cebra
Centre of Excellence for Biosecurity Risk Analysis

Proportional Value of Interventions across Pathways and Layers of New Zealand's Biosecurity System

CEBRA Project 170621: Interim Report

Andrew Robinson, CEBRA, The University of Melbourne

Melissa Welsh, Scion

Michael Ormsby, Ministry for Primary Industries

Eckehard Brockerhoff, Scion

Christine Reed, Ministry for Primary Industries

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Executive Summary

The biosecurity system faces increasing pressure from significant increases in the quantities of goods and passengers, changing pathways and types of goods. With this increasing pressure, all activities of the system need to work together cost-effectively to maximise the reduction of biosecurity risk to New Zealand under constrained resources.

In order to increase the efficiency of biosecurity investment and to identify opportunities for substantial improvement, the Ministry of Primary Industries (MPI) needs to determine the relative contribution of a continuum of biosecurity risk management activities toward overall system effectiveness.

Up until now there has been no agreed framework or process available to evaluate the comparative value of biosecurity activities implemented at intersecting sites across a matrix of entry pathways and across layers of the system. The three-year CEBRA project 1606E / 170621 is intended to develop such a framework and guide its deployment.

This second year report:

1. updates the representation of pre-border processes to improve three aspects, namely:
   (a) the simple framework advanced in the first year was unable to capture the complexities of the interactions of post-border investment choices,
   (b) often, pre-border activities did not fall neatly into the three pre-border layers, and
   (c) the structure of the three pre-border categories implied a hierarchy that was unsupported by reference to the activities being undertaken;

   (see Chapter 2);
2. develops a two-stage approach whereby more detailed snapshots of pathways will be used for estimating the impacts of activities, and simpler representations (namely, pre/at/post-border) used as summary tools;
3. reviews candidate bio-economic models to best represent the impacts of post-border investment (Chapter 3);
4. develops a means of aggregating the impacts of actions across pests (Chapter 5);
5. proposes a means of handling pest groups efficiently, e.g., timber pests, namely that elicitation and manipulation be carried out for the pests as groups (Chapter 2); and
6. considers a suitable representation of uncertainty (partially delivered, Chapter 6).

These changes update the pre-border model approach, improving its functionality, and provide a post-border model solution.

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Chapter 1

Introduction

1.1 Background

The biosecurity system faces increasing pressure from significant increases in the quantities of goods and passengers, changing pathways and types of goods. With this increasing pressure, all activities 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 increase the efficiency of biosecurity investment and to identify opportunities for substantial improvement, the Ministry of Primary Industries (MPI) needs to determine the relative contribution of a continuum of biosecurity risk management activities toward overall system effectiveness.

Up until now there has been no agreed framework or process available to evaluate the comparative value of biosecurity activities implemented at intersecting sites across a matrix of entry pathways and across layers of the system.

This report delivers the outcomes for the second year of a three-year project. The first year, CEBRA Project 1606E (reported in Robinson et al., 2018), initiated a framework through which MPI could summarize the actions of the biosecurity system against a pest. The framework comprised four pathways (cargo, mail, passengers, transport) that were divided into 24 sub-pathways, namely:

- 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

Eight layers have been identified, namely:

1. International Plant & Animal Health Standards (IPAHS; "International Agreements" in CEBRA report 1606E);
2. Trade Agreements & Bilateral Arrangements (TA & BA; "Bilateral Agreements" in CEBRA report 1606E);
3. Risk Assessment & Import Health Standards (RA & IHS; "Import Health Standards" in CEBRA report 1606E);
4. Border Interventions ("Border" in CEBRA report 1606E);
5. Surveillance ("Surveillance" in CEBRA report 1606E);
6. Readiness ("Readiness" in CEBRA report 1606E);
7. Response ("Response" in CEBRA report 1606E); and
8. Pest Management ("Pest Management" – nb: for the International Plant Protection Committee (IPPC), 'pest' includes pathogens and diseases).

The matrix was constructed using R software from data stored in a Microsoft Excel database. Example frameworks were constructed for two pests, namely brown marmorated stinkbug and Queensland fruit fly (see Figure 1.1).

The project leveraged some detailed information that was available within MPI, such as interception data and elicited expert opinion through a facilitated workshop of MPI and other biosecurity experts. An example of the outcome for an anonymous pest is provided as Figure 1.1. In this figure, each row represents a sub-pathway, gathered into blocks that represent pathways. The columns with solid symbols represent the unmediated (raw) approaching (left side), post-border (centre), and residual (right side) *exposure* by the size of the symbols (large is high, all are 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; see p. 2 for description). The scales for the three exposure columns 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. Low-risk and high-risk cruise passengers are combined because they do not differ operationally. Low-risk and high-risk air passengers remain separate because they sometimes differ operationally.

1.2 This Report

This report provides three of the deliverables for CEBRA project 170621: *Proportional Value of Interventions across Pathways and Layers of the Biosecurity System*, namely:

1. A suitable model to capture investment in post-border activities (Chapter 3),
2. A system for aggregating impacts across pests (Chapter 5), and
3. A proposal for handling uncertainty in system processes (Chapter 6).

We also provide an updated representation of the pathway, with a specific focus on pre-border activities, that better captures the complexity of pre-border biosecurity operations (Chapter 2). Note that, at present, the value of pre-border activities is not represented financially, unlike post-border activities.

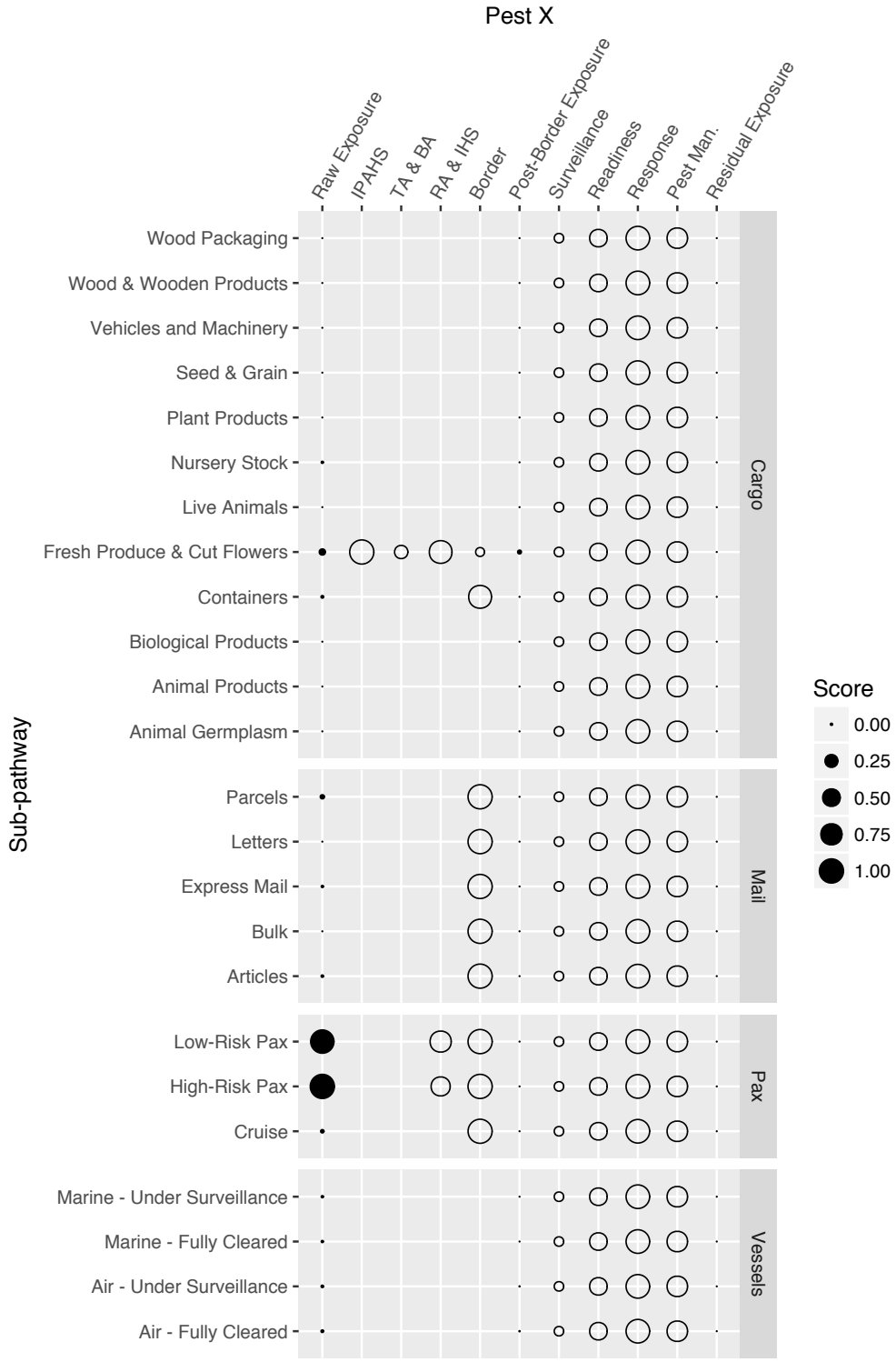

Figure 1.1: Example Phase 1 sub-pathway graph for an anonymous pest. Each row represents a sub-pathway, gathered into blocks that represent pathways. The columns with solid symbols represent the raw approaching (left), post-border (centre), and residual (right) *exposure* by the size of the symbols (large is high, all are 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; see p. 2 for description). *Score* provides a measure of the relative size of the symbols. The scales for the three exposure columns 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. Low-risk and high-risk cruise passengers (pax) are combined because they do not differ operationally. Low-risk and high-risk air passengers remain separate because they sometimes differ operationally.

Chapter 2

Updated Pre-Border Representation

This chapter details an update of the simple system model introduced in CEBRA project 1606E (Robinson et al., 2018) as presented as Figure 1.1 in the previous chapter. We first note the modest shortcomings that the update is designed to fix.

2.1 Previous model shortcomings

Some aspects of the model are inappropriate for a model of the biosecurity system. First, the model representation implies that there is some kind of sequence between the impacts of the three sets of pre-border activities, namely that 'International plant and animal health standard development' impacts *precede* 'Trade agreements and Bilateral Agreements' impacts, which in turn precede 'Risk assessments and Import health Standard development' impacts. This apparent precedence is misleading, and although it may be reasonable to categorise various activities under the labels, it is not appropriate to imply any kind of precedence of those categories.

Second, upon our attempted mapping of the biosecurity system to the simple matrix model, we found that portions of certain sub-pathways were treated differently than other portions. As a simple example, some fresh produce and cut flowers are produced from pest-free areas, others have requirements of treatments. Consequently, it is necessary to distinguish between the volumes of the portions of the sub-pathways that are subjected to different levels of biosecurity activity. In short, we cannot necessarily treat the sub-pathways as fundamental units, but will have to sub-divide them by volume and activity.

2.2 Updated model description

In order to better represent sub-pathway complexity, we developed more detailed model diagrams of the system for several pest–sub-pathway combinations; an example is provided at Figure 2.1, with others provided in Appendix A.

Such diagrams could possibly underpin the pathway descriptions but would not be suitable as high-level decision support tools. It will be necessary to combine the exposure across these pathways to a higher level, perhaps into three areas, namely *Pre-border*, *Border*, and *Post-border*. Such a representation would allow risk managers to assess the net exposure for portions of the pathway, with the detail of underpinning models such as Figure 2.1 enabling discussion of the possible impacts of changes to the system.

Producing a unique diagram for each possible combination of pest and sub-pathway, along with estimates of the impact of the activities, would be a substantial impost. Some activities will be common to different pests.

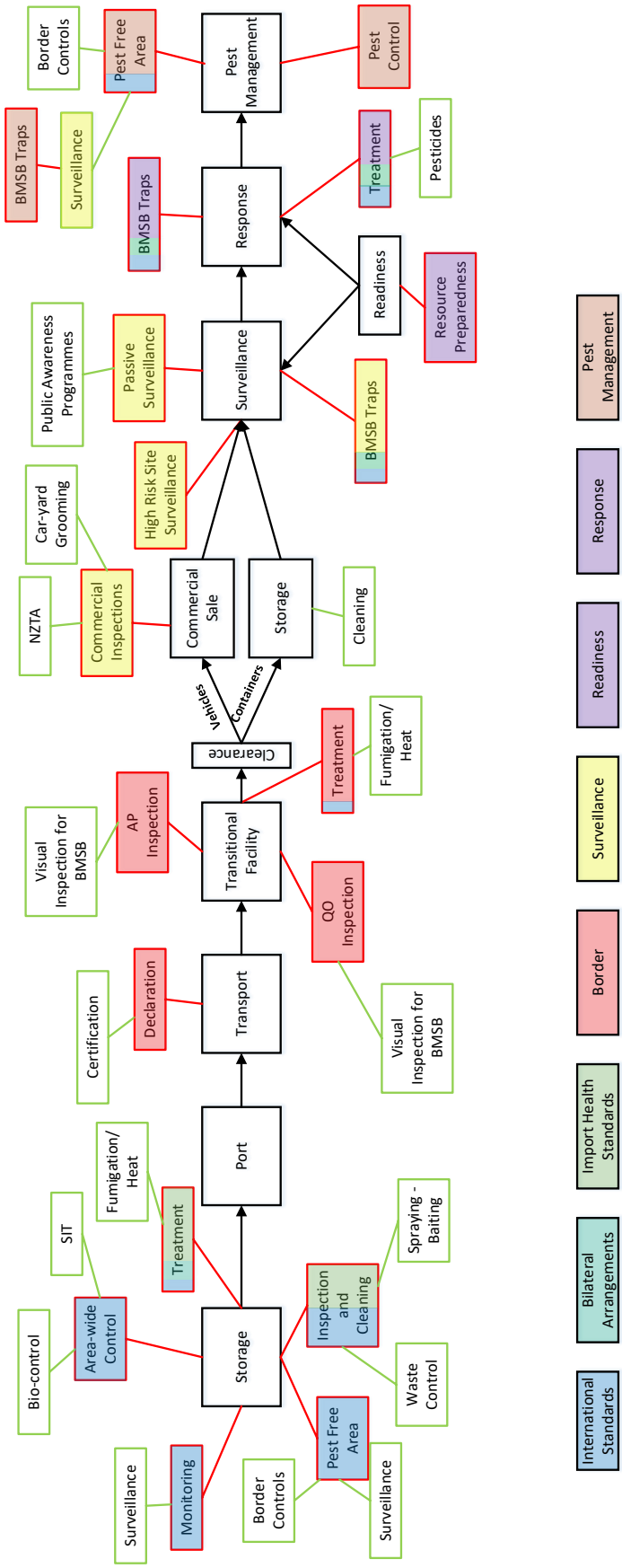

Figure 2.1: Updated model of biosecurity activities for imported vehicles against the brown marmorated stink bug. The colours of the activity boxes align with the colours of the layers of the biosecurity system. SIT is Sterile Insect Technology. NZTA is New Zealand Transport Authority. AP inspection is inspection by an approved person and QO inspection is inspection by a Quarantine Officer.

Chapter 3

Deliverable 1: Post-Border Activities Model

This chapter provides an updated model of the impact of post-border activities upon biosecurity exposure. The challenge of capturing the impacts of post-border activities is that they interact with one another, unlike the pre-border and border activities, which can be assumed to have independent impacts.

Taking account of the categories originally identified in Robinson et al. (2018), we begin by distinguishing those that occur before and after incursion. The reason for this distinction is that post-incursion expenses are affected by decisions such as whether or not to eradicate, which are in turn affected by the spread of the pest upon the point of detection, which depends on the investment of pre-incursion surveillance resources, and so on. Consequently, of the layers previously identified, we are only considering 'Surveillance' and 'Readiness'[1] as areas of pre-incursion investment. We consider the other categories, namely 'Response' and 'Pest Management', as part of the impacts of the pest.

3.1 Previous Studies

We located two substantive efforts at modeling the *post-establishment* effects of post-border surveillance, namely Epanchin-Niell et al. (2014) and Kompas et al. (2016). We provide a detailed review of each model approach. We do not know of studies that include the effect of 'Readiness' upon biosecurity exposure, so we propose to adapt the nominated model to allow for it.

3.1.1 Epanchin-Niell — cost-effective invasion surveillance

The Epanchin-Niell (EN) model proceeds as follows. Populations of an invader, of varying sizes, both detected and undetected, exist in the landscape, and their spread is represented as circular with radius growing linearly in time. Although there is no allowance for jumps to new areas in the landscape from existing populations, new invading populations will establish at a constant rate.

Undetected populations continue to increase in size with each time step, until they are detected. A population is detected with a probability dependent on the size of the invading population, and the amount of surveillance effort in terms of trap density.

Once a population has been detected, a decision is made to attempt eradication or not. The probability that an eradication attempt will be successful is solely a function of population size in this model, and decreases as size increases. The cost of eradication increases with population size. If the costs associated with the invading pest population remaining in the landscape are

[1] *Readiness* can be considered synonymous with *preparedness* for the purposes of this report.

greater than the eradication cost, accounting for the probability that eradication might fail, then an eradication attempt is made.

If an eradication attempt is successful, then the population is removed from the landscape at the start of the year following detection. If eradication is not attempted or is unsuccessful, however, then the population remains as a known population in the landscape, and continues to grow at the same rate as before, that is, the eradication effort is assumed to not affect subsequent growth.

The net present value of the total expected costs and damages is calculated as the discounted sum of costs and damages due to both detected and undetected populations, surveillance costs and the costs of eradication attempts, for all populations for the duration of the surveillance program, plus the discounted net present value of all populations remaining on the landscape.

3.1.2 Kompas — optimal surveillance for invasive weeds

Invasive populations establish at random intervals, varying about an expected interval time, then spread exponentially. The probability of detection depends both on population size and surveillance effort. Population size classes are defined by the longest distance north to south and east to west; these dimensions are identical for all populations of a given size class. For a given size class, detection probability is determined empirically as the mean probability of detecting each of 1,000,000 individual theoretical invasives. These individual detection probabilities are estimated as dimensions of the infestation divided by the dimensions of the search grid.

When a population is detected, the decision is made whether to eradicate it immediately, or delay eradication until it is determined to be efficient. The benefits of immediate eradication are estimated as the avoided loss due to the presence of the pest per unit of time and the extra cost of eradicating a population that has been allowed to grow for an extra time period. The benefits of delaying eradication are defined as 'the interest payments that could be earned if the eradication expenditure is not spent immediately', i.e., discounted costs. Eradication is deemed efficient when avoided losses outweigh the potential interest gain. Eradication is always successful in this model. This is unrealistic for most pests, but the model could be tweaked to allow for unsuccessful eradication attempts.

The discounted value of expected losses and eradication costs for all invading populations is estimated as the discounted expected damage and eradication costs for all population sizes accounting for detection probability, summed over all invading populations, conditional on their time of establishment.

3.2 Proposed approach for Risk–Return post-border model

We adopt a simple model similar in structure to the EN model because it provides the closest analog to our situation, and the EN approach will be adopted by B3 project 36 ("Optimising biosecurity investment and effort across all invasion phases"). This model is most readily extended to accommodate estimates of the value of readiness activities, and provides a library of existing functional forms that we can apply to ease development of our model framework. Our approach is also similar to that used by the Department of Agriculture, Water, and Environment's Risk–Return Resource Allocation (RRRA) model. Based on our review of the two approaches above, the EN model appears to be better aligned with MPI's system, although as noted above the model needs to be extended for 'Readiness'.

As mentioned earlier, we assume that the post-border activities affect the *consequences* of incursion but not the *likelihood*, so for the purposes of the model we condition on entry of a minimum viable population (MVP), that is, we assume that an MVP has entered the country. For the purposes of this model, Transitional Facilities are considered to be a part of the national

border, therefore pests that arrive at but do not escape from transitional facilities, by definition, have not entered the country.

We also assume that if eradication is attempted and successful, then the only costs and damages are financial. That is, the impact on (i) human health, (ii) the environment, (iii) cultural values, and (iv) social amenity are negligible. This assumption is probably false, but convenient, because it means that the impacts of incursion in these four different sets of values only need to be considered in the light of failure or refusal to eradicate. If we do not make this assumption then we are obliged to estimate the impact of all incursions as a function of the size of the invasive population at the time of detection in each of these four sets of values, which would be very taxing for the experts, instead of only those incursions for which eradication fails or is not attempted.

A key innovation in the following model development is to exclude time. From the point of view of incursion detection and response, time is a nuisance variable. To eliminate time, we aggregate across the effects of pest population growth rate, detectability, surveillance effort, and so on, instead of constructing separate models or parameters for each of these components. The model replaces these components with a probability density function that represents the size of the invasive population at the instance of its detection (either as number of individuals or size of infested area). We argue that once the population size has been determined, the factors that contribute to it are irrelevant. This argument proceeds as follows.

Several variables affect the magnitude of the loss due to incursion, for example, number and size of affected industries, availability of host material, climatic suitability, and so on. These variables can all be somewhat predicted in advance of the incursion, using data about pest traits, host material availability, and so on. One variable that cannot be easily predicted yet has a very significant impact on the loss is the size of the infesting population at the time of detection, which itself is a function of the time until detection, the speed of spread, the amount of surveillance, the quality of surveillance, good fortune, and so on. Each of these factors affects the loss by affecting the population size at the time of detection. If we know the infestation size at the time of detection, then none of those other things affect subsequent decision-making.

Assuming that we know the size of the infesting population at the time of detection, x, then we can compute the loss due to incursion, as follows. We consider two scenarios. In the first, we assume that eradication fails or is not attempted. Then, we assume that the annual loss due to the incursion would be independent of the size of the population. Let $\$_m$ be the expected annual loss due to pest management. Then the net present value of pest management assuming an annual cost of $\$_m$ can be calculated as:

$$\$_c = \frac{\$_m}{d}, \tag{3.1}$$

where d is the discount rate.[2] In the second scenario, the incursion is detected early enough to make eradication economically viable. Then the loss would be

$$\$_e(x) + (1 - P_e(x))\,\$_c, \tag{3.2}$$

where $\$_e(x)$ is the cost of the eradication attempt as a function of the size of the population at x, and $P_e(x)$ is the probability of successful eradication as a function of x. Examples of these functions taken from Epanchin-Niell et al. (2014) are

$$\$_e(x) = \exp(-0.46144 + 0.47376 \log x), \tag{3.3}$$

and

$$P_e(x) = 1/(1 + \exp(-0.55952 + 1.5919 \log x)), \tag{3.4}$$

respectively, where x is in units of km^2 invaded.

[2]See, e.g., `https://www.oxfordreference.com/view/10.1093/oi/authority.20110803100318555`

Denote the inflexion point in x at which eradication is no longer cheaper than pest management, all else being equal, by t. That is the point at which the loss due to attempting eradication (and possibly failing) is the same as the loss due to pest management. Using equations 3.1 and 3.2, this value can be written as:

$$t = x \; s.t. \; \frac{\$_e(x)}{P_e(x)} = \$_c \tag{3.5}$$

Taking as examples the models from Epanchin-Niell et al. (2014), we seek x so that

$$\begin{aligned} \$_c &= \exp(-0.46144 + 0.47376 \log x) \times (1 + \exp(-0.55952 + 1.5919 \log x)) \\ &= x^{0.47376} \times (0.360249 x^{1.5919} + 0.630375), \end{aligned} \tag{3.6}$$

with $\$_m$ expressed in \$US millions. We can only solve this equation for x by computation using a root-finding algorithm (see, e.g., Jones et al., 2014).

Then, let $\$_I(x)$ be the loss due to establishment as a function of the size of the population at the time of detection. The loss due to an incursion can be written as

$$\$_I(x) = \begin{cases} \$_e(x) + (1 - P_e(x))\,\$_c & \text{for } x < t \\ \$_c & \text{for } x \geq t \end{cases} \tag{3.7}$$

Now we assume that detection of the incursion must occur at some point in the infestation growth curve. That is, we consider the probability of detection from the point of view of *when* the incursion is detected. Then we can write a function that describes the probability of detection at any point in the infestation growth curve. We next need the functional form and the parameters in order to capture the variability of the size of the population at the time of detection. Here, we treat the problem of detection as being analogous to survival analysis, that is, the incursion detection happens once in time, and our challenge is to capture uncertainty about the time at which it happens and the impacts upon decision-making and loss (subsequent detections should be treated as part of the original incursion).

To proceed, we need the functional form of the probability density function for the size of the population at the time of detection. There are several ways to obtain such a functional form. The simplest is to use expert elicitation questions to identify at least two quantiles, which would allow us to estimate the parameters if we assume a distribution family, such as the Weibull. We represent this functional form by $f_X(x)$, and its cumulative density function by $F_X(x)$.

(NB: the *hazard function* expresses the probability that the incursion is detected in a given instant, conditional on not having been detected already. We might assume that the hazard increases linearly with the size of the infestation — that is, if the infestation size doubles, then the hazard doubles. Other assumptions are possible, and indeed the shape of the hazard function could be elicited, but the assumption of linearity is fine for the moment — and very useful. If the hazard of detection as a function of population size is linear then the probability density function of the population size at the time of detection is Weibull with shape parameter 2, leaving only one free parameter (the scale) for expert elicitation.)

As a reviewer noted, the probability of successful eradication may not be a function of population size alone in all cases. Other potential factors include, for example, efficacy of eradication tools (e.g., pesticides) and the ease of implementing eradication operations affect eradication success. However, we assume that there is no interaction between the effect of these factors and the effect of population size on eradication success. In short, these factors can be assumed to affect the slope of the hazard function, but we assume that they do not affect the shape of the hazard function.

In any case, our interest is in establishing the distribution and then the expectation of the loss. Following equation 3.7, the loss can be split into two additive portions, depending on the size of the population at the time of detection (x). The first portion can be computed as

the average of the loss as a function of population size, weighted by the probability that the infestation is detected at that population size, and the second is the fixed loss of pest management multiplied by the probability of detecting the incursion too late for response. Symbolically, the probability-weighted contribution to the loss due to an incursion can be written as

$$\begin{aligned} [\$_e(x) + (1 - P_e(x))\,\$_c]\, f_X(x) \text{ for } x < t \\ \$_c\,(1 - F_X(t)) \text{ for } x \geq t \end{aligned} \tag{3.8}$$

Then the expectation of $\$_I(x)$ is:

$$E_x(\$_I(x)) = \int_0^t [\$_e(x) + (1 - P_e(x))\,\$_c]\, f_X(x)dx + (1 - F_X(t))\,\$_c. \tag{3.9}$$

3.3 Caveats

1. This approach will be suitable for a small number of pests. However, as the number of pests increases, the chance that the impacts of the pests will overlap will also increase. It is important that the impacts upon particular resources not be double counted.

2. The probability of successful eradication may be a function of variables other than population size alone.

3. There can be additional regulatory costs to meet market access requirements of importing jurisdictions.

Chapter 4

Elicitation Approach

The elicitation approach is divided into four sections, namely: set-up, preparation, workshop, and wrap-up. The set-up includes recruiting and briefing experts, agreeing on a common vocabulary, and so on. The overall approach followed the IDEA protocol (Hemming et al., 2017). As a reviewer noted, this approach is influenced by the experience, understanding and biases of the experts. However, structured elicitation (e.g., IDEA) protocols may mitigate some of these biases and improve the accuracy and transparency of the resulting judgements. More detailed discussion on these challenges can be found in Burgman (2015).

Set-up The following questions are presented to the experts in a conference call.

1. Considering a pest or group of pests (hereafter, pest), please define the MVP, which is the minimum number of the pest at a given life stage that is required for a successful incursion.
2. Identify all the pathways by which an MVP of the pest might enter New Zealand, for example, air passengers, mail, or certain kinds of cargo.
3. For each identified pathway, identify the unit of intervention, which is defined as the level of the pathway at which biosecurity decisions are typically made.
   - For example, in used motor vehicles the unit is a car or motorbike, whereas for cut flowers the unit is a consignment.
4. For each identified pathway, 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, offshore cleaning, and so on.
   - We may need to stratify the pathway by the measures to which it is exposed; for example, international passengers may experience different measures depending on citizenship. If the differences are material then we will need to know how many units undergo each measure.
5. Nominate the metric of size to use to describe the severity of incursion. This might be infested area, number of invasives, or the number of infected hosts.
6. Nominate the largest population size at which it is reasonable to expect that eradication will still be attempted (A).
7. Examples of the questions and how they should be answered under the IDEA protocol will be presented.

Preparation Best performed by analysts, e.g., the Joint Border Management (JBM) team.

8. Determine the number of units of intervention arriving on each pathway at the border per unit of time, usually per year, typically using Customs/JBM databases.

Two-Stage Workshop All the questions below should be answered using data where possible. For circumstances in which the data are insufficient, we advocate expert elicitation, and propose to elicit uncertainties as well as estimates using the IDEA protocol (Hemming et al., 2017). A detailed example of the IDEA protocol is provided for the first question.

9. Estimate the raw, baseline contamination of each pathway to the pest, that is, the rate per unit at which an MVP of the pest would arrive on that pathway if no measures were in place. E.g., for each pathway, the setup and (bulleted) questions would be as follows:

   Imagine 1000 random, representative units (or more, some suitable multiple of 10) of the pathway arriving in New Zealand *without any biosecurity measures in place*, that is, the raw, unrefined exposure. Think about the number of such units that could be carrying an MVP of the pest in question.

   - List the reasons that this number might be **low**. What factors mitigate against these units carrying a MVP of the pest in question?
     Record the lowest reasonable number of the 1000 random, representative units that you would expect could be carrying at least one MVP of the pest.
   - List the reasons that this number might be **high**. What factors support these units carrying a MVP of the pest in question?
     Record the highest reasonable number of the 1000 random, representative units that you would expect could be carrying at least one MVP of the pest.
   - Record your **best guess** at the number of units carrying at least one MVP of the pest.
   - What is your personal probability that the **true value** for any random 1000 units would be **between your low and high values**?

10. For each pathway and each measure, estimate the multiplicative impact that each measure has upon the exposure on the pathway to which it is applied. The impact is a number from 0 (no impact) to 1 (completely stops all exposure). The setup might be:

    > Imagine 1000 random, representative pathway units, each of which is contaminated with at least one MVP. Imagine that each of these 1000 units are subjected to the proposed measure. Think about how many of the units would subsequently be clear of MVP.

11. For each pathway, estimate the probability that a successful entry will lead to pest establishment. The setup might be:

    > Imagine 1000 random, representative pathway units, each of which is contaminated with at least one MVP, arriving at NZ. Think about how many of these arrivals will lead to establishment of the pest.

12. Estimate the probability that a population grows to size A without being detected with the current biosecurity surveillance. The setup might be:

    > Imagine 1000 random, representative instances of successful establishment of the pest. Think about how many of these instances will be detected before the population reaches size A with the current biosecurity surveillance.

13. Estimate the probability that a population grows to size A without being detected in the absence of any biosecurity surveillance. The setup might be:

    > Imagine 1000 random, representative instances of successful establishment of the pest. Think about how many of these instances will be detected before the population reaches size A with no biosecurity surveillance.

14. Develop a model that describes eradication cost as a function of population size at detection[1]. If GERDA data suffice, we can fit a model, if not then we can elicit a multiplier from the experts to adapt a nearby model to the pest at hand.
15. Develop a model that describes eradication success as a function of population size at detection[2]. As above, if GERDA data suffice, then we can fit a model, if not then we can elicit a multiplier from the experts to adapt a nearby model to the pest at hand.
16. Estimate the total cost of and economic loss due to pest management assuming that eradication is not attempted, or is attempted but fails. NB: this information should already be available from ORS. If not, then the setup might be:

    > Imagine 1000 random, representative instances of successful incursion of the pest. Think about the damages cost and the annual loss to the NZ economy of each of these incursions. Think about the loss in terms of environmental impact, cultural impact, human health, and social amenity.

Wrap-up These steps can be completed after the workshop, but it may be useful to report them *in situ* to provide an intuitive check on the outcomes.

17. 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.
18. Then to estimate the residual exposure of the pathway, 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 $0.9 \times (1–0.2) \times (1–0.1) = 0.648$.

The total number of questions for p pathways and m measures per pathway would be $p \times (m + 2) + 6$.

[1] Or at the time of response initiation, which allows for consideration of readiness.
[2] See footnote 1.

Chapter 5

Deliverable 2: Aggregating Impacts Across Pests

We now address the problem of scaling the solution across multiple pests, thereby capturing the net benefits of activities. We do not present this as a new approach, but rather as a sensible way of proceeding that is intuitively reasonable to us.

In order to assess the value of interventions across the biosecurity system, it is important to be able to aggregate the impacts across multiple pests. This is because some activities mitigate the exposure of multiple pests, for example, fumigation treatment of fresh fruit and vegetables. Therefore in assessing the benefit of fumigation to the biosecurity system it is important to be able to roll up its effects against multiple pests.

5.1 Proposed approach

Given the model development of Chapter 3, we recommend that the net benefit of activities across pests be computed as the weighted sum of their impacts, where the weights are given by the net pest impact. The benefit B_a of activity a across p pests is then

$$B_a = \sum_{i=1}^{p} \$_{Ii} a_i, \tag{5.1}$$

where a_i is the impact on the exposure for the activity in the ith pest, and $\$_{Ii}$ is the net impact of the ith pest.

This approach ensures that the net effects of impacts are appropriately scaled to reflect the relative importance of the pests against which they act.

5.2 Example

A simple numerical example follows. Consider pest A with a residual pathway exposure of $\$_{IA} = \$1$ million, and pest B with a residual pathway exposure of $\$_{IB} = \$2$ million. Imagine that the impact of activity a is to reduce the exposure of pest A by 10% and pest B by 15%. Then the net impact of activity a would be $0.1 \times 1 + 0.15 \times 2 = \$0.4$ million.

5.3 Caveats

This approach is subject to an important caveat: that it does not correct for double-counting, which is the scenario under which losses against a single resource are counted against impacts more than once. For example, a naive calculation of the residual after the joint successive effect

of two pests A and B, each of which halves the value of a resource, would be $1 - 0.5 - 0.5 = 0$; however $1 * (1 - 0.5) * (1 - 0.5) = 0.25$; may better capture the likely successive impacts. Which of these options to use depends on the nature of the impact; there are scenarios under which A and B could jointly wipe out the resource (residual = 0), share the resource (residual = 0.25), or have to additional impact (residual = 0.5). A more detailed approach to measuring pest impact is provided by the CEBRA project: "Value of Australia's Biosecurity System" (Dodd et al., 2019).

Chapter 6

Deliverable 3: Uncertainty

In order to be used, the model that is presented in Chapters 2 (pre-border, border portions) and 3 (post-border portion) requires parameters, such as the effect of pest-free areas on the exposure of cargo pathways, or the growth rate of an incursion. These parameters may vary from pest to pest, and can be expensive or very difficult to determine. As noted earlier, we advocate the use of expert elicitation to obtain the best estimates for model parameters, which involves interviewing experts, for example using the IDEA protocol (Hemming et al., 2017).

Whether they are determined through experimentation, analysis of available data, or expert elicitation, the estimates of the model parameters are uncertain. This uncertainty has two important impacts on the use of the model: first, it means that the model predictions may be systematically wrong (biased), and second, it means that the model predictions should be expressed as a range instead of as a single value.

Developing an approach to handling uncertainty in decision support systems requires three distinct steps, namely (i) estimating uncertainty, (ii) scaling uncertainty, and (iii) representing uncertainty in the decision support system(s). Here, we resolve the first step, and discuss complications for the other two.

6.1 Estimating uncertainty

The IDEA protocol, which we used in the first year of the project, provides a mechanism for estimating the uncertainty of elicited estimates. Briefly, before the experts are asked for their best estimates of each parameter, they are guided through a discussion about why those values might be low, or high, and then asked to estimate the lowest and highest reasonable values that the true value could possible take. That is, we ask: what is the lowest value that is too high to be believable? And what is the highest value that is too low to be believable? They are then asked to estimate the probability that the true value lies between their highest and lowest reasonable values. Only then are their best estimates requested. The first part of the protocol allows the experts to express the magnitude of their uncertainty about the true value of the parameter.

6.2 Scaling uncertainty

By scaling uncertainty, we mean aggregating the effects of the experts' uncertainty about the true values of the model parameters into an expression of uncertainty about the model outputs. There are two primary ways to scale the uncertainty, namely deterministic and stochastic. A deterministic approach seeks to algebraically trace the transmission of uncertainty through the equations that represent the model. This process is straightforward when the model equations involve simple steps, such as addition and certain kinds of multiplication, but can be quite taxing when the model is more involved. A stochastic approach replaces the algebraic transmission

using model simulation, in which a computer simulates the model processes, tweaking the inputs in line with the uncertainty expressed by the experts, and gathering statistical information about the outputs. The choice between the approaches will depend upon the complexity of the final model, which is as yet unresolved.

6.3 Representing uncertainty

Representing uncertainty is essential in order to help put information into its proper context. Pathway risk managers need to know the uncertainty to help them weigh different options and outcomes, manage stakeholder expectations, and identify the knowledge-gathering activities that will result in the most efficient reduction in system-level uncertainty. How to represent uncertainty is the subject of a considerable amount of ongoing work[1]. The best way to approach representing uncertainty will depend not only upon the the nature of the information being reported but also the decision context in which it will be used. Consequently, we defer further consideration until these factors are better understood.

[1]See, variously, `http://flowingdata.com/tag/uncertainty/`, `http://flowingdata.com/2018/01/08/visualizing-the-uncertainty-in-data/`, and `https://atlas.cancer.org.au/2018/04/06/lets-get-visual/`

Chapter 7

Next Steps

The next steps for this model are to implement a number of case studies, as follows.

1. Fruit fly, to focus on of *readiness* or preparation for an incursion, specifically (i) defining the components and (ii) measuring the potential impacts. Readiness comprises such activities as knowing and stocking the best lures, having current maps of host material, appropriate training of personnel, maintaining social engagement for intervention activities such as spraying, and so on.

2. *Halyomorpha halys* (brown marmorated stink bug, BMSB), to capture a contemporary threat that will be relevant and relatively familiar to biosecurity stakeholders and have reasonably well understood mechanisms to remediate risk. At the same time, the threat posed by BMSB prompts questions about how changes in the international profile of pests can change their apparent threat levels locally.

3. Asian gypsy moth, to align with B3 project 36 ("Optimising biosecurity investment and effort across all invasion phases"). Furthermore, we have candidate parameter values and models from existing work. Epanchin-Niell et al. (2012) and (Blackburn et al., 2016) provide extensive cost estimates on gypsy moth surveillance. Finally, we can obtain economic impacts from Harrris Consulting (2003).

As a reviewer noted, it should be beneficial to link the modelling to resource allocation decision making for different biosecurity activities for and across various pest groups. We should quantify and aggregate the impact of various biosecurity activities/actions across pests.

The project team should also consider whether it would be straightforward and beneficial to link the modeling to existing MPI resources, such as the Organism Ranking Scheme, which has estimates of the economic damage of a large number of pests. It might be possible to simplify the model by substituting the entire post-border model with the ORS impact measure. We would need to understand the basis of elicitation of these quantities — did they assume a naive system for example? We could try both approaches for the first four pests, and assess the change in quality of the resulting outcomes.

Finally, the model should be tested using a cross-system workshop of managers.

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Appendix A

Pest–Sub-Pathway Diagrams

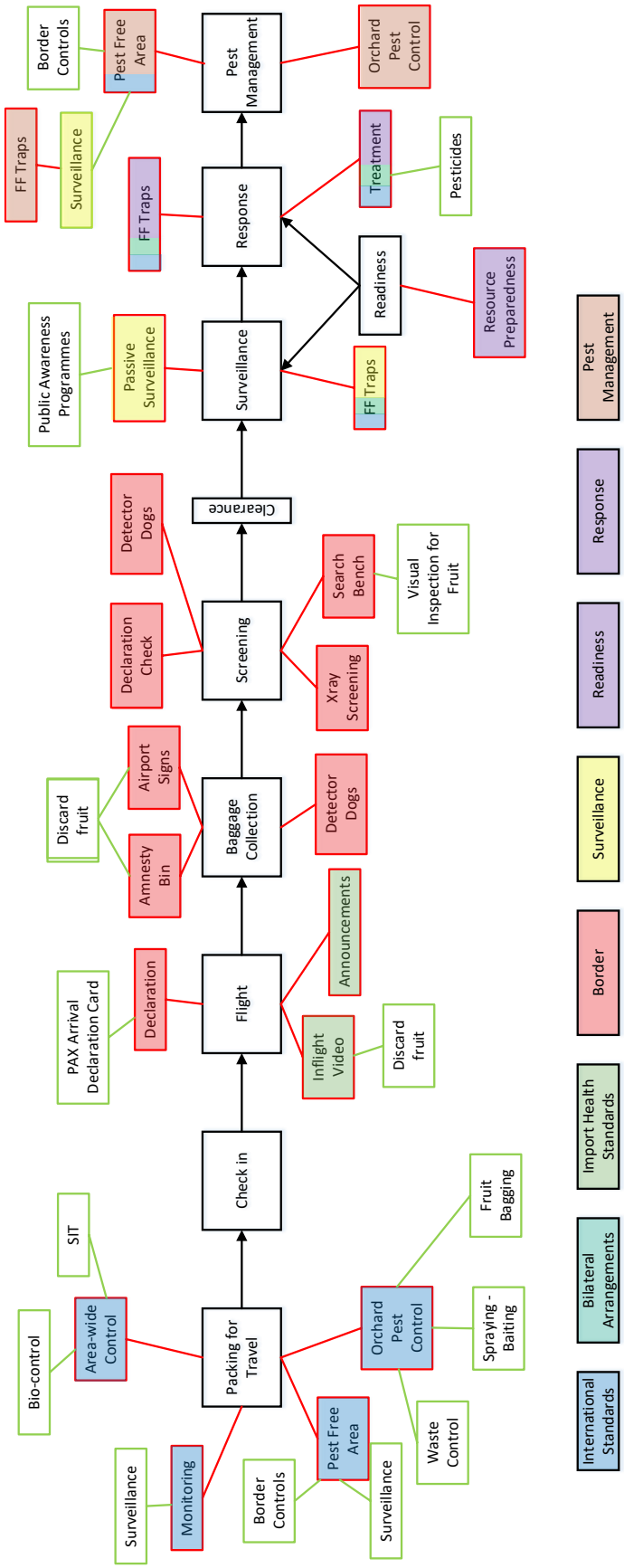

Figure A.1: Updated model of biosecurity activities for international passengers against Queensland fruit fly. Acronyms are described in the caption of Figure 2.1.

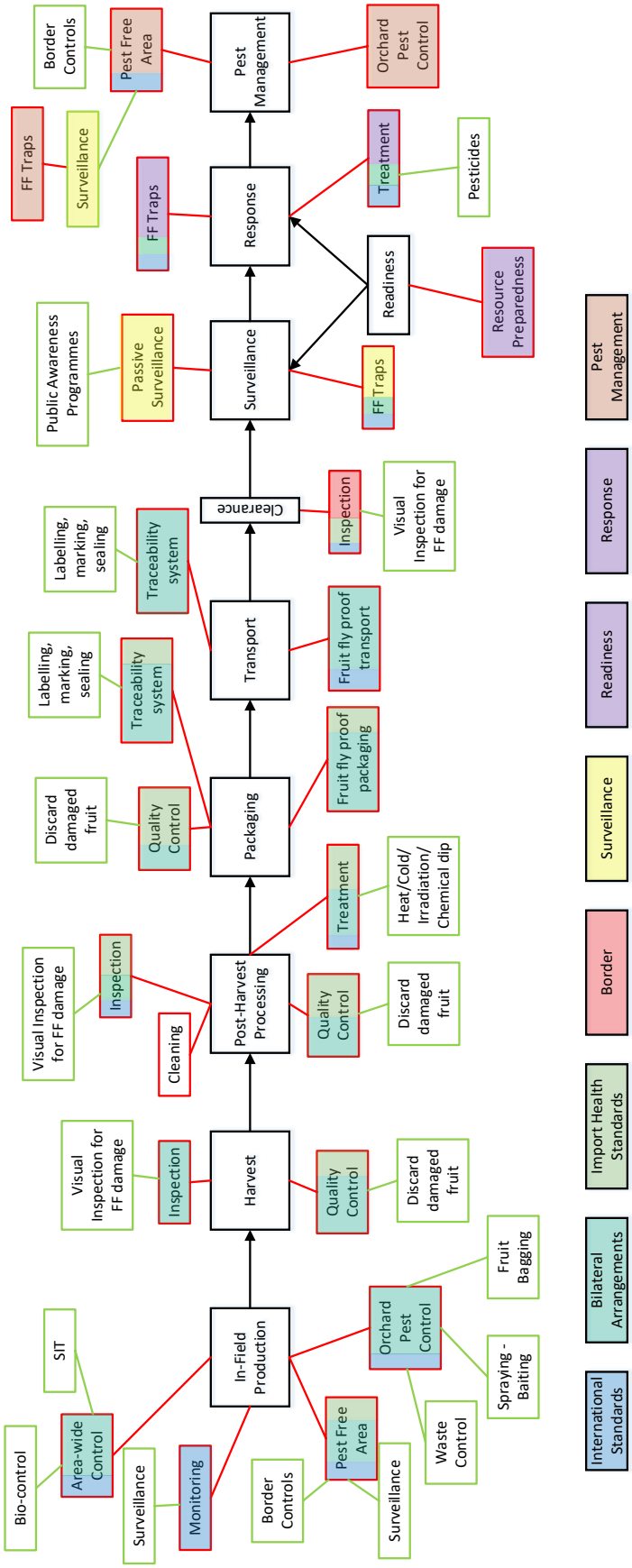

Figure A.2: Updated model of biosecurity activities for international fresh fruit cargo against Queensland fruit fly. Acronyms are described in the caption of Figure 2.1.