed (from 2005 to January 2017); however, the number of interceptions was scaled to an annual rate (for 2015) to ensure this was consistent with the overall approach of using 2015 as the focus year for this study. It has been suggested that pathways where aggregations of BMSB occur (e.g., with vehicles where often multiple BMSB are found on a single vehicle) are more important than pathways where smaller numbers or individual BMSB are found (such as passengers' luggage) because aggregations have a greater likelihood of establishment. This is true to some extent although several individual BMSB could still be released in relative proximity and form small aggregations. Therefore, we have decided not to discount the risk associated with individuals.

Mitigation measures were considered to be either '**pathway-specific**' or '**generic**' actions, the former mainly pre-border or at the border, and the latter mainly post-border. Because particular measures are not equally effective against different target organisms, both pathway-specific and generic actions were assessed in terms of their likely effectiveness for BMSB, mostly based on informed expert estimates (by Mike Ormsby and Eckehard Brockerhoff), with a best guess, lower and upper plausible values, and an estimated level of confidence.

Pathway-specific actions. The following 'pathway-specific' actions were included in the case study (Table 2.4)

- For passengers we considered border inspection, reporting by members of the public ("public.awareness.reporting"). Canine surveillance was assumed not to take place or be effective for BMSB because detector dogs are not targeting this species. We distinguished between high-risk and low-risk passengers (i.e., those from origins where BMSB is present or not), but this was not applied to any of the measures because it is unlikely that any of these have a substantial effect on BMSB arrivals. To our knowledge, any targeting of high-risk passengers would not have a large effect because passport holders of many countries where BMSB occurs would not be considered high-risk passengers. Conversely, low-risk passengers, including NZ and Australian passport holders, arriving from countries where BMSB occurs, are probably not undergoing any special scrutiny. Therefore, we did not add a specific targeting action for passengers regarding BMSB.
- For cargo, we considered a general area-freedom measure as well as a general cargo inspection measure applicable to all sub-pathways. Furthermore, we considered pathway-specific actions for the sub-pathways containers, vehicles and machinery, and wood packaging. For containers, we included two specific measures, inspection and targeting. For wood packaging, we assumed that container inspection would also be effective to some extent, given that approximately 50% of loaded containers carry wood packaging items. Although most wood packaging is treated according to ISPM 15, this was assumed not to have any effect on BMSB because treatments prescribed by ISPM 15 are carried out as part of the manufacturing process, prior to when BMSB colonisation would occur.
- For vehicles and machinery, we included border inspection and offshore treatment as measures.
- No specific measures were assumed for wood and wooden products, although this may need to be amended upon review.
- For mail, all inspection methods were bundled in a single inspection measure.
- Likewise, for vessels, only inspection was included.

Generic actions. The following generic actions were considered in terms of their effectiveness for BMSB: Passive surveillance by members of the public responding to BMSB awareness campaigns (e.g., public reporting of post-border detections), surveillance specifically for BMSB (which, to our knowledge, is currently not being carried out and therefore was given zero effectiveness), readiness in terms of infrastructure (i.e., tools, etc.), response in terms of the availability of a treatment plan specific for BMSB. Furthermore, we considered the effectiveness of pest management measures for BMSB.

Costs and impacts. Although we envisaged the inclusion of costs of measures as well as impacts of BMSB (in terms of damages), this part of the case study was not completed because no values were available at this point without further work (such as a BMSB-specific expert elicitation exercise and an updated economic impact assessment).

Results and Discussion

Information about most interceptions of BMSB was plausible in terms of the origins of cargo, passengers or vessels (Table 2.1). Where an origin was apparently erroneous, such as BMSB from Malaysia (where BMSB does not occur, to our knowledge), we assigned these interceptions to the group of 'unknown' origin, as presumably the pest has transhipped. Vehicles and machinery, containers, and wood and wood products were the main sub-pathways associated with BMSB interceptions. Most interceptions were associated with the USA and Italy as well as other European countries where BMSB invaded recently (Table 2.1). Passengers and marine vessels also scored interceptions of more than 30 BMSB each. Fewer BMSB were intercepted with consignments that were assigned to other sub-pathways such as mail and wood packaging.

Although these interception records are consistent with our understanding of the biology of BMSB and the role of different pathways in international movements of diapausing BMSB, it should be noted that there are likely to be large differences in survey effort among sub-pathways. It should also be noted that the rate and intensity of inspections is rarely recorded, and it is not known how many inspections took place that found no evidence of BMSB (i.e., negatives are not recorded). Therefore, these interception data should not be seen as an exact indication of infestation rates but rather as indicative of the relative importance of particular sub-pathways and origins. Nevertheless, this information is critical for our understanding of which pathways may facilitate invasions of BMSB and the effectiveness of mitigatory actions. There is scope for improving the way in which these interceptions are recorded to enable better matching of sub-pathways among different type of data and better statistical analysis (see the Data problems section below).

Table 2.1. Interceptions of BMSB as of January 2017, categorised by sub-pathway and country of origin

Sub-pathway	Origin	Sum of alive and dead BMSB
Containers	China	2
	Hungary	5
	Italy	193
	Japan	4
	Slovenia	30
	South Korea	6
	Taiwan	1
	Unknown	6
	USA	107
Fresh produce	Italy	5
Mail - express	USA	4
Mail - parcel	USA	4
Passengers	China	3
	South Korea	1
	Switzerland	1
	Unknown	1
	USA	32
Unknown pathway	Unknown	2
	USA	3
Vehicles and machinery	Italy	242
	Japan	19
	Korea	1
	South Korea	1
	Unknown	10
	USA	225
Vessel - air	Japan	1
Vessel - marine	Hong Kong	1
	Unknown	35
	USA	5
Wood & wooden products	China	48
	Italy	4
	USA	69
Wood packaging	Italy	4
	USA	2
Grand total	**all**	**1077**

Information about pathway volumes was more difficult to access than anticipated. We assumed this would be the simplest data to obtain, and initially we relied on a query of QuanCargo data to address all our information needs about pathway volumes. It turned out to be difficult to extract actual vehicle numbers from QuanCargo because the database contains a mixture of consignments that often don't provide the actual number of vehicles but only the number of lines, which had to be queried individually. We carried out a manual compilation of vehicle numbers and added these up; however, the resulting total number of vehicles and machinery was unexpectedly low and inconsistent with earlier data (for previous years).

For 2015, the Customs data indicates that nearly 300,000 vehicles were imported (possibly only on-road vehicles), and we relied on these data for our analysis (Table 2.2). This example highlighted that the QuanCargo and NZTA data were not suitable for our purpose. These difficulties are explained in more detail below in the Data problems section.

Table 2.2. Pathway volumes for the main pathways known to be relevant for BMSB

Sub-pathway	Volume	Volume Notes
Fresh Produce & Cut Flowers	21,500 consignments	Based on QuanCargo (2015) including **17,990** consignments of fresh produce; **3,455** consignments of cut flowers and stems of *Dracaena*, etc. There is uncertainty whether all consignments are entered in QuanCargo. Consignments vary considerably in size, and they are not an ideal measure of quantification.
Wood & Wooden Products	17,000 consignments	Based on QuanCargo (2015). **17000 consignments** (= 29000 lines) of wood and wooden products, including ca. **8000 consignments** from BMSB origins (i.e., native and main invaded regions which are origins of interceptions), mainly furniture. There is uncertainty whether all consignments are entered in QuanCargo.
Wood Packaging	300,000	Estimate based on the average of about one in two sea containers having wood packaging (WPM). Note that QuanCargo data can't be used; for 2015 QuanCargo lists only 1688 imports of WPM (not 300,000) because only WPM infested with insects is captured.
Vehicles and Machinery	293,332	Number of individual vehicles, not consignments, based on NZ Customs data. However, this includes only vehicles (not machinery). See more detailed information in the text. [Note that QuanCargo data accounts for less than 10% of these imports, and each line needs to be queried to determine the actual number of vehicles.]
Containers	600,000	There are a number of statistics on container movements. These vary in terms of how containers are categorised, either by 20-foot unit equivalents (TEUs), and may or may not include coastal shipping as well as international arrivals. For lack of better data, we used the figure of approximately 600,000 containers (of all sizes), which is close to the actual value.
All Passengers	5,400,000	Total passengers arriving is 5.4 M (including residents) according to Stats NZ (2015 numbers). Here we don't distinguish between high-risk and low-risk passengers, for BMSB and generally. However, in some cases it may be important to consider the differential effectiveness of actions. Note: ca. 850,000 arrivals were passengers from BMSB countries and 4.55 million from non-BMSB countries (presumably by passport and not by airport of departure).

Despite these difficulties with QuanCargo data, we relied on this as a source of pathway volume data for most other sub-pathways (Table 2.2) because this was the approach we chose initially and had already compiled most of the required information. Once we were aware of these difficulties in interpreting QuanCargo data, we approached the Data Analysis group of MPI for further assistance but there was insufficient time to revisit all sub-pathways before the report was due for completion.

Given these constraints, we dealt with most sub-pathways on a 'per consignment' basis. For example, there were about 17,000 consignments of wood and wood products (Table 2.2), ranging from individual pieces of furniture to large consignments of hundreds of pieces of furniture (within one consignment), or large packs of timber with hundreds of boards, etc. It is a challenge to standardise across such consignments and consider these on a per-item basis. The infestation rates were considered as the number of individuals per consignment, not the rate at which consignments were infested.

Table 2.3. Pathway contamination rates[1] used for the BMSB case study.

Sub-pathway	**Rate**	**Rate notes** (for details see "Contamination calculation sheet")
Passengers (all)	0.00014	Based on 2015 data from Statistics NZ, 5,400,000 passengers arriving, considering 38 BMSB interceptions with passengers and an assumed slippage rate of 95% (given their relatively small size, the majority of BMSB will probably be overlooked).
Containers	0.003	Based on 348 interceptions with 'containers' and assuming an 80% slippage rate.
Vehicles and machinery	0.0083	Based on 488 intercepted individuals & NZ Customs import data ('vehicles' only, excluding machinery) assuming 80% slippage pre-intervention [Note QuanCargo and NZTA data were incomplete]
Vessels (all)	0.001	Rough guesstimate. There were very few interceptions with vessels. Assumed a low rate of 1 in 1,000 vessels. This can be updated once better data become available.
Mail (all)	0.000001	Rough guestimate. There were very few interceptions with mail. Suggest we ignore this for now. Assumed a low rate of 1 in 1,000,000 mail items.
Wood & wooden products	0.03	Based on 'per consignment' rate and using uncertain QuanCargo data, assuming an 80% slippage rate.
Wood packaging	0.00001	Insufficient data to calculate a contamination rate. Assumed a low rate of 1 in 100,000.

[1] These are the overall infestation rates expressed as numbers of individuals per unit pathway activity, rather than as the rates of contaminated units (across all origins); however, these were broken down further by country to accommodate differences in infestation rates among countries.

Tables 2.3 and 2.4 were constructed by MO and EB using interception data and domain knowledge respectively. Table 2.3 provides approximate raw contamination and Table 2.4 the estimated effects of actions on pathway exposure to BMSB.

Table 2.4. Effectiveness of pathway-specific and generic actions on exposure by BMSB.

Sub-pathway	Action	Effectiveness			
		Low	High	Best estimate	Confidence
Pathway-specific actions					
High-risk passengers	Passengers border inspection	0.001	0.1	0.05	0.8
High-risk passengers	Public awareness reporting	0.1	0.25	0.15	0.8
High- & low-risk passengers	Passengers canine surveillance	0	0	0	1
All cargo	ISPM 4 area freedom BMSB	0.9	0.99	0.95	0.9
Containers	Border inspection	0.1	0.5	0.2	0.8
Containers	Container targeting	0.1	0.7	0.5	0.8
Vehicles and machinery	Border inspection	0.1	0.5	0.2	0.9
Vehicles and machinery	Vehicle treatment offshore	0.99	0.9993	0.999	0.95
Wood packaging	Border inspection	0.1	0.5	0.2	0.8
Wood packaging	ISPM 15 prescriptions	0	0	0	1
All mail	Border inspection	0.02	0.15	0.1	0.8
All vessels	Border inspection	0.02	0.15	0.1	0.8
Generic actions					
All	Passive surveillance	0.01	0.1	0.025	0.9
All	Active surveillance for BMSB (N/A)	0	0.1	0	0.95
All	Readiness, infrastructure BMSB	0.2	0.6	0.4	0.8
All	Response, treatment plan BMSB	0.05	0.5	0.2	0.8
All	Pest management BMSB	0.2	0.7	0.4	0.8

The outcomes of the results reported in this chapter are summarized in a matrix-style graphic presented in Figure 2.1 and Table 2.5. The preliminary model results suggest that the main sub-pathways for BMSB entry, which are vehicles and machinery, wood and wooden products, and containers, are relatively well-managed, judging by the residual risk score, whereas the residual risk of passengers moving BMSB appears to be greater. This is probably a reflection of the large number of passengers arriving from countries where BMSB is present, combined with the assumed high level of slippage (specific to BMSB). However, ongoing occasional detections of BMSB at the border or post-border and occasional incursions suggest that the low residual exposure value assumed for vehicles and machinery may be an under-estimate. For example, there was a case of potential exposure with machinery imported from Italy in November 2017, which was cleared in Auckland and shipped to Christchurch before 15 live BMSB were found by a member of the public (specifically, a staff member of the recipient). This warrants further investigation and, potentially, some adjustment of parameters.

Table 2.5: Summary of BMSB model using expert-elicited data. Very small numbers are presented in scientific notation, so 1.75E-06 corresponds to 1.75×10^{-6}, which is 0.00000175. Columns labeled 'Exposure' are all presented relative to the highest value, which is then set at 1. Uncertainty was elicited but is not represented here.

Pathway	Subpathway	Raw Exposure	IPAHS	TA & BA	RA & IHS	Border	Post-Border Exposure	Surveillance	Readiness	Response	Pest Man.	Residual Exposure
Cargo	Animal Germplasm	0	0.9	0	0.9	0	0	0.025	0.4	0.2	0.4	0
Cargo	Animal Products	0	0.9	0	0.9	0	0	0.025	0.4	0.2	0.4	0
Cargo	Biological Products	0	0.9	0	0.9	0	0	0.025	0.4	0.2	0.4	0
Cargo	Containers	0.739	0.9	0	0.9	0.6	0.00295	0.025	0.4	0.2	0.4	0.00083
Cargo	Fresh Produce & Cut Flowers	0	0.9	0	0.9	0	0	0.025	0.4	0.2	0.4	0
Cargo	Live Animals	0	0.9	0	0.9	0	0	0.025	0.4	0.2	0.4	0
Cargo	Nursery Stock	0	0.9	0	0.9	0	0	0.025	0.4	0.2	0.4	0
Cargo	Plant Products	0	0.9	0	0.9	0	0	0.025	0.4	0.2	0.4	0
Cargo	Seed & Grain	0	0.9	0	0.9	0	0	0.025	0.4	0.2	0.4	0
Cargo	Vehicles and Machinery	1	0.9	0	1.0	0.2	8.00E-06	0.025	0.4	0.2	0.4	2.25E-06
Cargo	Wood & Wooden Products	0.209	0.9	0	0.9	0	0.00209	0.025	0.4	0.2	0.4	0.00059
Cargo	Wood Packaging	0.00123	0.9	0	0.9	0.2	9.86E-06	0.025	0.4	0.2	0.4	2.77E-06
Mail	Articles	4.11E-06	0	0	0	0.1	3.70E-06	0.025	0.4	0.2	0.4	1.04E-06
Mail	Bulk	0.0205	0	0	0	0.1	0.0185	0.025	0.4	0.2	0.4	0.00519
Mail	Express Mail	4.11E-06	0	0	0	0.1	3.70E-06	0.025	0.4	0.2	0.4	1.04E-06
Mail	Letters	4.11E-05	0	0	0	0.1	3.70E-05	0.025	0.4	0.2	0.4	1.04E-05
Mail	Parcels	4.11E-05	0	0	0	0.1	3.70E-05	0.025	0.4	0.2	0.4	1.04E-05
Passengers	Air Passengers	0.311	0	0	0	0.2	0.251	0.025	0.4	0.2	0.4	0.07041
Passengers	Cruise Passengers	0	0	0	0	0	0	0.025	0.4	0.2	0.4	0
Vessels	Air - Fully Cleared	0.0123	0	0	0	0.1	0.0111	0.025	0.4	0.2	0.4	0.00311
Vessels	Air - Under Surveillance	0.00821	0	0	0	0.1	0.00740	0.025	0.4	0.2	0.4	0.00208
Vessels	Marine - Fully Cleared	0.00123	0	0	0	0.1	0.00111	0.025	0.4	0.2	0.4	0.00031
Vessels	Marine - Under Surveillance	0.00082	0	0	0	0.1	0.000740	0.025	0.4	0.2	0.4	0.00021

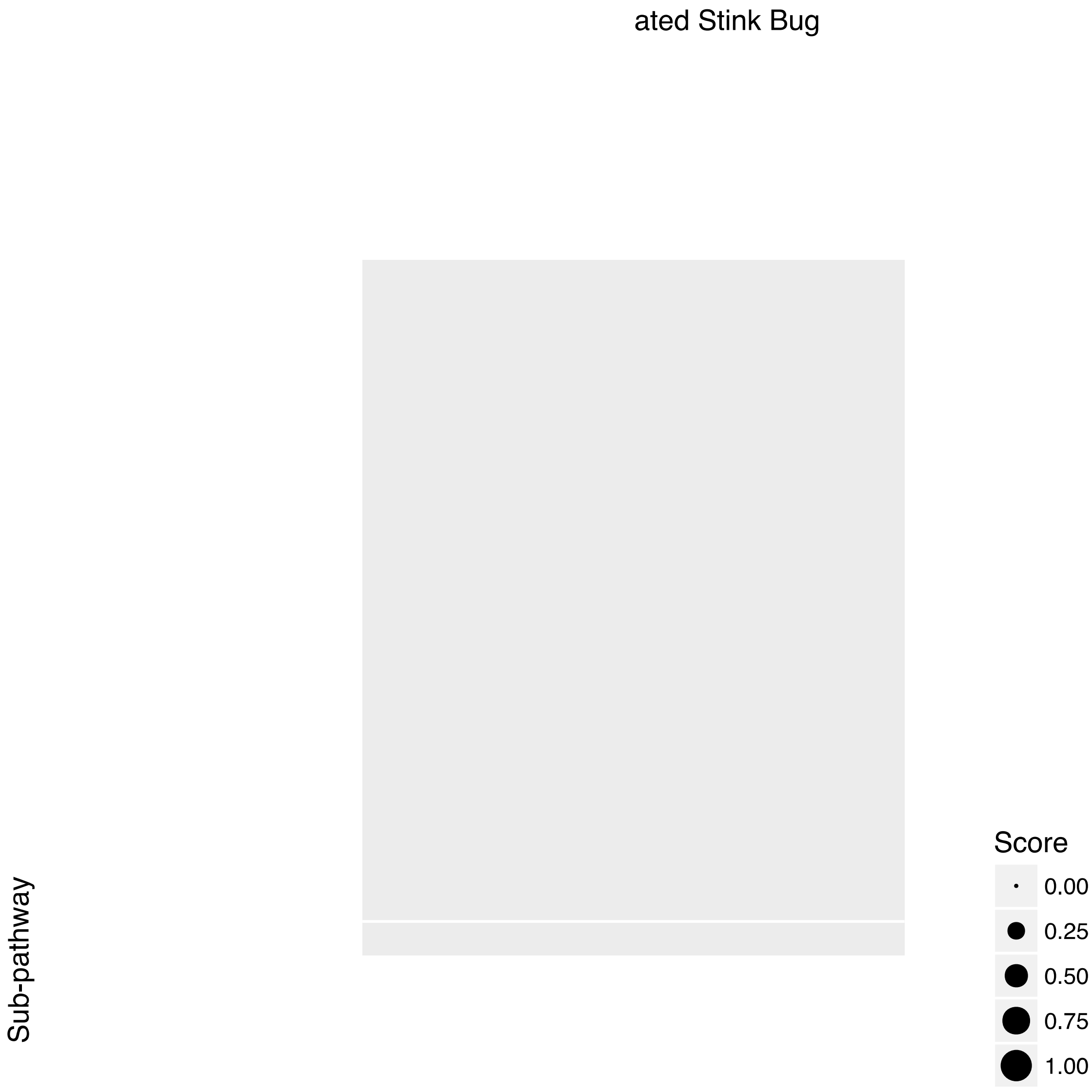

Figure 2.1: sub-pathway image for BMSB using researched and expert-elicited values. See caption of Figure 1.1 for an explanation of the symbols on the graphic. See Table 2.5 for the exact ‘residual exposure’ values, but note that these are to be taken as example outcomes of the proposed process and representation only. Operational interpretation is not intended.

Case Study 2: Queensland Fruit Fly

Background

The following information is taken from public materials produced by MPI. Queensland fruit flies belong to the fly family *Tephritidae*, which includes more than 4,500 species. Sixty species are known to infest commercial fruit types, and around 20 species can be considered as serious pests. Queensland fruit fly is very damaging, infesting more than 100 different fruits and vegetables such as pipfruit, kiwifruit, avocado, citrus, feijoa, grape, and summerfruit.

The Queensland fruit fly is a native of Australia, where it is the country's most serious insect pest of fruit and vegetable crops. It has spread to Pacific countries such as New Caledonia. Fruit flies damage fruits and vegetables when the female fly lays eggs inside the skin of the fruit. The larvae then develop and grow inside the fruit leaving the fruit pulp damaged – the larvae do not usually leave the fruit until the fruit is ripe.

Most countries harbour some species of fruit flies, but New Zealand is free of these pests. Fruit flies could enter New Zealand via imported fruit and vegetables or with fruit brought in by passengers arriving here from overseas. The pest is difficult to detect at the border because it can arrive as eggs or tiny larvae concealed inside fruit.

Export of horticultural produce from New Zealand earned $5 billion in 2016[2]. Over 90 percent of the fresh fruit and vegetable exports by value are for produce that could host fruit flies. Incursions are expensive and time consuming; for example, in 2015, an outbreak of QFF required 10 months and more than $13.6M.

Approach

The QFF study was carried out using expert elicitation (as follows) for pre-border and border layer estimates (International Agreements, Bilateral Agreements, Import Health Standards, and Border), including approaching raw contamination rate, and the same sources for the pathway volume as in the BMSB case study. The estimates for the post-border layers (Surveillance, Readiness, Response, and Pest Management) were provided by EB and MO (authors).

Much of the following text borrows heavily from Robinson et al (2016). In order to obtain estimates for the model parameters for QFF, we developed and carried out an expert elicitation exercise. These exercises are devices by which groups of experts can provide personal estimates for unknown quantities, whilst avoiding or mitigating many of the cognitive challenges that arise from posing questions to groups; see Burgman (2016) for more details.

We used the IDEA (Investigate, Discuss, Estimate, Aggregate) protocol (ACERA 2010a,b). The IDEA protocol recognizes that groups are better at making estimates than are individuals, and that discussion, properly handled, enhances group estimation, but that group elicitation can be subject to cognitive biases such as unreasonable belief in reputation, dominance, and so on. The protocol is designed to mitigate against these challenges.

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[2] http://www.freshfacts.co.nz/files/freshfacts-2016.pdf

Expert elicitation IDEA Protocol

Briefly, the IDEA protocol involved application of the following steps.

Stage 1: experts are briefed and presented with templates that guide them through answering a series of questions that are designed to minimize cognitive biases. For example, we present questions in terms of integer numbers of, e.g., passengers, as people find reasoning easier using counts rather than rates. An example question, appropriately framed might be:

1. Think of 10,000 random, representative parcels in the mail pathway. Think of all the reasons that the parcels *might not* carry infestation by QFF. Try to be as optimistic as you reasonably can about these parcels. Now write the lowest reasonable number of parcels in this random, representative set of 10,000 that you think could be infested with QFF, the number below which you would be truly surprised.
2. Now think of all the reasons that the parcels *might* carry infestation by QFF. Try to be as pessimistic as you reasonably can about these parcels. Now write the highest reasonable number of parcels in this random, representative set of 10,000 that you think could be infested with QFF, the number above which you would be truly surprised.
3. Now write your best guess at the number of 10,000 random, representative parcels that are infested with QFF.
4. Now write the confidence that you feel that your lower and higher estimates capture the range of infestation outcomes for 10,000 parcels.

In order to answer these questions, it was necessary for the experts to be able to define the different pathways satisfactorily, for example, the difference between parcels and articles, and the difference between low-risk and high-risk passengers. It was also necessary to define an infestation of QFF, which was not collectively undertaken until Stage 2.

The experts provided their estimates using the attached template. These estimates were used to construct summary plots as per Figure 3.1, which were used as props during the Stage 2 discussions.

Stage 2: four of the eight experts were able to meet in Wellington, and the other four attended by Skype meeting. In Stage 2, we started by identifying the highest priority pathways, and used these as a guide to determine which activities should be examined, because otherwise there would be too many questions to get through in the available time.

We needed an agreed definition of contamination so the contamination rate could be discussed. The experts agreed that contamination should be sufficient to present a clear risk of incursion. After discussion, the experts settled upon a definition of contamination as being any of: 40 eggs, 30 larvae, 20 pupae, or 10 adults.

The elicitation process was as follows. For each question;

1) Display of graphical summary and brief description by moderator,
2) Discussion to agree on term definitions,
3) Discussion about factors that might make the estimate low,
4) Experts privately record updated low estimates,
5) Discussion about factors that might make the estimate high,
6) Experts privately record updated high estimates,
7) Experts privately record updated best guess estimates, and

8) Experts privately record updated coverage estimates, that is, the confidence with which they think their interval covers the true value.

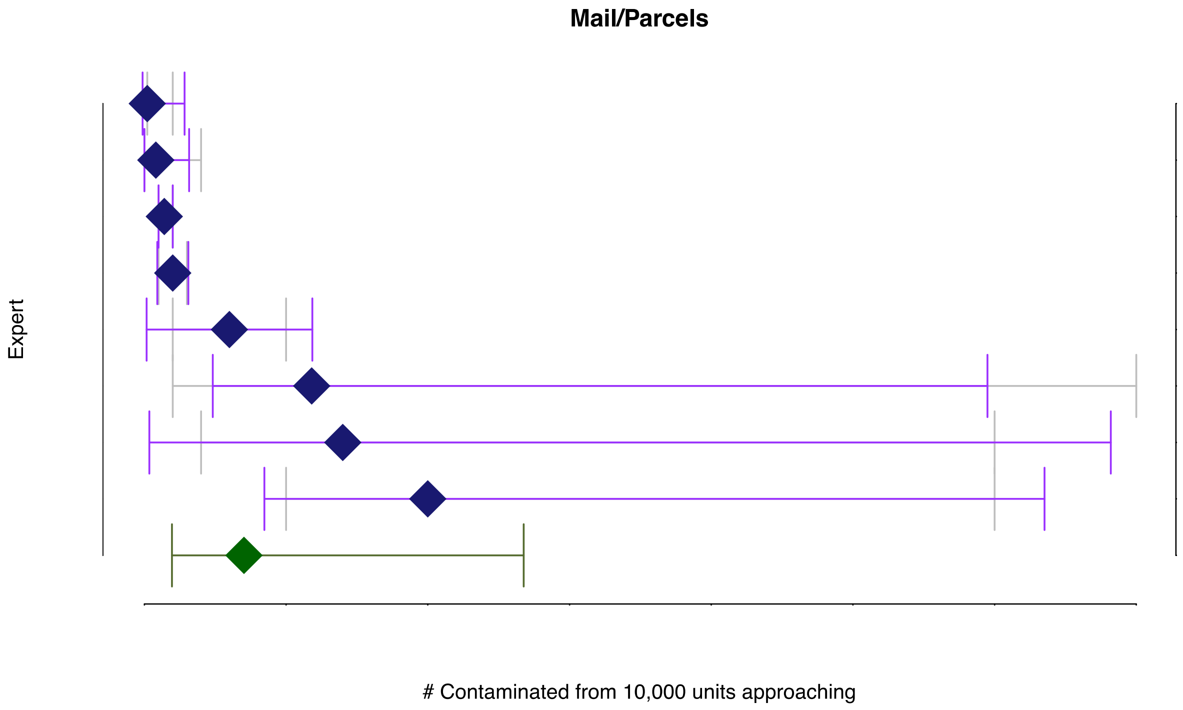

Figure 3.1: an example graphical summary of the outcome of the expert elicitation exercise. The blue diamonds are the best guesses, the green diamond is the average of the best guesses. The grey intervals are the reported low/high values with coverage as reported by the experts, which is noted on the right-hand axis; the purple intervals are transformed to 80% coverage as described in the text. The green interval is the average of the purple intervals. The expert numbering on the left-hand axis is arbitrary and provided to guide discussion; in every graph, the experts are sorted on the basis of their best guess.

Results and Discussion

The results of the exercise are presented in Table 3.1 and Figure 3.2. These results are still tentative, so the discussion will be brief. Table 3.1 shows that the highest threat is believed to come from air passengers, by a considerable margin. The residual risk of all pathways, according to the elicited opinions, is extremely low. This is likely due to the very high rating given to the border activities (such as inspection, amnesty bins, and so on). The discussion record has not yet been finalized, but may shed light on some of the experts' reasoning. Note that these results differ from impressions that arise from border interception data (according to a reviewer), however, border interception data are also unreliable. The net effect of border activities against exposure by QFF is estimated to be very high; this is because of the large number of activities that take place at the border (namely, arrival hall amnesty bins and signage, declaration cards, detector dogs, in-flight videos, profiling, and x-ray screening), and although the estimated impact of each is at least moderate, the joint effect is substantial.

Table 3.1: summary of QFF model using expert-elicited data. Very small numbers are presented in scientific notation, so 1.75E-06 corresponds to 1.75×10^{-6}, which is 0.00000175. Columns labeled ‘Exposure’ are all presented relative to the highest value, which is then set at 1. Uncertainty was elicited but is not represented here.

Pathway	Subpathway	Raw Exposure	IPAHS	TA & BA	RA & IHS	Border	Post-Border Exposure	Surveillance	Readiness	Response	Pest Man.	Residual Exposure
Cargo	Animal Germplasm	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Cargo	Animal Products	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Cargo	Biological Products	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Cargo	Containers	0.0023	0	0	0	0.884	0.00027	0.1225	0.5	0.95	0.7	1.75E-06
Cargo	Fresh Produce & Cut Flowers	0.0413	1	0.2691	0.874	0.105	0.0270	0.1225	0.5	0.95	0.7	2.72E-15
Cargo	Live Animals	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Cargo	Nursery Stock	8.12E-07	0	0	0	0	8.12E-07	0.1225	0.5	0.95	0.7	5.34E-09
Cargo	Plant Products	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Cargo	Seed & Grain	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Cargo	Vehicles and Machinery	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Cargo	Wood & Wooden Products	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Cargo	Wood Packaging	0	0	0	0	0	0	0.1225	0.5	0.95	0.7	0
Mail	Articles	0.00132	0	0	0	0.998	3.12E-06	0.1225	0.5	0.95	0.7	2.06E-08
Mail	Bulk	0	0	0	0	0. 998	0	0.1225	0.5	0.95	0.7	0
Mail	Express Mail	0.00054	0	0	0	0. 998	1.27E-06	0.1225	0.5	0.95	0.7	8.36E-09
Mail	Letters	0	0	0	0	0. 998	0	0.1225	0.5	0.95	0.7	0
Mail	Parcels	0.0133	0	0	0	0. 998	3.15E-05	0.1225	0.5	0.95	0.7	2.07E-07
Passengers	Cruise	0.00645	0	0	0	0.993	4.84E-05	0.1225	0.5	0.95	0.7	3.18E-07
Passengers	High-Risk Passengers	1	0	0	0.603	1.000	0.000367	0.1225	0.5	0.95	0.7	9.59E-07
Passengers	Low-Risk Passengers	0.9267	0	0	0.750	1.000	1.65E-05	0.1225	0.5	0.95	0.7	2.71E-08
Vessels	Air - Fully Cleared	0.00224	0	0	0	0	0.0022	0.1225	0.5	0.95	0.7	1.47E-05
Vessels	Air - Under Surveillance	0.00149	0	0	0	0	0.00149	0.1225	0.5	0.95	0.7	9.83E-06
Vessels	Marine - Fully Cleared	0.00045	0	0	0	0	0.00045	0.1225	0.5	0.95	0.7	2.95E-06
Vessels	Marine - Under Surveillance	0.00030	0	0	0	0	0.00030	0.1225	0.5	0.95	0.7	1.97E-06

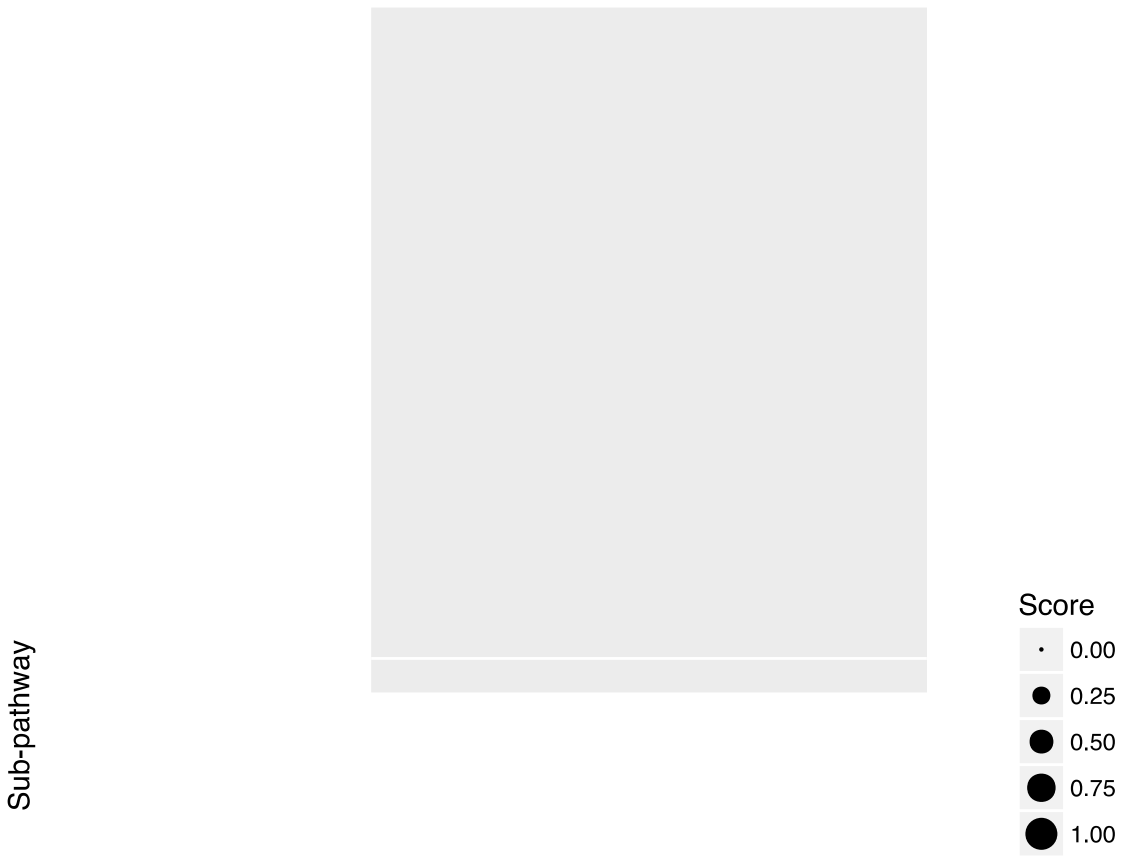

Figure 3.2: sub-pathway glimpse for Queensland fruit fly (QFF) using expert-elicited values. See caption of Figure 1.1 for an explanation of the symbols on the graphic. See Table 3.1 for the exact ‘residual exposure’ values, but note that these are to be taken as example outcomes of the proposed process and representation only. Operational interpretation is not intended.

End to End Data Challenges and Opportunities

This chapter focuses on the opportunities and challenges presented by the analysis of end-to-end data holdings for the biosecurity system. In this draft, we only report the challenges, because they have not yet been sufficiently overcome to provide us confidence that end-to-end data analysis is possible.

Challenges

The principle challenges with end-to-end data analysis is that the various data sources do not align in terms of definitions and detail, and harmonizing them sufficiently to permit some kind of analysis is a very methodical and time-consuming process. Two examples follow.

Example: Matching sub-pathways between pathway volume and interception data

As mentioned earlier, in several cases it was not clear whether interceptions occurred with containers as such or with the cargo in containers (e.g., vehicles, wood and wood products, etc.), and it was often not possible to ascertain this based on the information provided. Also, interceptions with containers were variously assigned to “container” in the data columns “Pathway” or “Host”. Likewise, interceptions with vehicles were variously recorded as “vehicle” in the columns “Pathway” or “Host” or “Commodity class”. Furthermore, there were many variants of the way “vehicles” were described. Consequently, it was difficult to summarise these interception data by Pathway and Sub-pathway to allow a summary analysis and categorisation of BMSB interceptions with the sub-pathway types as described in MPI’s framework. It appears that there are no clear guidelines on how inspectors complete the data entry for interceptions in a way that would facilitate automatic data compilation without manual processing of each record. Furthermore, the details provided with each record still left uncertainty, following manual processing, about the actual identity of the relevant sub-pathway.

Example: Number of new and used vehicles imported in 2015

New and used imported vehicles are among the most important pathways for arrivals of brown marmorated stink bug (BMSB). Nearly half of all BMSB interceptions on imports to New Zealand were associated with new or used imported vehicles. Therefore, to identify pathway risks and their mitigation, it is important to quantify vehicle import volumes, infestation rates of BMSB of this pathway, and the effectiveness of mitigation measures. It is also important to distinguish between alive and dead BMSB, and pathways that are managed (e.g., treatment for USA) and those that are not.

We obtained import data for new and used vehicles from QuanCargo for the 2015 calendar year. **New vehicle** imports were received in one spreadsheet entitled ‘new equipment’ with data on 1927 consignments with a total 2129 lines. This included data for the product subclass ‘new vehicles’ (341 consignments, 494 lines) with the remainder being ‘new car parts’ and ‘other equipment (new)’. Unfortunately, the actual number of new vehicles that were imported was not provided (except for a few cases where this was mentioned in the line description field), and this information had to be extracted manually by opening the documentation for each of the 341 consignments and 494 lines (of these we excluded one consignment/line that originated in New Zealand). The total number of new vehicles imported, according to QuanCargo was 5391. However, this value appeared suspect because 93% of new vehicle imports were from the United States and only 0.6% from Japan (Table 4.1) even though Japanese brands represent the majority of market share in New Zealand.

Table 4.1. New vehicle imports in 2015 according to a QuanCargo data query.

Country	**Consignments**	**Units** (vehicles)	**% of total**
Vehicles (new) (total)	**493**	**5391**	100.0%
Australia	24	42	0.8%
Belgium	12	17	0.3%
Canada	2	3	0.1%
China	4	91	1.7%
France	7	56	1.0%
Germany	7	7	0.1%
Indonesia	1	87	1.6%
Jamaica	1	3	0.1%
Japan	19	33	0.6%
Korea - South	1	6	0.1%
Mexico	2	13	0.2%
Netherlands	1	1	0.0%
Singapore	2	2	0.0%
Spain	1	1	0.0%
Switzerland	1	1	0.0%
United Kingdom	8	14	0.3%
USA	400	5014	93.0%

Given the apparent inconsistency in the QuanCargo data on imports of new vehicles, we consulted another data set on new and used vehicles to verify these values. The NZ Transport Agency (NZTA) publishes data on new and used vehicle registrations (see https://www.nzta.govt.nz/resources/new-zealand-motor-vehicle-register-statistics/new-zealand-vehicle-fleet-open-data-sets/). The NZTA data differ substantially from those of QuanCargo; the total number of new vehicle registrations according to the NZTA was more than 150,000 (Table 4.2) whereas the QuanCargo imports totalled 5391. Furthermore, the NZTA data appeared to be more plausible with most new registrations originating from Japan, Thailand, South Korea and Europe, and only ca. 5% originating from the USA (Table 4.2), whereas the QuanCargo data suggested that 93% of all imports originated from the USA (Table 4.1).

Table 4.2. New vehicle registrations in 2015 according to the NZ Transport Agency (NZTA)

Country	**Count (of import status)**	**% of total**
Grand Total	**151,258**	**100.0%**
Argentina	1	0.0%
Australia	7817	5.2%
Austria	658	0.4%
Belgium	226	0.1%
Brazil	40	0.0%
Canada	158	0.1%
China	4980	3.3%
Czech Republic	1106	0.7%
Denmark	10	0.0%

France	1848	1.2%
Germany	11885	7.9%
Hong Kong	81	0.1%
Hungary	1321	0.9%
India	1699	1.1%
Indonesia	154	0.1%
Italy	2191	1.4%
Japan	44963	29.7%
Malaysia	7	0.0%
Mexico	11	0.0%
Netherlands	280	0.2%
Norway	17	0.0%
Not known	17	0.0%
Other	2843	1.9%
Poland	456	0.3%
Slovakia	3	0.0%
South Africa	658	0.4%
South Korea	17763	11.7%
Spain	3036	2.0%
Sweden	823	0.5%
Switzerland	93	0.1%
Taiwan	331	0.2%
Thailand	31996	21.2%
Turkey	44	0.0%
United Kingdom	5560	3.7%
United States (USA)	8182	5.4%

It is likely that the new registrations (according to the NZTA) include new registrations of imported used vehicles that are registered for the first time in New Zealand. Therefore, the NZTA’s new registrations probably conflates new and used vehicle imports. Subsequently we obtained another data set on vehicle imports from Customs New Zealand (New Zealand Customs Motor Vehicle Statistics December 2015). A comparison of new and used vehicle imports and registrations (Table 3) shows that the QuanCargo data are incomplete and include only about 10% of the actual number of vehicles imported according to Customs NZ data. The Customs NZ data are the most plausible vehicle import data and these were used in our analysis; however, they do not include machinery other than vehicles and are therefore still incomplete to some degree.

Table 4.3: Comparison of 2015 data on new and used vehicle imports according to QuanCargo, new and used vehicle registrations based on NZ Transport Agency (NZTA) data, and import data from NZ Customs

	QuanCargo (product subclass)		**NZ Transport Agency (NZTA)** (vehicle type)		**NZ Customs motor vehicle imports**	
	Type	**Units** (vehicles)	**Type**	**Units** (vehicles)	**Type**	**Units** (vehicles)
Total	**New and used**	**24,912**	**New and used**	**151,258**	**New and used**	**293,332**
New vehicles	**New vehicles (total)** incl. passenger and commercial vehicles, ATVs, ride-on lawnmowers, etc.	**5,391**	**New registrations (total)** only vehicles requiring registration	**147,110**	**New vehicle imports** (passenger and commercial)	**135,906**
Used vehicles	**Used vehicles imported**	**19,521**	**Used vehicle registrations**	**3,720**	**Used vehicle imports** (passenger and commercial)	**157,426**

Discussion and Future Directions

This interim report provides a rapid prototype of a draft modelling approach that can be used to try to assess the impact of different activities undertaken by MPI and other parties upon the biosecurity risk presented by identified pests. It is not intended to be read as a definitive analysis of either pest.

The exercise suggests that reasonable generalizations about the performance of the system can be made from a simple model and expert elicitation, although further work is required for the case studies documented herein before they could be used to guide robust discussions about the system.

We used a very simple representation of the biosecurity system for this exercise. The representation of the system enabled simple modelling and summaries, but as noted, has the disadvantage of not allowing for conceptually reasonable interactions between the outcomes of the activities. An alternative approach would have been to try to develop a comprehensive model of the system using a tool such as conceptual mapping (see e.g., Walshe and Burgman, 2010), and MPI may wish to assess the utility of this strategy for future developments.

This model is not a sufficient tool for assessing the impacts of changing the pattern of investment within a pathway, tempting though it seems. First, as observed earlier, the impacts of some of the activities are not independent of one another. Consequently, changing investment in these actions may have knock-on effects on these other activities, which would have to be accounted appropriately. Second, although the model presents an estimate of the impacts of the activities, this estimate depends on the current rate of investment in the activities. Some activities will be binary, i.e. on or off, which does not present a conceptual problem. Others are continuous in their effect and there is no warranty that halving or doubling the amount of effort on an activity will halve or double its impact, although there may be some simple exceptions. Briefly, if this model is to be used as the basis for a benefit-cost exercise then the effect upon the impact of the activities as a function of changing investment must also be modelled.

Future Directions

Owing to the difficulties of extracting usable data from MPI's and other systems and getting sufficient time with subject matter experts, the parameterization of the model used in each case study is cursory at best. Some of the estimates supplied are defensible, and others are less so. Future work carried out in the next phase of this project will develop mechanisms for propagating and representing the uncertainty inherent in the system, and identifying which portions of uncertainty are the most important for further work. In addition to that exercise, we will revisit the parameterization of these models.

At present, we are looking at the system from the point of view of individual pests. This approach provides a conceptually attractive angle on the system, but is inefficient, because the exercise must be repeated for each target pest. A future case study, as part of the next phase of the project, will look at two key questions, namely: 1) how do we aggregate the models across target pests? and 2) how do we construct such models for collections of pests?

Finally, short-comings in the representation of the post-border activities are obvious upon examination of the tables and figures of the two case studies. It is reasonable to believe that when an incursion has occurred, the mechanisms by which it is handled and the activities that occur are defensibly independent of the pathway in which the incursion arrived. Therefore, representing the values of the post-border actions for all of the sub-pathways seems a little forced, given that they are all the same.

Furthermore, the post-border portion of the model is notable for being that in which the lack of connectedness between the actions is most problematic – recall that, for example, the value of *readiness* really should be conditional on the implementation of *response*, and furthermore the reduction of risk due to pest management should depend on the probability of response failure, which in turn depends on the level of investment in the response. We think that it would be worthwhile for the project to revisit the structure of the post-border activities, perhaps replacing the rather forced and unsatisfying matrix representation with a simple economic model, such as that developed by Kompas et al (2016).

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Appendix

Attachments:

1) BMSB database.xlsx, which provides the parameter estimates for brown marmorated stink bug.
2) QFF EE Stage 1 Preparation.docx, which are preparatory notes provided to the experts for the expert elicitation workshop for Queensland fruit fly (EEQFF).
3) QFF EE Stage 1 Template.xlsx, which is the Stage 1 blank used by the experts to record their early opinions.
4) QFF EE Stage 2 Template.xlsx, which is the Stage 2 blank used by the experts to record their later opinions.
5) QFF database.xlsx, which provides the parameter estimates for Queensland fruit fly.
6) QFF EE Stage 2 Notes.docx, which is an approximate transcript of the discussions undertaken during stage 2 of the EEQFF (IN DRAFT FORMAT, AS YET NOT REVIEWED BY EXPERTS).
7) QFF EE Stage 2 Activities.pdf, which summarizes the final anonymised expert opinions on approaching risk from the EEQFF.
8) QFF EE Stage 2 Arrival.pdf, which summarizes the final anonymised expert opinions on the effects of actions from the EEQFF.

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2) Jo Berry, MPI
3) George Gill, MPI
4) Barney Stephenson, MPI
5) Lloyd Stringer, Plant and Food
6) David Voice, MPI
7) Bernie Dominiak, NSW DPI
8) Eckehard Brockerhoff, Scion