CEBRA 17062102: Marine Pest Structural Risk Model

Final Report

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Executive Summary

The New Zealand biosecurity system faces increasing pressure from substantial increases in goods and passengers, changing pathways and types of goods. All activities of the system need to work together cost-effectively to reduce 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 for Primary Industries (MPI) needs to determine the relative contribution of biosecurity risk management activities toward overall system effectiveness.

This project is one of a suite of projects undertaken by CEBRA that develop and apply a model framework to evaluate the comparative value of biosecurity activities. The activities are implemented on a matrix of entry pathways and layers of the system. The Centre of Excellence for Biosecurity Risk Analysis (CEBRA) developed the framework in Project 1606E (reported in Robinson et al., 2018), and completed the structure of the framework for terrestrial pests in CEBRA Project 170621 (reported in Robinson and Ormsby, 2021). The framework was applied to develop a model to a terrestrial pest, namely spongy moth, during the latter project (Robinson and Ormsby, 2021).

This report extends the framework to cover marine pests, and creates a model for a marine pest as a case study, namely brown mussel (*Perna perna*). Briefly, such a model comprises a *likelihood* module, which represents pre-border and border exposures and risk management, and a *consequences* module, which represents impacts and post-border activities.

Key aspects are:

1. Yachts are held to be heavy exposure pathways (Table 2.3).
2. The exposure due to biofouling is substantially higher than the exposure due to ballast discharge (Table 2.5).
3. The establishment risks seem highest to Auckland and Tauranga because of their greater exposure via the biofouling (in particular) and ballast water discharge pathways (Table 2.6).
4. The predicted number of establishments is higher than the experienced number (Section 2.4.1).
5. Invasive populations of brown mussel are very unlikely to be detected before they reach a size that would render eradication prohibitively expensive (Figures 1.2 and 3.1).
6. The eradication costs of an establishment in Whangarei are higher than other ports because of its deeper potential habitat (Tables 3.2 and 3.3).
7. The eradication costs of an establishment in Dunedin, Lyttleton or Picton are lower than other ports because of their minimal exchange (Tables 3.2 and 3.3).
8. The apparent benefits of the current surveillance relative to no surveillance setting for detecting *P. perna* seem negligible (Table 3.3).

List of Recommendations

Acknowledgements

The authors are very grateful to the following expert scientists: Graeme Inglis, Ian Davidson, Chris Woods, Daniel Kluza, Eugene Georgiades, and Jonathan Gardner for their generous and thoughtful engagement with the expert elicitation process.

Two reviewers provided extensive and thoughtful commentary, which has been very much appreciated. The report is considerably improved because of their careful work. The review by Biofouling Solutions provides considerable useful insight for future biofouling modelling exercises; this review is reproduced entirely as Appendix D.

Chapter 1

Introduction

1.1 Background

The biosecurity system faces increasing pressure from significant increases in incoming 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 reduce 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 for Primary Industries (MPI) needs to determine the relative contribution of each biosecurity activity to the overall initiative.

Up until now there has been no agreed framework or process available to evaluate the comparative value of biosecurity activities. CEBRA developed the framework in Project 1606E (reported in Robinson et al., 2018), and completed the structure of the framework for terrestrial pests in CEBRA Project 170621 (reported in Robinson and Ormsby, 2021). The framework was applied to develop a model to a terrestrial pest, namely spongy moth, during the latter project (Robinson and Ormsby, 2021).

This report covers the parameterisation and testing of the risk management structural model for brown mussel (*Perna perna*). The report is structured as follows. The rest of this chapter provides an overview of the model structure as developed in the previous CEBRA projects. Chapter 2 reports the outcome of the expert-elicitation exercise for the likelihood module (pre-border and border modules) of the model, along with some comparison data, and Chapter 3 reports the outcome of the expert-elicitation exercise for the consequences (post-border) module, also with comparison data. Chapter 4.2 reports the conclusions that we draw from the model fit. This report shares considerable background with the final report for CEBRA Project 170621 (Robinson and Ormsby, 2021), from which the current project was established.

Briefly, we assume that the biosecurity risk of a pest is the product of the *likelihood* and the *consequences*. The pre-border and border modules focus on the effect of activities upon the likelihood, and the post-border module focuses on the effect of activities upon the consequences.

1.2 Parameterisation: Structured Expert Judgement

As in previous variants of this model, we used a mixture of regulatory data from MPI and Structured Expert Judgement to obtain the needed parameters for the model. This process is detailed at length in, for example, Robinson and Ormsby (2021). Here, the process involved answering variations on six SEJ questions, which are listed in Section B.2 along with notes. The process involved the following steps.

- Design the structural model
- Establish and access regulatory data sources (eg pathway volumes of activity)
- Recruit experts
- Phase 1 conference call (25 March 2019, Section A)
- Phase 2 workshop (11 June 2019, Section B)
- Phase 2 workshop follow up

1.3 Risk–return model: likelihood module

This section introduces the generic likelihood module of the model, which we shaped and simplified to represent the marine biosecurity risk pathways. The framework is detailed in Robinson et al. (2018). Briefly, it generically covers four pathways (namely cargo, mail, passengers, transport) that are divided into 24 sub-pathways, namely (the sub-pathways that were used for the brown mussel model described in this report are noted in bold):

- 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**

Although these categories have been used in this and other projects, there are complications in their application because they do not align faithfully to the data collection protocols in QuanCargo[1]. Hence, future structural risk models will be greatly enhanced by a better aligned characterisation of the pathways in order to ease gathering and presentation of information about their volumes of activity.

For the current study, based on discussion with the experts, the two nominated pathways were further divided between commercial vessels (ballast discharge or biofouling) and yachts (biofouling), commercial vessel risk types (high risk — tankers and bulk carriers, low risk — others), and whether the vessel arrived from a presumed brown-mussel infested port. Therefore nine pathways were defined for the current project.[2]

[1]QuanCargo is a database used by MPI to store the data relevant to the management of biosecurity risk of cargo.

[2]A reviewer commented that a vessel's operational history and maintenance history is a better predictor of risk status, and that in the absence of this data, the CRMS long and short-stay categories would be a better categorisation of risk than that applied (Appendix D).

Recommendation 1. The likelihood model requires volumes of activity across the range of pathways administered by MPI as inputs, for example, numbers of vessels arriving by country of origin, and so on. Future instances of structural models such as these developed here should define the pathways in terms of the classifications that are used in MPI's existing data resources in order to ease gathering and presentation of activity volume data. This will enhance expert elicitation outcomes

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The generic likelihood module also includes activities or measures classified into four layers, namely:

1. International Plant & Animal Health Standards ("International Agreements");
2. Trade Agreements & Bilateral Arrangements ("Bilateral Agreements");
3. Risk Assessment & Import Health Standards ("Import Health Standards"); and
4. Border Interventions ("Border").

The parenthesised labels were used in CEBRA report 1606E (Robinson et al., 2018). For the current study we only applied border measures, as noted above.

1.3.1 Likelihood module description

The likelihood module is a simple accounting model that starts with raw exposure of a biosecurity risk along a pathway, which is then attenuated by different measures classified into the four layers mentioned above. Figure 1.1 provides a schematic example.

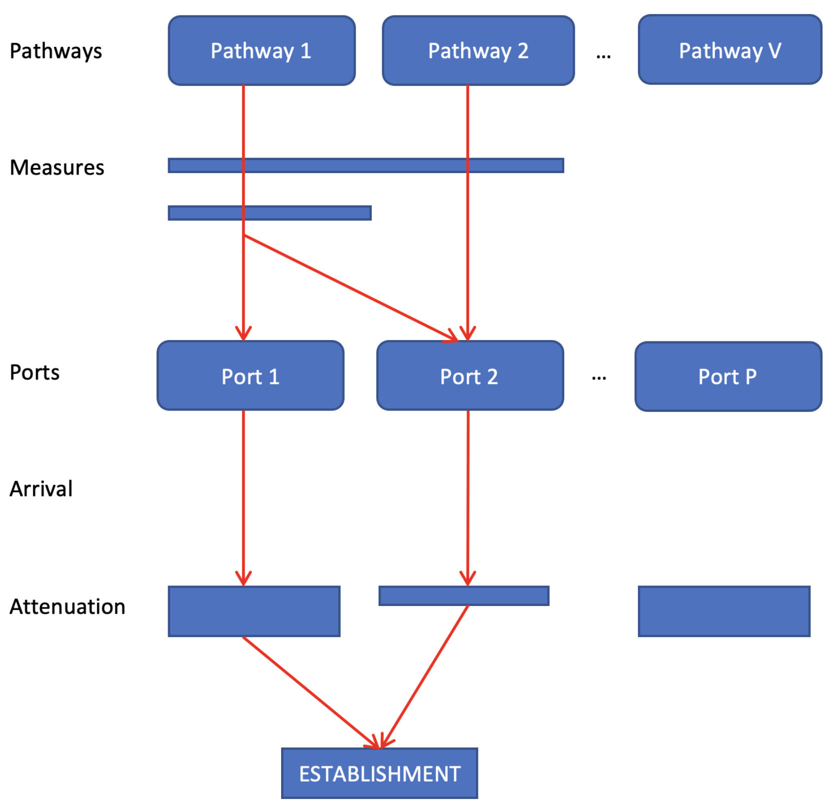

Figure 1.1: Schematic diagram of the general likelihood model.

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. Label these pathways $v = 1 \dots V$.

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 ports ($p = 1 \dots P$) on the border per unit of time, typically using QuanCargo or Customs databases (u_{pv}), noting that it may be zero for certain pathway/port combinations. The distinction between ports might be operational (e.g., seaports / airports) or geographic (e.g., Auckland / Dunedin) or both.
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 establishment of pest-free areas, border inspection, treatments, and so on. We may need to stratify the pathway by these measures —- for example, international passengers experience different measures depending on the country that issued their passport.
5. We estimate the multiplicative impact that each measure has upon the exposure on the pathway (say, m_{vj} for measure j) — the impact is a number from 0 (no impact of the measure on the spread of invasive species) to 1 (completely stops all exposure of the invasive species upon that pathway). We typically use expert elicitation for this estimation, and elicit uncertainties as well as best guesses.
6. Then we define a *minimum viable population* for the invasive pest, which is the minimum number of the pest that is required for a successful establishment. This may differ between different life stages, which may be carried at different rates on different pathways, for example biofouling and ballast water. This is defined in discussion with the experts.
7. We estimate the raw, baseline pest contamination potential of each pathway, that is, the rate per pathway unit at which a propagable unit of the pest would arrive on that pathway if no measures were in place (c_v). Pathway units are the infestible entities that the pathway comprises, for example, sea containers, all the ballast tanks of a vessel (for ballast water), vessel hulls (for biofouling), etc.
8. We compute the raw pathway exposure (i.e. baseline exposure) as the product of the baseline contamination and the number of units of intervention per unit time ($u_{pv}c_v$).
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 $0.9 \times (1 - 0.2) \times (1 - 0.1) = 0.648$.
10. We conclude by attenuating the expected number of incursions to reflect the fact that not all incursions will result in establishment (a_p). However, this attenuation rate is assumed to be independent of risk management activities.

Then the expected annual establishment rate arising from port p is:

$$e_p = a_p \sum_{v=1}^{V} u_{pv} c_v \prod_{j=1}^{M_v} (1 - m_{vj}), \tag{1.1}$$

where a_p is the attenuation rate from arrival at port p to establishment ($0 \leq a_p \leq 1$), u_{pv} is the annual number of units arriving at port p from pathway/vector v, c_p is the contamination rate in terms of minimum viable population for each unit on pathway p ($0 \leq c_p \leq 1$), and m_{vj} is the effect of measure j upon the contamination rate for pathway v, upon which a total of M_v measures are imposed. Consequently, the overall establishment rate is

$$e = \sum_{p=1}^{P} a_p \sum_{v=1}^{V} u_{pv} c_p \prod_{j=1}^{M_v} (1 - m_{vj}). \tag{1.2}$$

Chapter 2 reports the outcome of the expert-elicitation exercise for this module of the model.

1.4 Risk–return model: consequences module for marine pests

Eradication of marine pests is substantially different than eradication of terrestrial pests. Numerous factors play into the cost and success probability of marine pest incursion response differently the terrestrial setting. Therefore we developed a different consequences module for marine pests than that used for terrestrial pests in Robinson and Ormsby (2021).

The consequences module for marine pests builds on the work of Crombie et al. (2007), hereafter labelled the *Crombie model* for convenience. That project used expert elicitation to develop a model that predicts the cost of an eradication as a function of

1. pest characteristics,
2. biophysical characteristics,
3. the maturity of the incursion, and
4. the level of funds dedicated to eradication.

The predictive model was then inverted to allow estimation of the investment required to provide a 95% probability of successful incursion response along with 95% confidence intervals that capture the expert-to-expert variation. The Crombie model is summarised in Table 1.1, which provides the levels for the statistically significant categorical predictor variables, and sketched in Figure 1.2. Deployment of this existing infrastructure greatly simplifies the consequences module.

To use the Crombie model, we need to know the *habit* (grouped or solitary, specific to pest), *incursion extent* (specific to incursion), *maximum habitat depth* (specific to species and to incursion location but fixed across New Zealand ports), and *retention* (specific to incursion location but fixed across New Zealand ports) (Table 1.1). Each variable is categorical. These could be elicited for specific scenarios, but an overall approach was deemed to be more efficient. An advantage of adopting the Crombie model is that it can and should be used across a number of marine pests for consistency across different invasive species models.

Table 1.1: Crombie parameters: significant predictor variables for the expected cost of response for 95% eradication success from Crombie et al. (2007).

Variable	Explanation	Levels
Habit	Common spatial pattern of the organism	**Solitary** or **Grouped**
Area currently infested	The area currently infested by the pest. This is defined to include the areas in which the pest has been found as well as the area between non-contiguous locations.	**Very small**: < 100 m^2; **Small**: $100 - 1000$ m^2; **Medium**: $0.1 - 1$ ha; **Large**: > 1 ha.
Maximum depth of suitable habitat	The maximum depth at which suitable habitat for the species can be found in the area.	**Shallow**: $0 - 15$ m; **Deep**: > 15m.
Retention	Rate of exchange of water between the affected area and surrounding areas.	**Minimal** exchange refers to areas such as marinas whereby natural or human-made means a body of water is effectively isolated. **Low** exchange applies to areas such as estuaries or bays with narrow openings which will limit flows of water in and out of the area. **High** exchange suggests there are no significant restrictions on water flowing through the area. This may apply to open ocean or ports in wide, open bays.

1.4.1 Consequences module description

The goal of the consequences module in the model is to estimate the impact of a single incursion (the likelihood module handles the expected incursion rate). As noted above, we used the consequences model reported in Crombie et al. (2007), referred to as the Crombie model.

Crombie model

The steps we used to deploy the Crombie model were as follows:

1. Identify the Crombie parameters for each arrival port (Table 1.1).
2. Using expert elicitation, develop a function that can be used to estimate the probability of detecting the incursion as a function of the size of the invading population (here, we used the Weibull distribution with shape parameter set to 2, following the development documented in Robinson and Ormsby, 2021).
3. Determine $p(s)$, the probability of detecting the incursion as it grows through each of the size categories established by the Crombie model (Table 1.1; note: $\sum_{s=1}^{4} p(s) < 1$).
4. For each port (p) and each of four invasive population size categories (s) specified by Crombie et al. (2007), predict the eradication costs ($\$_{Eps}$) to a 95% probability of eradication success.
5. We convert the \$AUS to \$NZ in 2007 by multiplying by 1.2.[3] and then \$NZ from 2007 to 2021 equivalent by multiplying by 1.293.[4] The overall conversion is multiplication by 1.5516.
6. For each port and invading population size scenario, estimate the impact of an uneradicated incursion, $\$_{Ips}$, using $\$_C$ from Soliman and Inglis (2018); set overall impact as a function of invasive population size x:
$$\$_{Ips} = \min(\$_{Eps} + 0.05 \times \$_C, \$_C) \tag{1.3}$$
7. Estimate the port impact by the weighted sum of the size-specific impacts:
$$\$_{Ip} = \sum_{i=1}^{4} \$_{Ips} p(s) \tag{1.4}$$

The overall expected impact of a single incursion in port p is then

$$\$_{Ip} = \sum_{i=1}^{4} p(s) \min(\$_{Eps} + 0.05 \times \$_C, \$_C) \tag{1.5}$$

where $p(s)$ is the probability of detecting the incursion when its size is within size category s, $\$_{Eps}$ is the Crombie-estimated cost of eradicating the pest with 95% probability in port p at size category s, and $\$_C$ is the combined impact and management cost of an uneradicated incursion.

We then distribute the biofouling and ballast-water discharge risks among the ports using data and models developed in previous CEBRA work (CEBRA Project 170618 — Hatami et al., 2021, Table 2.1), giving port-specific establishment rates (e_p), which include establishments by both ballast water discharge and biofouling exposure.

Chapter 3 reports the outcome of the expert-elicitation exercise for this module.

Uneradicated impacts

For impact ($\$_C$), we rely on earlier work by Soliman and Inglis (2018), who provided an estimate of the impacts of two other pests upon New Zealand green-lipped mussel *P. canaliculus* aquaculture. We convert the \$NZ from 2018 to 2021 equivalent by multiplying by 1.0537.[5]

[3] See, e.g., `https://www.rba.gov.au/statistics/historical-data.html`.
[4] See, e.g., `https://www.inflationtool.com/new-zealand-dollar`.
[5] See, e.g., `https://www.inflationtool.com/new-zealand-dollar`..

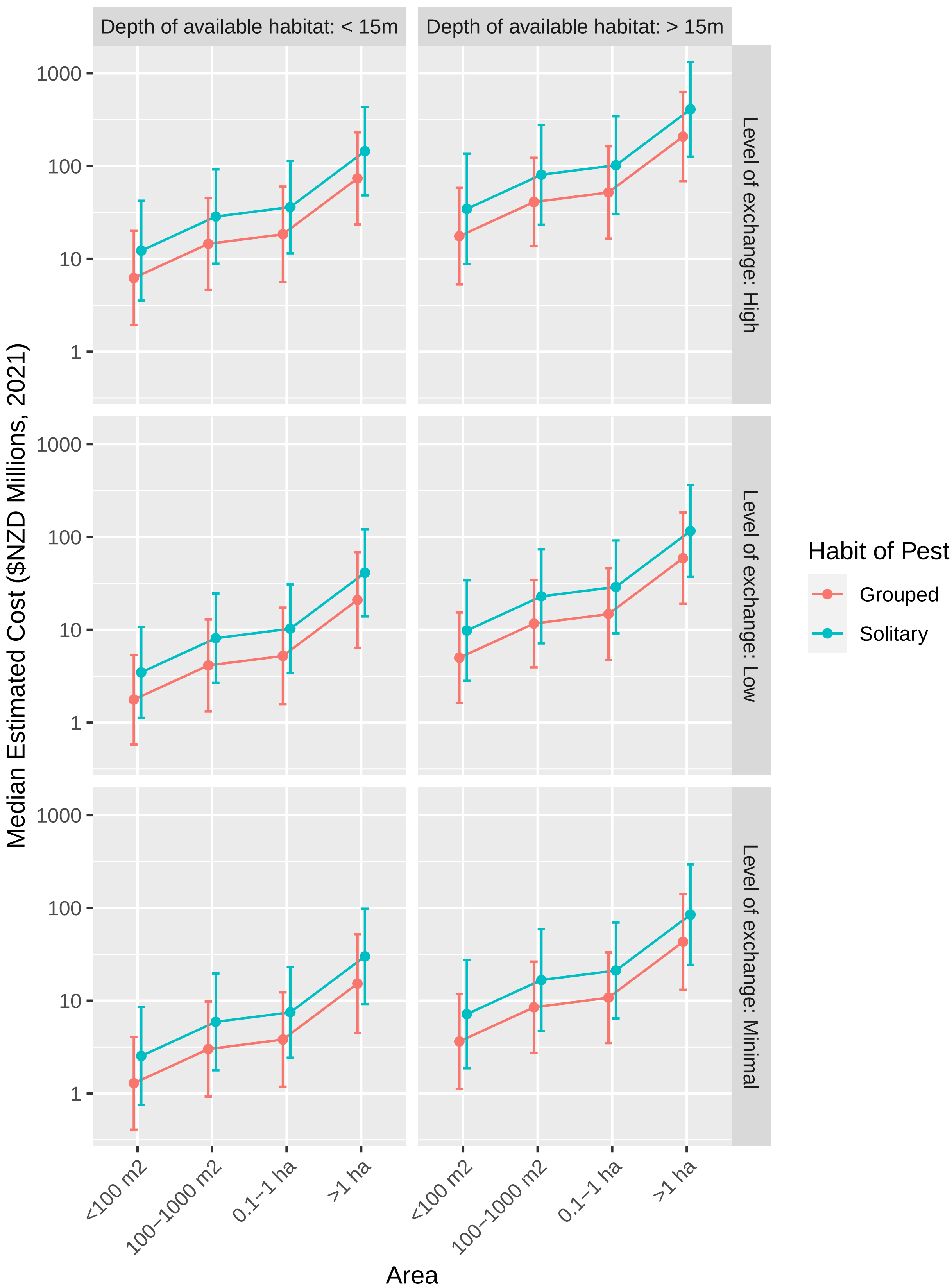

Figure 1.2: Predicted cost of 95% probability of successful eradication. The bars represent 95% confidence intervals. The y-axis is on log-10 scale. Amounts in 2021 New Zealand dollars (Crombie et al., 2007).

Chapter 2

Likelihood module fitting

Brown mussel can be transported by either biofouling (as adults) or ballast water (as larvae). In each case the pathway unit is the vessel. The likelihood module comprised the following components:[1]

- Raw exposure — the rate per 1000 at which units arriving on the pathway are contaminated with brown mussel (Section 2.1);
- Interventions — the activities that are performed or mandated by MPI to reduce the exposure and therefore the likelihood of incursion (Section 2.2);
- Attenuation from incursion to establishment — propagules that arrive past the border may still fail to establish (Section 2.4);

In this chapter, the expert-elicited values for raw exposure, impacts of interventions, and the consequent pathway-level exposure, are provided in Tables 2.1, 2.2, and 2.4 respectively. The tables are constructed as follows. The best guesses, lowest and highest values, are all averaged across all experts who responded to the question. A hyperlink is provided to each summary graph in the Appendix; for example, the summary graph for Question 1a in Table 2.1, which concerns the raw exposure to brown mussel via biofouling on high-risk ships, is in Figure C.1 and can be accessed by the hyperlink in the column of the table labelled "Graph".

The outcome of the likelihood module is the expected number of establishments per year.

2.1 Raw exposure on pathways

Table 2.1 provides the expert-elicited raw exposure rate for the pathways that were identified in the preliminary workshop as possibly carrying *P. perna* risk. We used the following definitions: *high-risk* commercial vessels are bulk carriers and tankers, and *brown mussel* ports are those in areas within *P. perna*'s geographic range.[2]

In each case the rate refers to the proportion of units on the pathway that are carrying minimum viable populations (MVPs) of brown mussel, defined after discussion with the expert group as 3 adults or at least 100,000–1,000,000 larvae.[3]

2.2 Interventions

Three different interventions are imposed on the different pathways that present *P. perna* risk, namely: (i) profiling and inspection of commercial vehicles, (ii) offshore discharge of ballast water, and (iii) profiling and

[1] A reviewer commented that better outcomes might result from a more faithful mapping of the components used in the modules to stages in the invasion pathway, namely Colonisation, Translocation, Transfer, Colonisation (again!) and Establishment. We agree with the comment but note that it would occasion an increase on the number of questions to be posed to experts, so sits in the broader question of the SEJ "budget" (Appendix D).

[2] `https://invasions.si.edu/nemesis/species_summary/568077`; blue is native range, red is introduced, and yellow is of uncertain origin, D. Kluza pers. comm. 2021.

[3] A reviewer commented that a cadre of three individuals in a biofouling community has a low likelihood of resulting in a self-sustaining population of *P. perna* establishing during typical vessel operations.

Table 2.1: Question 1: Expert-elicited raw exposure; number of units contaminated per 1000 in the absence of any biosecurity effort. High risk (HR) vessels are tankers and bulk carriers, others are low risk (LR). BM refers to arrivals from presumed brown mussel infected ports. Biof refers to biofouling and BW to ballast-water exchange. For ballast water risk, vessels are assumed to have taken on ballast in brown-mussel ports and discharged in New Zealand. The Graph column contains hyperlinks to the raw data.

Question	Summary	Best	Low	High	Graph
1a	Biof.: HR Ships (BM)	375.000	115.00	700.00	C.1
1b	Biof.: LR Ships (BM)	92.500	8.00	202.50	C.2
1c	Biof.: HR Ships (not BM)	1.000	0.00	8.00	C.3
1d	Biof.: LR Ships (not BM)	0.375	0.00	3.75	C.4
1e	Biof.: Yachts	281.750	62.75	539.25	C.5
1i	BW: HR Ships (BM)	186.250	41.25	447.50	C.6
1j	BW: LR Ships (BM)	82.500	13.00	225.00	C.7
1k	BW: HR Ships (not BM)	0.375	0.00	4.00	C.8
1l	BW: LR Ships (not BM)	0.050	0.00	1.75	C.9

inspection of yachts. [4] The effect of these interventions on the rate of arrival of MVPs on the pathways was elicited from experts and is presented in Table 2.2.

Table 2.2: Question 2: Expert-elicited impacts of interventions; number of units still contaminated after intervention on 1000 contaminated units. Prof. & Insp. refers to Profiling and Inspection. CV means commercial vessels (as opposed to yachts). The Graph column contains hyperlinks to the raw data.

Question	Summary	Best	Low	High	Graph
2a	CV Prof. & Insp.	740.000	550.00	856.00	C.10
2b	Offshore Discharge	822.500	547.50	982.50	C.11
2c	Yacht Prof. & Insp.	746.667	563.33	833.33	C.12

2.3 Pathway risk estimates

Given volumes of vessels on the pathways (provided by MPI), the expert-elicited raw exposure rates in Table 2.1 and the expert-elicited intervention benefits provided in Table 2.2, we can determine the rate at which MVPs arrive past the border. The vessels that presented the highest risk of arrival of *P. perna* according to the experts were 624 yacht arrivals (Table 2.3). A caveat is that we do not know how many yachts may have passed through brown mussel waters; the risk represented by private yachts may be overestimated if the yachts did not pass through locations where *P. perna* is present. Risk predictions could be improved if yacht masters were asked about their itinerary, and a reviewer commented that the risk of yachts being exposed to *P. perna* was unlikely (Appendix D).

2.3.1 Module check using border interceptions

In earlier-developed instances of the likelihood module, the predictions could be cross-checked by reference to intervention data (Robinson and Ormsby, 2021). In this case there are no records of border interceptions

[4] In project design we also considered within-tank ballast water treatment such as Type D-2 ballast water treatment systems but lacked the pathway information to apply this treatment.

Table 2.3: Pathway-level arrival rates before and after intervention. *Volume* is the number of vessels per year. *Approach* and *Impact* are percentages of vessels that are contaminated and risk reduction from interventions upon contaminated units, respectively. *Reduction* is the number of arrivals averted by the pathway intervention and *Remains* is the number of arrivals per year. High risk (HR) vessels are tankers and bulk carriers, others are low risk (LR). BM refers to arrivals from presumed brown mussel infected ports. Biof. refers to biofouling and BW to ballast-water exchange. Prof. & Insp. refers to Profiling and Inspection. CV means commercial vessels (as opposed to yachts).

Path	Volume	Approach	Intervention	Impact	Reduction	Remains
Biof.: HR Ships (BM)	4	37.50	CV Prof. & Insp.	26.00	0.39	1.11
Biof.: HR Ships (not BM)	882	0.10	CV Prof. & Insp.	26.00	0.23	0.65
Biof.: LR Ships (BM)	17	9.25	CV Prof. & Insp.	26.00	0.41	1.16
Biof.: LR Ships (not BM)	1321	0.04	CV Prof. & Insp.	26.00	0.13	0.37
Biof.: Yachts	624	28.18	Yacht Prof. & Insp.	25.33	44.54	131.27
BW: HR Ships (BM)	4	18.62	Offshore Discharge	17.75	0.13	0.61
BW: HR Ships (not BM)	882	0.04	Offshore Discharge	17.75	0.06	0.27
BW: LR Ships (BM)	17	8.25	Offshore Discharge	17.75	0.25	1.15
BW: LR Ships (not BM)	1321	0.01	Offshore Discharge	17.75	0.01	0.05

of brown mussel by MPI, if for not other reason than because of the difficulty of inspecting and identifying specific invasives within the relevant pathways (namely, discharged ballast water and biofouling). We retain this section as a place-holder.

2.4 Establishment after arrival

An MVP might arrive in New Zealand ports despite the interventions detailed in Section 2.2, but the population might still fail to establish. For example, adults may not mate, larvae may disperse or die, and so on. We account for this attenuation of risk by a simple expert-elicited multiplier, reported in Table 2.4. In each case, from ballast water discharge and biofouling, the rate of attenuation is about 20%.

Table 2.4: Question 3: Establishment rate; number of establishments arising from 1000 vessels. Biof. refers to biofouling and BW to ballast-water exchange. The Graph column contains hyperlinks to the raw data.

Question	Summary	Best	Low	High	Graph
3a	Establishment from Biof.	86.250	38.00	367.50	C.13
3b	Establishment from BW	135.500	87.88	452.50	C.14

The establishment rate from Table 2.4 can then be combined with the post-intervention arrival rate from Table 2.3 to create an expected establishment rate (Table 2.5). This is the annual rate at which populations of *P. perna* are expected to establish, based on the expert elicitation rates and the volumes of activity on the nominated pathways (here, number of vessels).

The expected number of established incursions per year across all pathways is 11.89 (sum of final column in Table 2.5). The exposure due to biofouling (11.606 *P. perna* MVPs/yr) was substantially higher than the exposure due to ballast discharge (0.284 *P. perna* MVPs/yr).

The expected port-level annual establishment rates per port show that the establishment risk is highest in Auckland due to the port's high exposure to biofouling (highest among all ports) and Tauranga because of greater exposure to biofouling and ballast water discharge, which is twice as large as the next highest port, which is New Plymouth (Table 2.5).

Table 2.5: Pathway-level post-border annual establishment rates. *Establishment* is the percentage of establishments per incursion. *Established* is the expected number of establishments per year.

Path	Intervention	Remains	Establishment	Established
Biof.: HR Ships (BM)	CV Prof. & Insp.	1.11	8.62	0.10
Biof.: HR Ships (not BM)	CV Prof. & Insp.	0.65	8.62	0.06
Biof.: LR Ships (BM)	CV Prof. & Insp.	1.16	8.62	0.10
Biof.: LR Ships (not BM)	CV Prof. & Insp.	0.37	8.62	0.03
Biof.: Yachts	Yacht Prof. & Insp.	131.27	8.62	11.32
BW: HR Ships (BM)	Offshore Discharge	0.61	13.55	0.08
BW: HR Ships (not BM)	Offshore Discharge	0.27	13.55	0.04
BW: LR Ships (BM)	Offshore Discharge	1.15	13.55	0.16
BW: LR Ships (not BM)	Offshore Discharge	0.05	13.55	0.01

Finally, the annual establishments are then divided among the ports according to the risks reported in the Ballast and Biofouling columns of Table 2.6, leading to the expected port-level annual establishment rates as reported in that table. The establishment risks seem highest to Auckland and Tauranga because of their greater exposure via the biofouling and ballast water discharge pathways.

A caveat is important: we have allocated all the likelihood among the ports proportionally to both their exposure to the risk of ballast water discharge and biofouling arising from commercial vessels. In doing so, we have assumed that the biofouling exposure for yachts is distributed among the ports identically to the biofouling exposure for commercial vessels. This assumption may not hold. It would be necessary to gather port-level yacht biofouling datasets to test whether it is reasonable.

Table 2.6: Relative exposure to biofouling and ballast discharge, from CEBRA Project 170618 (Hatami et al., 2021), and consequent annual establishment rate. Units for ballast water discharge are kilotons and for biofouling are tons. Taharoa is omitted as there is no data for it in Table 3.2.

Port	Biofouling	Ballast	Establishment
Auckland	70	308	2.8
Bluff	9	214	0.4
Dunedin	14	530	0.6
Gisborne	4	582	0.2
Lyttelton	30	905	1.2
Napier	26	823	1.1
Nelson	16	534	0.7
New Plymouth	10	1043	0.4
Picton	3	209	0.1
Tauranga	65	2206	2.6
Timaru	13	248	0.5
Wellington	25	288	1.0
Whangarei	9	609	0.4

2.4.1 Module check using detected establishments

There has been one example of an established invasive brown mussel population in New Zealand, which was on an oil rig. MPI reported this incursion as follows.[5]

> An oil rig was defouled (had fouling organisms removed from its below-water surfaces) in Tasman Bay in December 2007.
>
> It was later determined that *Perna perna* had been present on the oil rig at the time of its defouling. MAFBNZ initiated a response to this detection and in early March 2008 dredged the drop zone beneath the rig defouling sites. Debris from the seabed was removed and disposed of in a landfill. Any suspected *Perna perna* were removed, and the risk of the species establishing in New Zealand was greatly reduced.

The incursion response was estimated to cover 12.5 Ha and cost $200,000.

Consequently the establishment rate reported in Table 2.6 seems much higher than is supported by establishment records. In order to try to improve the alignment between the elicited and the observed establishment rates, we provided a third opportunity for the experts to update their estimates, and included in the elicitation spreadsheet a first-order approximation to the establishment rate that is implied by the expert's choices. The elicited establishment rate decreased but not sufficiently; these are the values reported in Table 2.6. A reviewer commented that these estimates were higher than expected and that the expert group may have been uncertain about whether establishment entails colonisation within the recipient location or the establishment of a self-sustaining population (Appendix D).

[5] Text taken from `https://apps.mpi.govt.nz/applications/nzpests-view/Article/1205/Perna-perna`, last accessed September 5, 2023.

Chapter 3

Consequences module fitting

The consequences module focuses on the effect of post-border activities upon the *consequences* of incursion. It comprises the following modules:

- Detection of the established pest — this is assumed to happen sooner or later, so the unknown is the size of the population at detection (Section 3.1); and
- Eradication of the population, for which the success probability and the cost are some function of the size of the population at the time of detection, which is of course unknown and therefore can be represented as a random variable in this strategic setting.

3.1 Incursion size at time of detection

In order to provide insight as to the potential value of the surveillance activities for *P. perna*, the incursion size at time of detection question included two scenarios, namely assuming the current surveillance system and assuming no surveillance at all.

Table 3.1: Question 4: Incursion size at time of Detection (ha). Number of 1000 incursions that are detected before reaching 100 ha.

Question	Summary	Best	Low	High	Graph
4a	Incursion Size at Detection under Current Surveillance	287.500	58.75	525.00	C.15
4b	Incursion Size at Detection under No Surveillance	161.750	10.00	365.00	C.16

We assumed that the probability density function (pdf) of the invading population size at the time of its detection is from the Weibull family, with shape parameter equal to two (see Robinson and Ormsby, 2021, for more detail). Following our earlier work and the expert-elicited values in Table 3.1, we obtained an incursion size distribution for the current surveillance system as

$$\text{Weibull}(\alpha = 2, \beta = 171.758),$$

and for the counterfactual of no surveillance system,

$$\text{Weibull}(\alpha = 2, \beta = 238.069).$$

These distributions are compared in Figure 3.1. The probability of detecting the invasive population before it reaches the largest Crombie size category cut-off (namely, 1 ha) is expected to be nearly twice as high under the current surveillance as opposed to a no-surveillance regime, but even then is very low, something like 0.003%. Consequently, invasive populations of brown mussel are considered to be very unlikely to be detected before they reach a size that would render eradication prohibitively expensive.

Predictions from terrestrial versions of this model were compared to data taken from GERDA,[1] but this database does not include aquatic species.

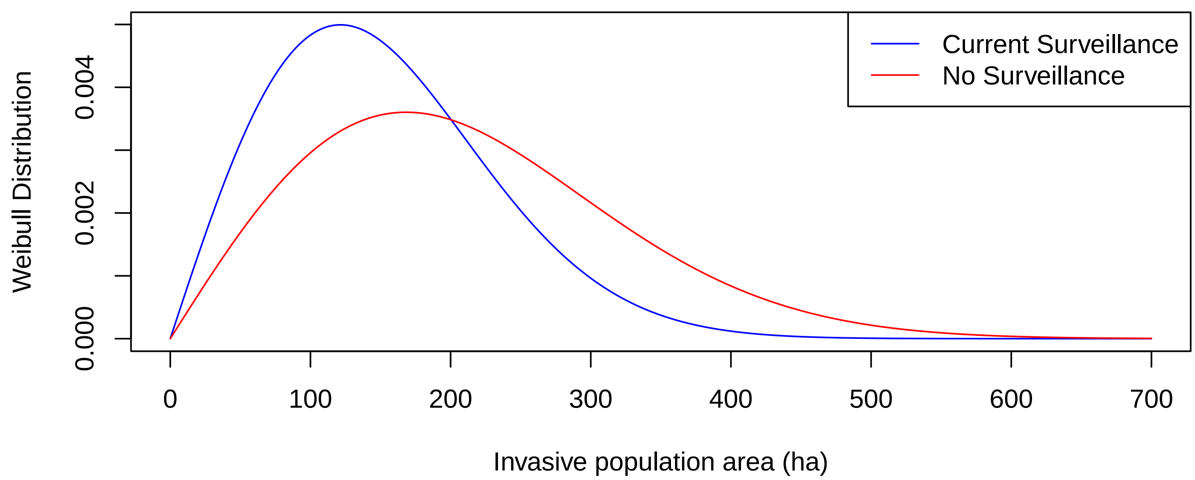

Figure 3.1: Probability density functions for the size of the incursion (ha) at the time point of detection.

3.2 Estimated cost of eradication

3.2.1 Model inputs

As noted earlier, in order to use the Crombie model, we need to know the *habit* (grouped or solitary, this is specific to the pest species), *incursion extent* (this is specific to the incursion instance), *maximum habitat depth* (specific to species and to incursion location, but fixed within each of the individual New Zealand ports), and *retention* (specific to incursion location but fixed within New Zealand ports). Each variable is categorical. Table 3.2 provides the values needed to run the model documented in Crombie et al. (2007) for eradication of any invasive marine population.

Habit

Brown mussel is a *grouped*, as opposed to a *solitary* pest (Crombie et al., 2007).

Retention

Retention depends on the location of the incursion and possibly the season. We assumed that the most important vectors for the pest were biofouling and ballast discharge from international vessel arrivals, so we focused specifically on only the ports that receive commercial vessels arriving from international waters.

Estimates of retention upon NIWA hydrodynamic modelling of particle dispersion (Inglis et al., 2006) and Google Earth Images of each port location, positioning in relation to mouth of the port and river mouth, and the mouth width of the harbour entrance.[2]

[1] See `https://b3.net.nz/gerda/`

[2] Information provided by Eugene Georgiades and Daniel Kluza of MPI.

Table 3.2: Estimates of Depth and Retention of New Zealand Ports of First Arrival (POFA).

Port	Depth[1]	Mouth Width[1]	Max. Depth by area (m)[2]		Crombie Depth	Crombie Retent.	Notes
Whangarei	4.5	1300	Channel	7.6	> 15	Low	Exchange based on Inglis et al. (2006)'s Appendix 4: Figure 4.
			Pier	9.1			
			Anchorage	21.3			
			Oil terminal	16			
Auckland	12	2030	Channel	10	< 15	Low (Min.)	Exchange based on Inglis et al. (2006)'s Appendix 4: Figure 137.
			Pier	9.1			
			Anchorage	12.2			
			Oil terminal	9.1			
Tauranga	14	540	Channel	10	< 15	Low (Min.)	Exchange based on Inglis et al. (2006)'s Appendix 4: Figure 138.[3]
			Pier	10			
			Anchorage	21.3			
			Oil terminal	13.7			
Napier	11	290	Channel	10	< 15	Low	Assumed anchorage outside port environment.
			Pier	12.2			
			Anchorage	21.3			
			Oil terminal	12.2			
Wellington	9.4	250	Channel	12.2	< 15	Low (Min.)	Exchange based on Inglis et al. (2006) Appendix 4: Figure 139.[3]
			Pier	9.1			
			Anchorage	10			
			Oil terminal	9.1			
Picton	9.1	190	Channel	13.7	< 15	Minimal	Assumed minimal exchange due to location at the end of Queen Charlotte Sound.[3]
			Pier	9.1			
			Anchorage	> 23.2			
Nelson	4.8	180	Channel	7.6[4]	< 15	Low (2.8 m. tidal diff.)	Exchange based on Inglis et al. (2006) Appendix 4: Figure 140.[3,5]
			Pier	9.1			
			Anchorage	12.2			
			Oil terminal	9.1			
Lyttleton	12.3	170	Channel	10	< 15	Minimal[6]	Exchange based on Inglis et al. (2006)'s Appendix 4: Figure 141.[3,5]
			Pier	9.1			
			Anchorage	12.2			
			Oil terminal	9.1			
Gisborne			Channel	10	< 15	Low	Assumed anchorage outside port environment.
			Pier	10			
			Anchorage	18.2			
New Plymouth			Channel	7.6	< 15	Low	Assumed anchorage outside port environment.
			Pier	10			
			Anchorage	18.2			
			Oil terminal	10			
Timaru			Channel	10	< 15	Low (Min.)	Assumed minimal exchange due to location of barriers mid port with mouth of ~ 100 m.
			Pier	10			
			Anchorage	13.7			
			Oil terminal	9.1			
Dunedin			Berth[7]	13.9	< 15	Minimal	Exchange based on Inglis et al. (2006)'s Appendix 4: Figure 142.[8]
Invercargill			Channel	9.1	< 15	Low	Exchange based on Inglis et al. (2006)'s Appendix 4: Figure 142.[3]
			Pier	10			
			Anchorage	15.2			
			Oil terminal	10			

[1] Depth and Mouth width in m. are taken from EPA MAMPEC document (where available), and included for information.
[2] https://www.searates.com/maritime/new_zealand.html
[3] Assumed anchorage outside port environment.
[4] Controlling depth is 7.6m in the main inside harbour channel at chart datum, and 8.1m in the outer channel at chart datum.
[5] http://www.portnelson.co.nz/operations/port-access-marine/
[6] Assumed minimal exchange due to outputs from MAMPEC model.
[7] https://www.portotago.co.nz/marine-and-shipping/berth-facilities/
[8] Assumed minimal exchange due to location compared to entrance of embayment.

Note that the variable is named 'Retention' in the Crombie model but the levels (minimal, low, high) refer to the amount of exchange, which might be considered the opposite of retention in common use.

Maximum habitat depth

The Crombie model divides maximum habitat depth into two classes, namely shallow ($\leq$ 15 m) and deep ($>$ 15 m). The nature of the habitat depends on the organism and the port and perhaps other factors.

Given the ports in scope for this exercise, we decided to declare (i) whether the port has *any* habitat at all, and (ii) if so whether *any* of the habitat could be below 15 m. This should be sufficient for the purposes of using the model. It seems unnecessarily fastidious to argue that an infestation might be in a part of the port that lacks deep habitat.

Depth estimates are based on NZ EPA inputs to MAMPEC (Gadd et al., 2011) and `https://www.searates.com/maritime/new_zealand.html`.

Area Infested

This part of the Crombie model aligns nicely with our elicitation approach, in that we elicit the probability of detecting the incursion before it reaches a certain size, which we then use to determine the cumulative distribution function of the size of the invading population upon detection.

3.3 Incursion impact: cost of management if not eradicated

The impact of *Styela clava* and *Sabella spallanzanii* on New Zealand green-lipped mussel *P. canaliculus* aquaculture was estimated as NZ$23.9 million and $14.0 million, and $26.4 million combined, over a 24 yr period (Soliman and Inglis, 2018). Societal impacts at the market level for the two species were $10.2M (7.4–91.9), $8.0M (2.5–56.7) and $10.7M (7.4–99.7), respectively.

Subsequent discussion among the experts noted that effects on the non-market values are difficult to assess; green-lipped mussels are a culturally (and economically) important species for Maori, so in addition to the issues raised by others, any effect of brown mussels on the availability of green-lipped mussels will have a disproportionate impact on Maori.

Recognising the limitations of this aspect of the model, we adopted the distribution of incursion impacts as $34.1M (31.4–115.8), ignored the uncertainty and used $34.1M, converted to 2021 $NZ as $35.8M.

3.4 Consequences module outputs

We now present the outputs of the consequences module. The estimated cost of a single establishment varied depending on the arrival port (Table 3.3), and the differences between the ports were driven by the effect of the different port characteristics upon the cost of eradication. Notably, the ports cluster into three groups distinguished as follows: (i) shallow habitat and minimal exchange (Dunedin, Lyttleton and Picton), (ii) deep habitat and low exchange (Whangarei), and (iii) shallow habitat and low exchange (all other ports).

Startlingly, the Crombie model predicted cost of eradication to 95% success probability in Whangarei is almost as high as the cost of an uneradicated incursion was estimated to be. Also, the increase in probability of detecting the incursion under the current surveillance compared with no surveillance is too small to make a significant difference to the cost of an establishment (comparing the two columns in Table 3.3).

Table 3.3: Estimated cost of a single establishment of brown mussel, by port and surveillance scenario (namely the *current*, and the counterfactual *no* surveillance scenario, Nil). Units are millions of 2021 New Zealand dollars.

Port	Current	Nil
Auckland	22.7	22.7
Bluff	22.7	22.7
Dunedin	17.1	17.1
Gisborne	22.7	22.7
Lyttelton	17.1	17.1
Napier	22.7	22.7
Nelson	22.7	22.7
New Plymouth	22.7	22.7
Picton	17.1	17.1
Tauranga	22.7	22.7
Timaru	22.7	22.7
Wellington	22.7	22.7
Whangarei	35.8	35.8

Chapter 4

Outputs

4.1 Results

The expected annual cost due to *P. perna* by port (excluding the costs of pre-border and border measures) were highest in Auckland and Tauranga (Table 4.1). The difference between the costs under the current surveillance and the counterfactual of no surveillance is negligible, because the existing surveillance system is not held under SEJ to substantially increase the probability of detecting the species within a timeframe that makes eradication economically feasible. The overall annual cost is \$263.8 million NZ (2021). If the experienced establishment rate were used in place of the estimated establishment rate then the overall annual cost would be less than \$1 million.

Table 4.1: Estimated annual cost of brown mussel, by port and surveillance scenario (namely the current, and the counterfactual no surveillance scenario). Units are millions of 2021 New Zealand dollars. Cost of risk-management measures are excluded, but effects are included.

Port	Cost (Current)	Cost (No Surveillance)
Auckland	62.6	62.6
Bluff	8.3	8.3
Dunedin	10.0	10.0
Gisborne	4.1	4.1
Lyttelton	20.8	20.8
Napier	24.1	24.1
Nelson	15.1	15.1
New Plymouth	9.6	9.6
Picton	2.0	2.0
Tauranga	59.7	59.7
Timaru	11.7	11.7
Wellington	23.1	23.1
Whangarei	12.8	12.8

4.2 Discussion

The expert-elicited estimation of the likelihood of brown mussel establishment is substantially higher than the detected establishment record would suggest (Section 2.4.1). This is the same outcome as observed for spongy moth (Robinson and Ormsby, 2021) for which reasonably arbitrary deflating multipliers were applied to the likelihood to better match the known establishment record. Instead of adopting such an approach we produced an updated elicitation instrument that allowed the experts to see the aggregated effects of their individual decisions, allowing them to revise their predictions. This approach still resulted in relatively inflated establishment rates.

Recommendation 2. In this study, as in Robinson and Ormsby (2021), the rates of establishment as elicited from experts were substantially higher than have been historically detected and recorded. MPI should request a CEBRA study to develop a protocol that guides expert elicitation so that compound estimates that have real-world interpretations are provided to the experts in real-time, to assist in SEJ model calibration.

4.2.1 Caveats

We consider the following caveats to be material in interpreting the results of this project.

1. The outcome of the project is sensitive to the size and composition of the expert pool that was recruited for the structured expert judgement exercise. Only five experts were available for the exercise, which means that the outcomes are relatively fragile to outliers. The results should be interpreted with this limitation in mind.
2. The apparent relative risks of the biofouling and ballast exchange pathways may result from different MVP definitions for each pathway. The use of different definitions is hard to avoid based on the physical settings.
3. Yachts may represent a significant risk to biosecurity in New Zealand but yacht movement data are not available. In particular, it is impossible to know whether yachts have passed through ports of brown mussel infestation, or how many of them have effective anti-fouling treatment.
4. Data on the general impact of brown mussel establishment were not available. A study on the economic impact of similar species was used instead (Soliman and Inglis, 2018).
5. This model assumes that the consequences are immediate and occur nationally, so nuance such as the location of the invasive population relative to vulnerable enterprises is ignored.
6. The distribution of risk according to biofouling exposure and ballast water discharge among the ports ignored ship origin and transits, and therefore ignored the risk status. It is possible that certain ports are more likely to be visited by ships that reflect a specific risk status. This gap could be corrected by use of the Lloyd's shipping data, of which MPI has a reasonably recent subscription.
7. As noted earlier, we have allocated all the likelihood to the ports proportionally to their exposure risk of ballast water discharge and biofouling exposure of commercial vessels. In doing so, we have assumed that the biofouling exposure for yachts is distributed among the ports identically to the biofouling exposure for commercial vessels. This assumption may not hold true.
8. Robinson and Ormsby (2021) noted that uncertainty propagation and expert-specific parameterisation ("aggregate late") are important components of the construction of structural models such as reported here. As the purpose of the current exercise was to establish the marine pest consequences module, these activities were undertaken in this instance.
9. This model assumed that the probability of detecting an invasive population was unaffected by its location. However, the presence or absence of deep habitat may affect the probability of detecting an invasive population. In that instance, an invasive population might be less likely to be detected in Whangarei. However, this consideration is probably less important than the risks associated with which vessels visit which ports.

4.2.2 Interpretation

Despite the numerous caveats listed in Section 4.2.1, the outcomes of the modelling exercise provide some useful information and insights. Even though the absolute exposures and costs reported in Tables 3.3 and 4.1 respectively might be too high, a comparison of their relative levels can be instructive. For example, Table 3.3 accords the highest risk to the port Whangarei because of its deep habitat, whereas Table 4.1 shows that the effect of deep habitat is dwarfed by the relative exposure rates developed in the likelihood section. The fact that the likelihood of exposure dwarfs the consequences that reflect the characteristics of the port suggests that more careful consideration be applied to allocating the exposure risks to the ports (see caveat 6 above).

Recommendation 3. Exposure likelihood is a dominant factor in the relative risk of ports to *P. perna* establishment. MPI should consider updating the exposure model to account for the transit of vessels through brown mussel infested ports, using Lloyd's data.

Three parts of the consequences module as developed here are specific to the invasive species in question, namely (i) its habit as invoked in the Crombie model (solitary or grouped), (ii) the likelihood of detecting an invasive population as a function of its size (Figure 3.1), and (iii) the consequences of an uneradicated invasive population, whether that occur because of failure in eradication or not attempting to eradicate. This consequences module should therefore be directly applicable to other invasive marine species by resolving these three unknowns.

4.3 Conclusions

The purpose of this report is to describe a new marine pest consequences module, which differs from the terrestrial pest consequences module as developed by Robinson and Ormsby (2021). The new marine pest consequences module operationalises an existing model proposed by Crombie et al. (2007). The advantage of this approach is that generalising the outcome to other species should be relatively straightforward. The likelihood (pre-border and border) module presented here is the same as for spongy moth (Robinson and Ormsby, 2021), although described here in more detail.

Bibliography

Crombie, J., Knight, E., and Barry, S. (2007). Marine Pest Incursions — A Tool to Predict the Cost of Eradication Based on Expert Assessments. Technical report, Australian Government, Bureau of Rural Sciences.

Gadd, J., Depree, C., and Hickey, C. (2011). Relevance to New Zealand of the OECD emission scenario document for antifouling products: Phase 2 report. Technical Report 2006-17, NIWA report for the Environmental Protection Authority (EPA), Wellington.

Hatami, R., Lane, S., Inglis, G., Todd-Jones, C., Seaward, K., and Robinson, A. (2021). Improving New Zealand's marine biosecurity surveillance programme. Technical Paper 170618, Biosecurity New Zealand.

Inglis, G., Hurren, H., Gust, N., Oldman, J., Fitridge, I., Floerl, O., and Hayden, B. (2006). Surveillance design for early detection of unwanted exotic marine organisms in New Zealand. Technical Report 2006-17, Biosecurity New Zealand Technical Paper.

Robinson, A., Brockerhoff, E., and Ormsby, M. (2018). Scoping the value and performance of interventions across the NZ biosecurity system. Peer-Reveiwed Technical Report 1606E, CEBRA.

Robinson, A. and Ormsby, M. (2021). Proportional value of interventions across pathways and layers of the biosecurity system. Final Report 170621, CEBRA.

Soliman, T. and Inglis, G. J. (2018). Forecasting the economic impacts of two biofouling invaders on aquaculture production of green-lipped mussels *Perna canaliculus* in New Zealand. *Aquaculture Environment Interactions*, 10:1–12. `https://doi.org/10.3354/aei00249`.

Appendix A

Phase 1 conference call

Expert elicitation workshop: Preliminary Conference Call for Brown Mussel (*Perna perna*). 25 March 2019. Attendees: Graeme Inglis (marine biosecurity), Chris Woods (marine biosecurity), Daniel Kluza (marine biosecurity and risk assessment), Jonathan Gardner (marine biosecurity; molecular and ecological), Michael Ormsby (plant biosecurity, MPI), and Andrew Robinson (CEBRA).

1. Introductions (AR, 5 min)
2. Project background (AR, 5 min)
3. Expert elicitation protocol (AR, 10 min)
4. Preliminary Questions – for now (AR & MO, 30 min)

   (a) What is the minimal propagable unit (MPU), that is, the smallest size of the likeliest invasive life stage that may result in an establishment? (AR)
   G: Need a male and female.
   D: Larvae need magic number
   J: sex ratios 1:1, therefore 2.
   G: allee effects – minimum pop size
   G: q suited to elicitation further on. Set smallest size and upper limit.
   A: ok to explore? Smallest size: 2. Upper limit:
   G: logistic increase in mind. Upper: higher for larvae than adults.
   J: mx min?
   A: yes
   M: FF have sex ratio 1:1. Minimum size at 3. Upper 50 eggs. All conditions.
   G: if larvae in BW then establishment requires settling, and adults then to be close enough for MF reproduce. Biofouling MF adult create offspring but do they establish in area? Different probabilities from adults or larvae.
   A: ok to say biofouling adults and BW larvae?
   G: probably ok.
   A: let's split – larvae under average circumstances
   J: 1e5 – 1e6.
   G: agrees. How many eggs from spawn?
   J: 1e7 from one female.
   A: adults?
   G: 1 decent fertilization from 1 female to get enough eggs for establishment.
   G: 3, using FF analogy?

   (b) What are all the pathways / vectors by which the pest may enter New Zealand? (MO)
   G: vessel biofouling, but different vessel types. Towed oil rigs.
   G: Gut feeling commercial vessels small numbers per vessel. Oil rigs big.
   List: oil rigs, commercial vessels, recreational vessels, bulk carriers and tankers, passenger vessels,

containers + fishing vessels (foreign charters?)(South Africa).
G: slower vessels are higher risk. Deeper water safer; coastal fouled.
BW: tankers bulk carriers heavy lift ships; and others.
Biofouling: commercial / cruise, rec, rigs.
C: flotsam?
M: is it of the same order of magnitude.
C: noted.

(c) For each pathway, what are the units of biosecurity intervention? (MO)

(d) On each pathway, what are the measures that may affect the biosecurity risk before or at the border? (MO) BW: G: Open-ocean exchange, increasing treatment systems (3-5% atm)
B: D: management plan with inspection result. Targeting? Auditing?
M: generic and specific.
D: don't always have anti-fouling or have old. Selective. Risk matrix. Elevation to inspection. Variety.
G: not species specific.
M: Profiling all vessels.
A: how many inspected?
D: low. 1800 vessels 22% audited 18% failed, of which 20% had direction (14). Measures → audited.
M: May be irrelevant to *Perna perna*.

(e) What is the best metric of incursion size at the time at which the incursion is detected we can use to describe the incursion? (AR)
G: tried area and count; ended up with combination. Area, rather than numbers, based on next question.
J: depends on stage as well. 6 on a jetty is easy to count.
G: NZ example: rig had been cleaned; specimen were Pp. Overseas: incursions reported after establishment; area makes sense.
M: FF has a surveillance grid. More sensitive than it needs to me. Single male is inadequate for incursion. 5 males or single juvenile. 6 adults on a post would occasion a response. Is 2 an incursion? What is likely detection scenario?
G: 1000 to 10000.
J: unless we get lucky, e.g. Undaria.
G: density also relevant. Have modelled both ways.

(f) What is the largest incursion size at which you think that eradication will still be attempted? (AR)
J: Ports aren't particularly ecologically sensitive.
G: right in the public eye. Political dimension.
G: previous nearly 13 ha, 44 m of water, far from port.
M: 1 ha 50B have a go. 50 ha less then not have a go.
J: NZ govt would look good. Recover in 3 years.
G: cost scales with area.
J: density of population hugely important. 100 hectares.
G: report by ABARES cost estimator for marine eradications. Can send.
M: revisited: 0.5 ha

5. Demonstration of expert elicitation protocol (AR, 30 min). For a given pathway (ships), imagine 1000 random, representative units (or more, e.g. 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 MPU of the pest?

(a) List the reasons that this number might be low. What factors mitigate against these units carrying an MPU of the pest in question? NB: please exclude ALL existing biosecurity measures for this question!
Short deployment, dry carried instead of towed, recent defouling.

(b) Record a lower limit of the 1000 random, representative units that you would expect could be carrying at least one MPU of the pest, specifically that you think would be exceeded 1 in 16 (four heads in four tosses).
A: 5% or less?
J: 50-100.

(c) List the reasons that this number might be high. What factors mitigate in favour of these units carrying an MPU of the pest in question?
D: Because they're oil rigs.
G: sit still.
D: usually not antifouled.

(d) Record an upper limit of the 1000 random, representative units that you would expect could be carrying at least one MPU of the pest, specifically that you think would be exceeded 1 in 16 (four heads in four tosses).

(e) Record your best guess at the number of the 1000 units carrying at least one MPU of the pest.

6. Wrap up and debrief (AR, 5 min).

Appendix B

Phase 2 workshop

B.1 Workshop minutes

Expert Elicitation Workshop, 11 June 2019. Attendees — Ian Davidson, Jonathan Gardner, Graeme Inglis, Eugene Georgiades, Dan Kluza, Mike Ormsby, Andrew Robinson, and many cookies.

Biofouling :

- What are the high risk vessels for biofouling? Risk factors are recent history and condition.
- From conversation — yachts and oil rigs. Others include any vessel with an operational profile that would mean low maintenance, poor antifouling, etc.
- All yachts from BM areas will come through Panama Canal which is fresh water and as such risk will decline.
- 2004-07 200 yachts surveyed — NZ on circuit, through Panama Canal, then islands, then NZ.
- 16% of bulk carriers have biofouling — study covered all commercial vessels and was voluntary.
- 30% may have bivalves on them based on operational profile.
- Baseline assumption: Antifouling or not? Include antifouling in baseline (as almost always done) but note it may be degraded due to maintenance.
- Split Yachts and Commercial Vessels high and low risk.
- HR Yacht operational profile — More than 1 year since antifouling (new coating out of water)
- HR Commercial vessel operational profile — 500 days which equals about half service life (service life of 5 years). Lay-up period also important — greater than 8 days (90% of bulk carriers). Cont. ships on "bus route" do not lay-up.
- Interventions: Commercial — Offshore inspection etc. Yachts — reporting only. Baseline is for yachts is that they must meet a higher level of hull cleanliness (as they are most likely long stay). Majority inspected on arrival but not baseline as $$.
- Rate of infestation — studies show that the distribution of infestation rate of infested vessels declines quickly with a long tail e.g. few are heavily infested, most have small infestations.

Ballast water :

- 18 to 20 days for transit of from BM ports. After 20 days very little survives.
- Commercial vessels only. Some big recreational vessels and fishing boats do carry ballast but low numbers/volume, likely to keep it, and on circuit so will take time to get here.
- Tankers and bulk carriers have more water than others. Need to carry and discharge in NZ. Offshore discharge will mitigate.

BM areas :

- Tropical Atlantic (Up to Portugal, Brazil, failed in Florida (perhaps)), Western Med, Southern India and Northern Sri Lanka.

Eradication data for BM :

- No data in GERDA. Crombie et al. (2007) estimator from ABARES could be used but based on expert elicitation.
- 12.5 ha incursion cost $200,000 in NZ, calculated out to 100 ha would be around $1.2 million (as a lower number). Would need to include ongoing surveillance etc.
- Complex question given the complexity of the environments possible infested.
- Will take discussion offline to see if eliciting information for Crombie model will work better.

What does readiness mean? Current state is that we are not ready, so the counter-factual is a state of readiness, factors of which (e.g. surveillance etc.) must be agreed by experts.

B.2 SEJ questions and specific notes

The questions were originally numbered 9–14 in the workshop. Question enumeration is rescoped to facilitate comparison with text.

1a Consider high-risk commercial vessels that have moved through brown mussel ports. Imagine 1000 random, representative commercial vessels arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of commercial vessels that could be carrying at least three adult brown mussels in biofouling.

- LR factors: outside of post spawning larvae settlement period (could spawn all year in native regions); fast turn-around time in port; attrition for long voyages/pass through fresh water (Panama canal); very decent (high spec) biofouling coating; has been subject to in-water cleaning; Visiting environmentally unsuitable ports for long length of time e.g. cold, fresh/brackish water, etc.
- HR factors: opposite to LR e.g., fast and direct route to NZ.

1b Consider low-risk commercial vessels that have moved through brown mussel ports. Imagine 1000 random, representative commercial vessels arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of low-risk commercial vessels that could be carrying at least carrying at least three adult brown mussels in biofouling.

- LR factors: recently out of dry dock. Other reasons hold as above.
- HR factors: poor application of antifouling; niche areas problem; damage to hull coating.

1c Consider high-risk commercial vessels that have NOT moved through brown mussel ports. Imagine 1000 random, representative commercial vessels arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of commercial vessels that could be carrying at least three adult brown mussels in biofouling.

- LR factors: Zero? Or close to it.
- HR factors: BM in areas not already identified; pick up infestation passing through BM area (not stopping at port, slow moving); interact with infested vessel.

1d Consider low-risk commercial vessels that have NOT moved through brown mussel ports. Imagine 1000 random, representative commercial vessels arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of low-risk commercial vessels that could be carrying at least three adult brown mussels in biofouling.

- LR factors: Zero? Or close to it.

- HR factors: poor application of antifouling; niche areas problem; damage to hull coating; BM in areas not already identified; pick up infestation passing through BM area (not stopping at port, slow moving); interact with infested vessel.

1e Consider high-risk yachts that have moved through brown mussel ports. Imagine 1000 random, representative yachts arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of yachts that could be carrying at least three adult brown mussels in biofouling. (DEF: More than one year out of service life.)

- LR factors: outside of post spawning larvae settlement period (could spawn all year in native regions); fast turn-around time in port; attrition for long voyages/pass through fresh water (Panama canal); very decent (high spec) biofouling coating; has been subject to in-water cleaning; Visiting environmentally unsuitable ports for long length of time e.g. cold, fresh/brackish water, etc
- HR factors: opposite to LR e.g. fast and direct route to NZ; poor husbandry.

1f Consider low-risk yachts that have moved through brown mussel ports. Imagine 1000 random, representative yachts arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of low-risk yachts that could be carrying at least carrying at least three adult brown mussels in biofouling. (DEF: Less than one year out of service life.)

- LR factors: recently out of dry dock. Other reasons hold as above.
- HR factors: poor application of antifouling; niche areas problem; damage to hull coating.

1g Consider high-risk yachts that have NOT moved through brown mussel ports. Imagine 1000 random, representative yachts arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of yachts that could be carrying at least three adult brown mussels in biofouling.

- LR factors: Zero? Or close to it.
- HR factors: poor application of antifouling; niche areas problem; damage to hull coating; BM in areas not already identified; pick up infestation passing through BM area (not stopping at port, slow moving); interact with infested vessel.

1h Consider low-risk yachts that have NOT moved through brown mussel ports. Imagine 1000 random, representative yachts arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of low-risk yachts that could be carrying at least three adult brown mussels in biofouling.

- LR factors: Zero? Or close to it.
- HR factors: poor application of antifouling; niche areas problem; damage to hull coating; BM in areas not already identified; pick up infestation passing through BM area (not stopping at port, slow moving); interact with infested vessel.

1i Consider high-risk commercial vessels that have taken on ballast at a brown mussel ports. Imagine 1000 random, representative commercial vessels arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of commercial vessels that could be carrying at least 100,000 brown mussel larvae in ballast water. (Def: Higher volume of ballast (bulk carriers and tankers); taken on ballast water in BM port; not discharged before arriving in NZ; vessels that discharge (some BW) in NZ.)

- LR factors: Slow transit (¿20 days from loading); seasonality (spawning); ports with low infestation rates.
- HR factors: Ports with high infestation rates; high transit speed.

1j Consider low-risk commercial vessels that have taken on ballast at a brown mussel ports. Imagine 1000 random, representative commercial vessels arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of low-risk commercial vessels that could be carrying at least 100,000 brown mussel larvae in ballast water. (LR Def: Low volume ballast (not a bulk carrier or tanker); taken on ballast water in BM port; not discharged before arriving in NZ; vessels that discharge (some BW) in NZ.)

- LR factors: Slow transit (¿20 days from loading); seasonality (spawning); ports with low infestation rates.
- HR factors: Ports with high infestation rates; high transit speed.

1k Consider high-risk commercial vessels that have NOT taken on ballast at a brown mussel ports. Imagine 1000 random, representative commercial vessels arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of commercial vessels that could be carrying at least 100,000 brown mussel larvae in ballast water.

- LR factors: Zero?
- HR factors: Picking up ballast water recently discharged from ballast picked up at BM port.

1l Consider low-risk commercial vessels that have NOT taken on ballast at a brown mussel ports. Imagine 1000 random, representative commercial vessels arriving in New Zealand without any biosecurity measures in place, that is, the raw, unrefined exposure. Think about the number of low-risk commercial vessels that could be carrying at least 100,000 brown mussel larvae in ballast water.

- LR factors: Zero?
- HR factors: Picking up ballast water recently discharged from ballast picked up at BM port.

2a Consider onshore profiling and inspection of commercial vessels. Imagine 1000 random, representative commercial vessels, each of which would have been contaminated with at least three brown mussel adults by biofouling. Imagine that each of these 1000 contaminated commercial vessels are subjected to offshore certification and inspection. Think about how many of the units would subsequently be clear of BM.

- Def: Efficacy of profiling + inspection + cleaning. Profiling on maintenance condition and lay-ups (record books).
- L Efficacy factors (most not clear): Low risk vessels are the contaminated; Poor inspection skills; Small infestation size; poor cleaning application.
- H Efficacy factors (most are clear): High risk vessels are the contaminated; good inspection skills; large infestations; good cleaning application.

2b Consider offshore ballast exchange by commercial vessels. Imagine 1000 random, representative commercial vessels, each of which would have been contaminated with at least 100,000 brown mussel larvae in ballast water. Imagine that each of these 1000 contaminated commercial vessels are subjected to offshore ballast exchange. Think about how many of the units would subsequently be clear of BM.

- L Efficacy factors Poorly executed exchange; too close to NZ; Flow-through refill (not 100% exchange).
- H Efficacy factors Empty refill more effective.

2c Consider on-arrival inspection of yachts. Imagine 1000 random, representative yachts, each of which would have been contaminated with at least three brown mussel adults by biofouling. Imagine that each of these 1000 contaminated yachts are subjected to on-arrival certification and inspection. Think about how many of the units would subsequently be clear of BM.

- L Efficacy factors (Most yachts are inspected); Infestation is cryptic; poor inspection skills; poor cleaning effort.

- H Efficacy factors Opposite.

2d Consider offshore ballast exchange by commercial vessels. Imagine 1000 random, representative commercial vessels, each of which would have been contaminated with at least 100,000 brown mussel larvae in ballast water. Imagine that each of these 1000 contaminated commercial vessels are subjected to in tank treatment (ballast water management systems). Think about how many of the units would subsequently be clear of BM.

- L Efficacy factors System employed/applied is not completely effective; poor maintenance; human error (poor use of system e.g. low training).
- H Efficacy factors Opposite.

3a Consider biofouling. Imagine 1000 random, representative marine vessels, each of which is contaminated with at least three adult brown mussels by biofouling, arriving at NZ. Think about how many of these arrivals will lead to establishment of the pest.

- LR factors: Contamination is widely separated; environment unsuitable (larval survival etc.); high port flushing; short stay; predators present in numbers; no/few suitable settlement areas; Allele effect (low numbers); not spawning.
- HR factors: Opposites. Adults fall off and establish a population.

3b Consider ballast water. Imagine 1000 random, representative marine vessels, each of which is contaminated with at least 100,000 brown mussel larvae in ballast water, arriving at NZ and discharging. Think about how many of these arrivals and discharges will lead to establishment of the pest.

- LR factors: Environment unsuitable (larval survival etc.); high port flushing; predators present in numbers; no/few suitable settlement areas; Allele effect (low numbers); dilution effect of discharge; long voyage (larvae not in good condition).
- HR factors: Opposites.

4a Imagine 1000 random, representative instances of successful establishment of the pest. Think about how many of these instances will be detected before the incursion reaches 100 ha with the current biosecurity surveillance.

- Current lack of targeted surveillance.
- LR factors: Other native/endemic species present that are difficult to distinguish from BM; Patchy 100 ha; Not public/industrial area; In subtidal area therefore harder to find.
- HR factors:

4b Think about how many of these instances will be detected before the incursion reaches size 100 ha with targeted biosecurity surveillance (e.g., port surveys and eDNA).

- eDNA detects presence, survey determines where it is etc.
- LR factors: Sampling method may not get infested water; misinterpret signal; sampling at wrong time; Growth to 100 ha between surveys (survey frequency to infrequent).
- HR factors: Opposite

5a Imagine 1000 random, representative instances of an incursion that has reached 100 ha. Think about what would be the cost of an eradication attempt, whether successful or not.

5b Imagine 1000 random, representative instances of an incursion that has reached 100 ha. Think about what would be the cost of an eradication attempt, whether successful or not, in the absence of NZ's readiness.

6a Imagine 1000 random, representative instances of an incursion that has reached 100 ha. Think about what would be the probability of eradication success, funded at a given level (Q 13).

6b Imagine 1000 random, representative instances of an incursion that has reached 100 ha. Think about what would be the probability of eradication success, funded at a given level (Q 13), in the absence of NZ's readiness.

Questions 5 and 6 were deferred pending assessment of Crombie approach.

B.3 Workshop debrief

1. Can we find out the retention (as defined in Table 1.1) for the New Zealand ports that receive marine vessels from international waters?

   JG: If no such data exist, might be possible to have some sort of qualitative guesstimate - some sort of ranking - that provides a guide to level of retention aligning with low/medium/high in Table 1.1

   EG: NIWA report to EPA by Gadd et al (2011) has some port-by-port data that could help (incl. depth, size, water flow etc)

   JG/EG/ID: Two sides to this: high and low water retention could promote establishment for different reasons (biology of organism); low retention areas may promote self-dispersal of propagules, but high retention areas (harbors) may have more vectors. Retention of whole bay versus conditions at ports and harbours within bays should be considered.

   GI: Remember that this variable is part of the Crombie et al (2007) model to predict the level of resourcing needed to give eradication attempts a high chance of success. Implicit in this is that the prospects for eradication are affected by the ability to delimit and contain. In this context, human vectors are not relevant since they can (theoretically and legally) be contained. Retention relates more to natural containment of the population and the prospects for detection and delimitation if larvae of the organism are scattered widely over a large area. W.R.T. information on retention, see the attached reports by Gadd et al (2011) and Inglis et al (2006).

2. Is it reasonable to classify the ports by whether or not they have any suitable deep habitat, or should we worry about the relative proportions of shallow and deep habitat within the ports?

   JG: binary presence/absence is fine if data don't exist

   ID: In the particular case of brown mussels, is there much restriction on suitability of potential habitat? The eradication of BM in Tasman Bay outlined by Hopkins et al (2011) was soft-sediment at around 44m depth. Is the seafloor of all ports & harbors potential habitat? Is temp/salinity a bigger deal?

   GI: Temp. and salinity were not relevant to the Crombie et al (2007) because the model assumes that an incursion has occurred. It does not address the prospects for establishment. Depth in the model really relates to how easy/difficult it is for response operations (divers, etc) to be implemented.

3. Can we find out whether the New Zealand ports that receive marine vessels from international waters (i) have any *P. perna* habitat, and (ii) have any deep *P. perna* habitat?

   JG: intertidal, shallow and deep may be worth considering (not just subtidal categories)

   EG: All ports likely to have BM habitat, temperature is probably a bigger issue. Also NEMESIS highlights wide-range of potential habitat for BM

   ID: Temp (and possibly salinity) may be more discriminating

   GI : See my comment above. Temp. and salinity are only relevant if considering prospects for establishment. If dealing with the likelihood of eradication, given that an incursion has occurred (as the Crombie et al 2007 model does), then they have no real bearing. In the Crombie model the depth variable had three levels (¡ 2m, 2-15 m and ¿ 15 m). The model coefficients are calculated relative to the ¡ 2m level. That level should also be considered as including intertidal habitats.

4. Do you think that detectability of the incursion will vary depending on the retention and/or the depth of habitat? That is, when we elicit the probability that an incursion could reach large size before it is detected, should we do so specifying the system's retention and whether or not it has deep habitat?

JG: both factors are important, may not be able to provide good answers at this level of inquiry/detail

EG: High retention likely to positively affect establishment and pool/cluster invader meta-populations. Depth and habitat type will drive detection and influence decisions about response.

JG: both factors are important, may not be able to provide good answers at this level of inquiry/detail

EG: High retention likely to positively affect establishment and pool/cluster invader meta-populations. Depth and habitat type will drive detection and influence decisions about response.

ID: Depth should have a major effect on detection. Passive detection much less likely in deep habitats and only possible in surveillance if designed into it. The two-sided aspect of retention suggests it may not be a useful factor for estimating detection (is it easier to detect concentrated and contained or dilute and dispersed invaders?).

Response not necessarily more difficult or expensive if the incursion is in deep water – the one example we have from NZ shows this (albeit very context dependent). Incursion across a range of shallow habitats (port structures, pilings, adjacent natural & artificial habitat) would be more difficult to tackle than a large deep incursion on relatively uniform sea-floor.

GI: Again, if we are to consider the Crombie et al (2007) model an expression of expert knowledge on the factors that affect the likelihood of eradication in marine environments, then there seems no point in relitigating the model. Remember that, in arriving at the final model, the analysis considered a range of potential predictors of success, including:

- Size of the organism
- Appearance
- Habit
- Preferred habitat
- Larval duration
- Time to maturity
- No. propagules per reproductive event
- No. reproductive cycles per year
- Capable of asexual reproduction
- Area infested
- Profusion
- Pattern of infestation
- % utilization of habitat
- Maturity of organisms detected
- Max. depth of infestation
- Max. depth of available habitat
- Turbidity
- Retention of water in the incursion area

5. Does anyone have any insight as to the potential market & non-market value of an unmanaged / unmanageable *P. perna* outbreak?

JG: No $ values, but could estimate effects on Greenshell mussel industry from direct fouling; BM as a disease agent; can't rule out hybridization between Greenshell & brown (though unlikely); possible competition/displacement on NZ shores; impact on native marine ecosystem services; novel fouler may change fouling pressure

EG: NEMESIS has some general impact text

ID: we could possibly guesstimate market effects, or Graeme has recent experience with bioeconomic modeling pest impacts on mussel farming (Soliman and Inglis, 2018). Estimates are likely to involve many sectors or sub-sectors, nearly always without much information. Agree with JG's list, and below!

GI: Our paper on the potential economic impacts of the Mediterranean fanworm really only addresses direct impacts on producers and markets for NZ's green shell mussels. It also only considers reduction in production through competition for food (not displacement). Nevertheless, there are some data used to parameterize the model that will be relevant here. Effects on the non-market values are much more difficult to address. Greenshell mussels are a culturally (and economically) important species for Maori, so in addition to the issues raised by others, any effect of brown mussels on the availability of Greenshell mussels will have a disproportionate impact on Maori.

Appendix C

SEJ results

This appendix presents the SEJ workshop results as graphical summaries of the round two estimates. The full phrasing of the questions is provided in Section B.2. The graphs can be interpreted as follows. The title provides the name of the relevant module for which the value is being elicited. The experts are arranged on the y-axis, in order from the highest mean (lowest on the axis) to the lowest mean (highest on the axis). The x-axis provides the scale for the best guess (blue diamond) and the upper/lower bars that delimit the interval. The mean interval provides the average of the best guesses and upper and lower intervals. The expert interval coverage rate is provided on the secondary y-axis.

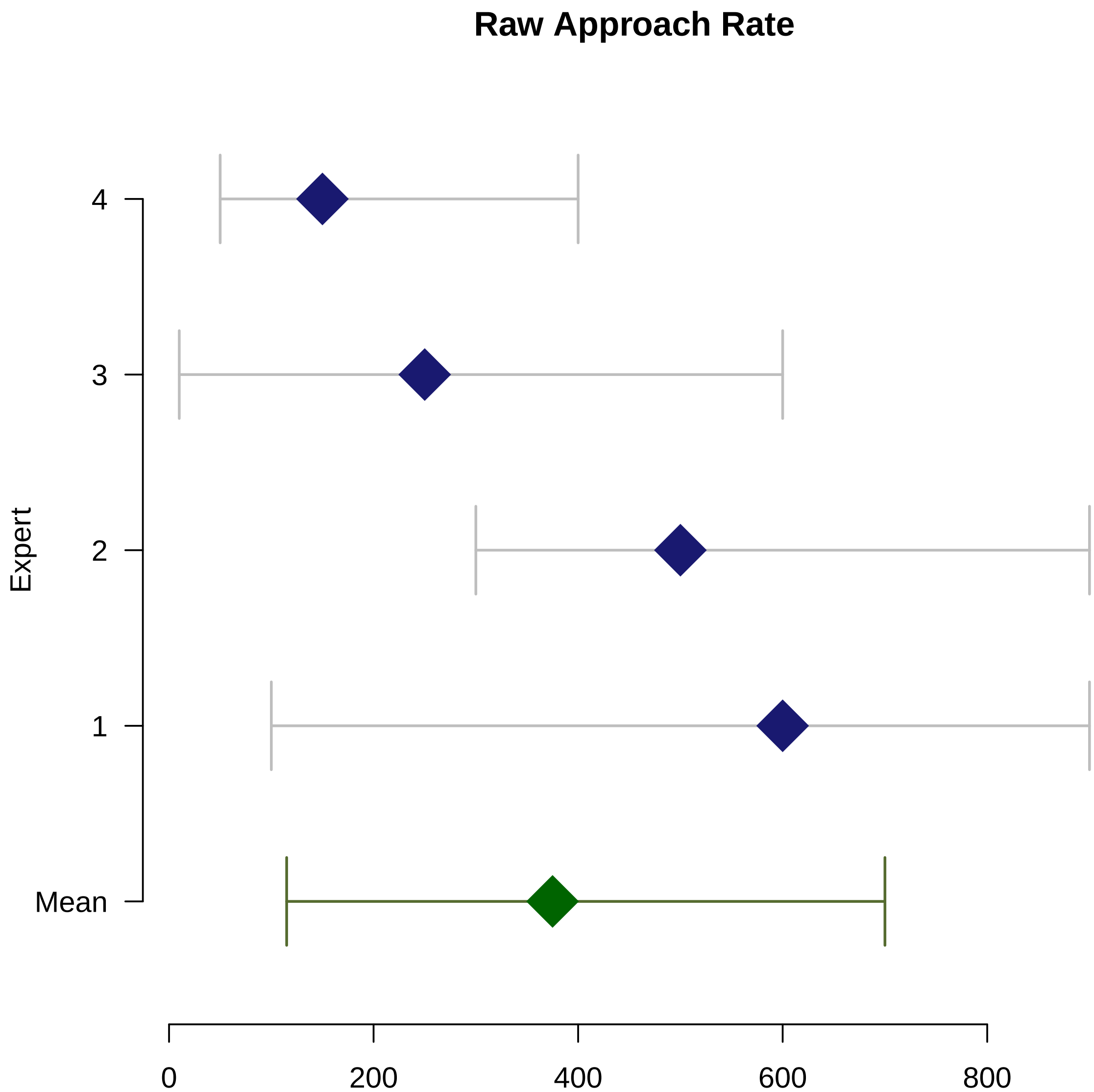

Figure C.1: Question 1a; Biofouling: high-risk ships (Ports with Brown mussel).

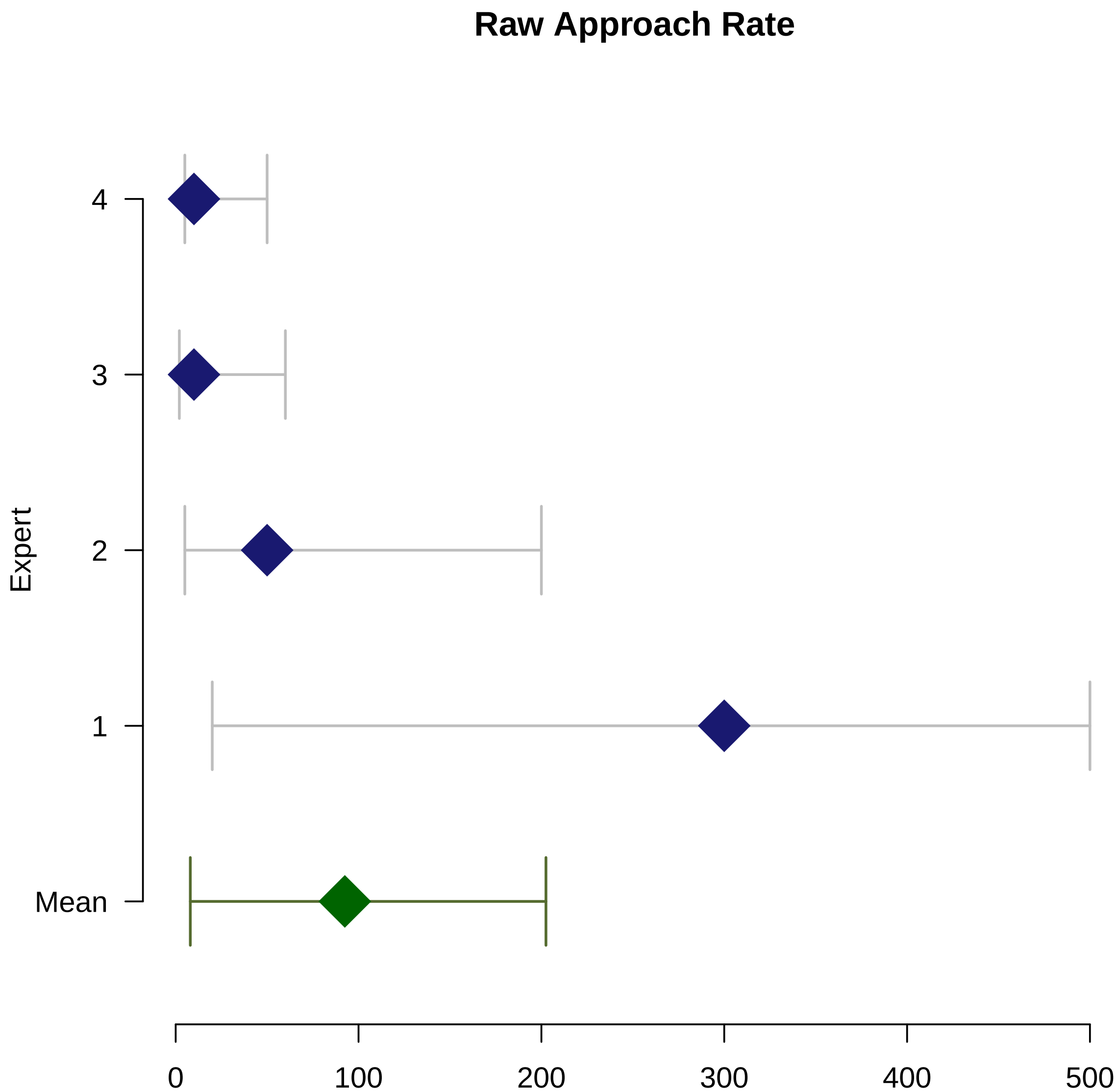

Figure C.2: Question 1b; Biofouling: low-risk ships (Ports with Brown mussel).

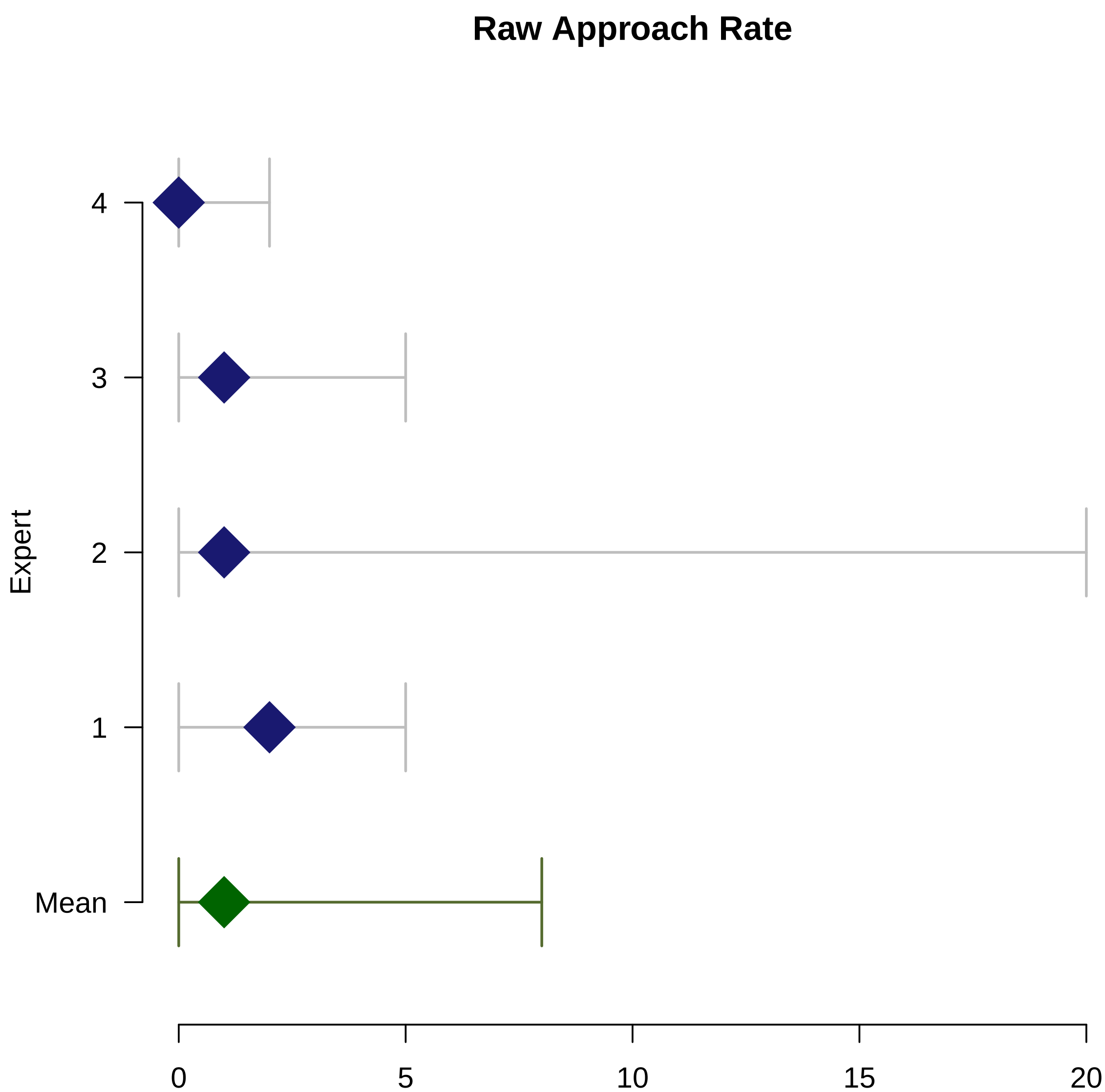

Figure C.3: Question 1c; Biofouling: high-risk ships (not Ports with Brown mussel).

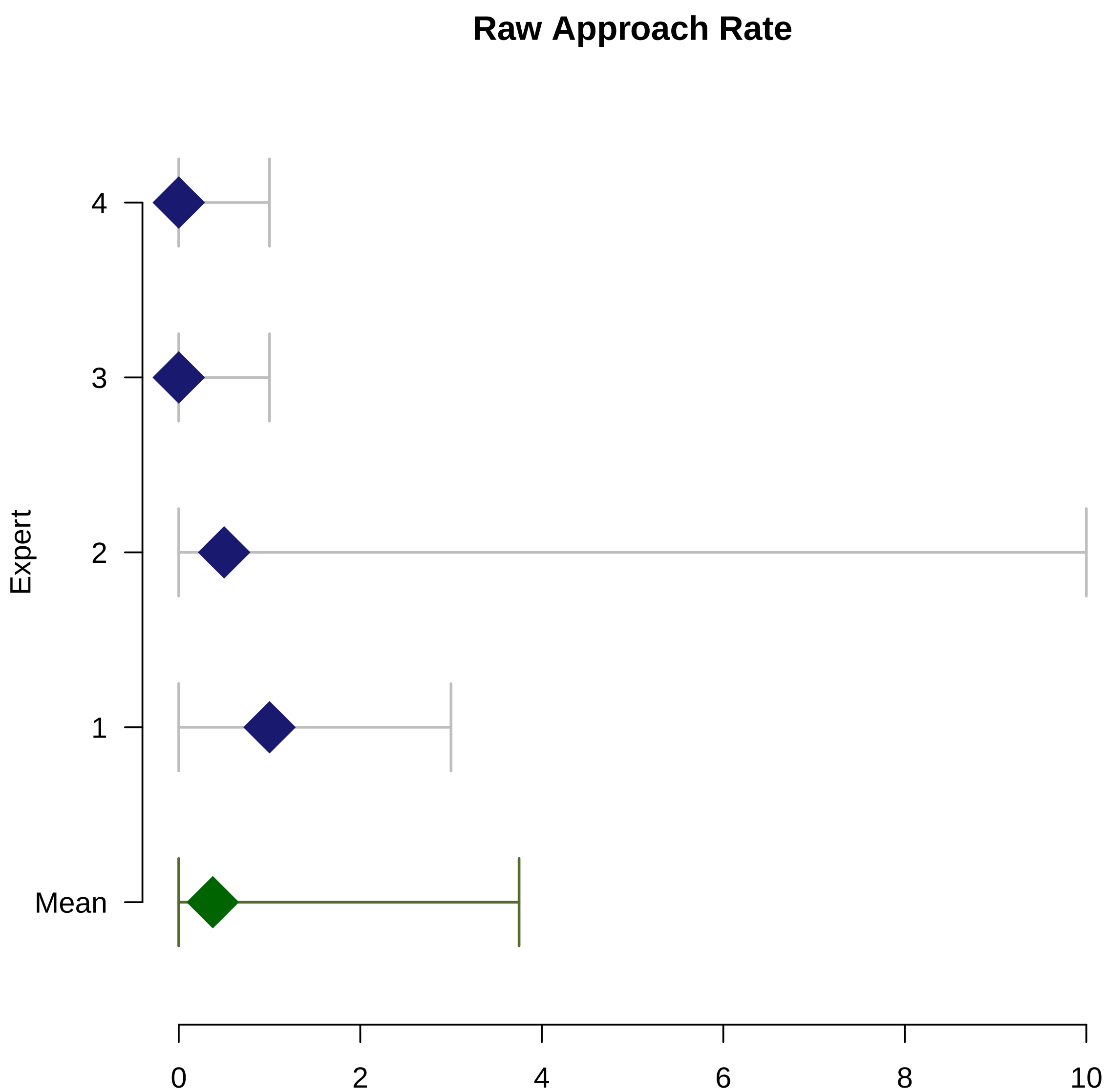

Figure C.4: Question 1d; Biofouling: low-risk ships (not Ports with Brown mussel).

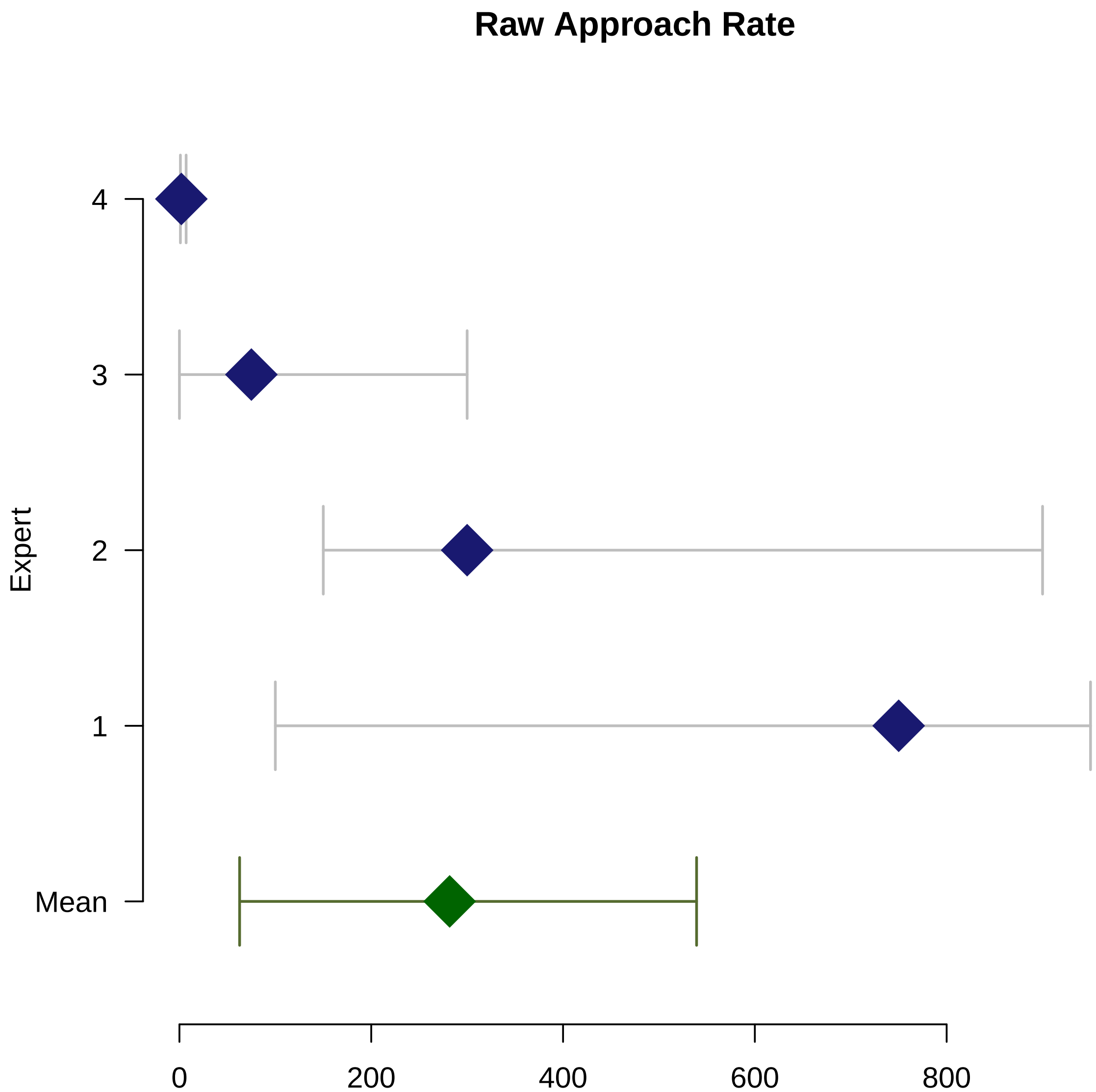

Figure C.5: Question 1e; Biofouling: yachts.

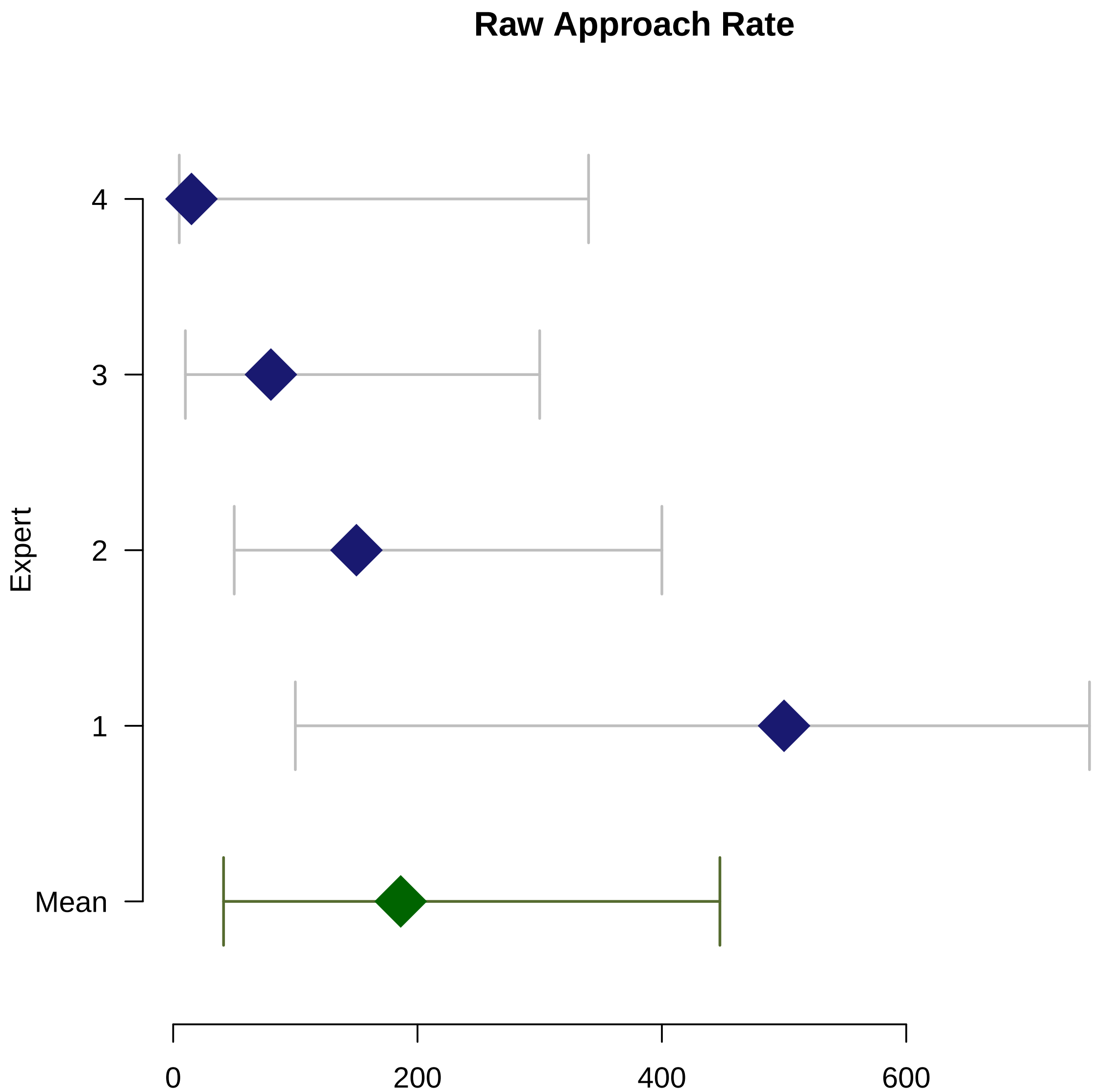

Figure C.6: Question 1i; Ballast water discharge: high-risk ships (Ports with Brown mussel).

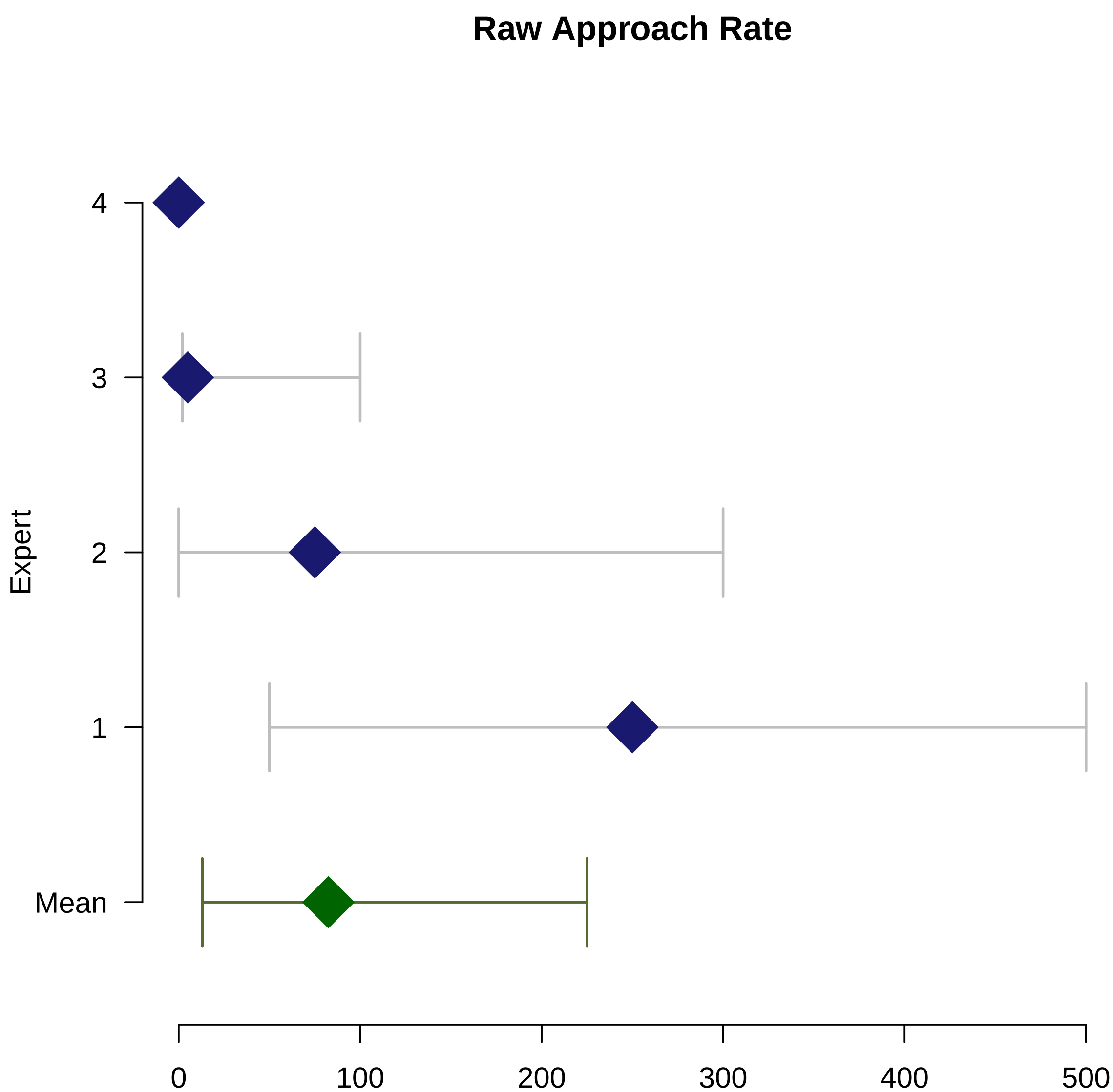

Figure C.7: Question 1j; Ballast water discharge: low-risk ships (Ports with Brown mussel).

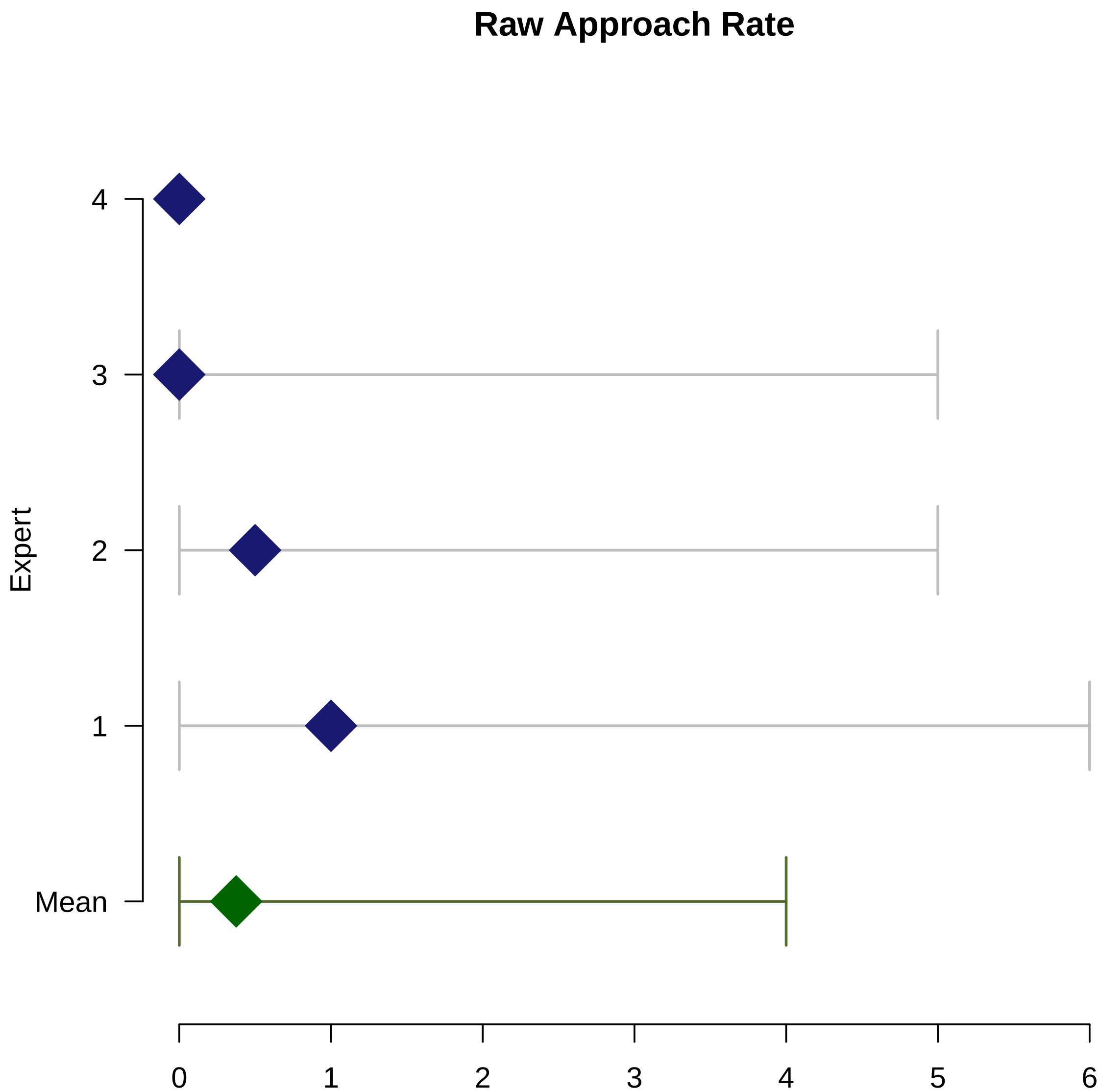

Figure C.8: Question 1k; Ballast water discharge: high-risk ships (Ports without Brown mussel).

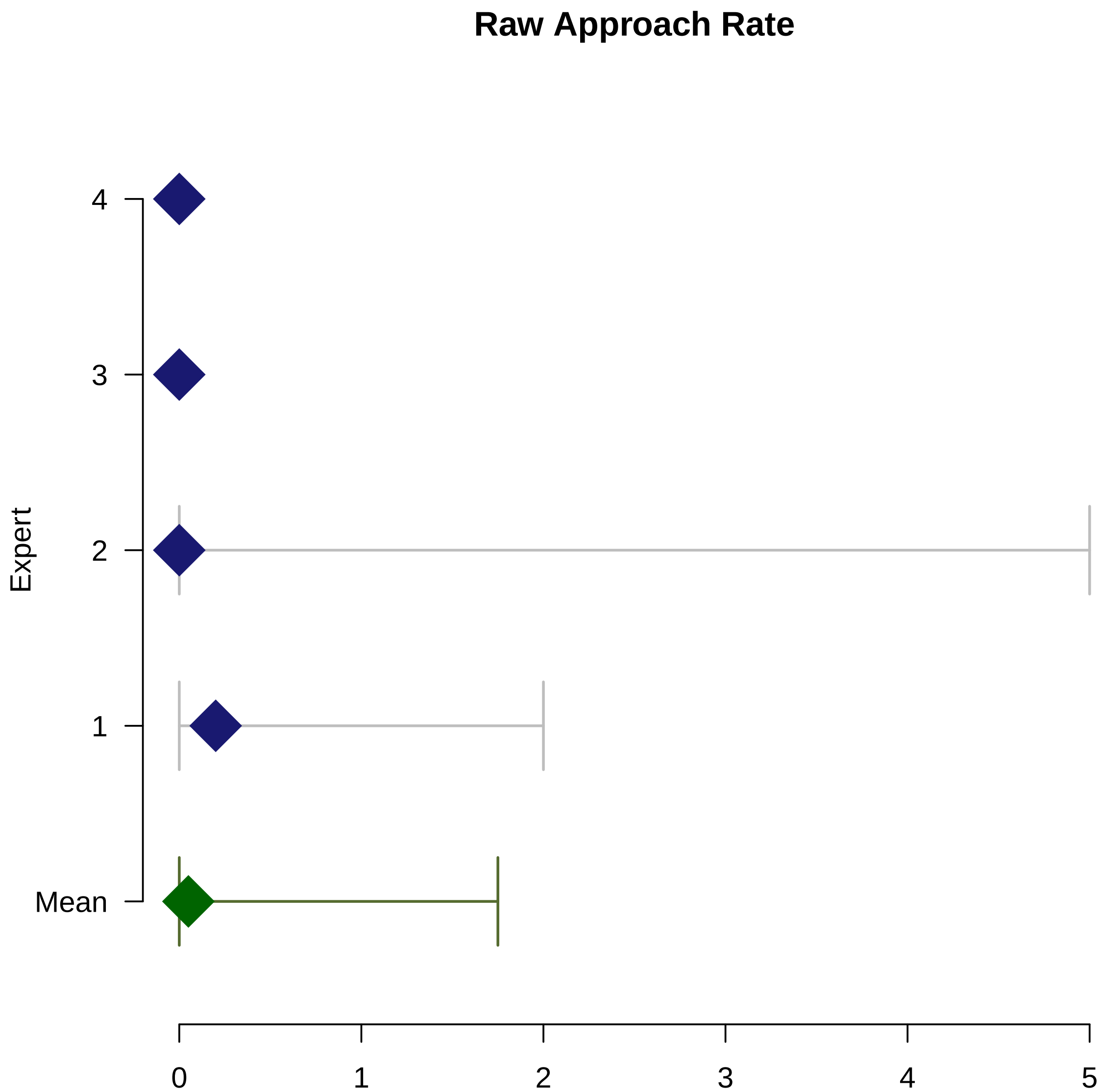

Figure C.9: Question 1l; Ballast water discharge: low-risk ships (Ports without Brown mussel).

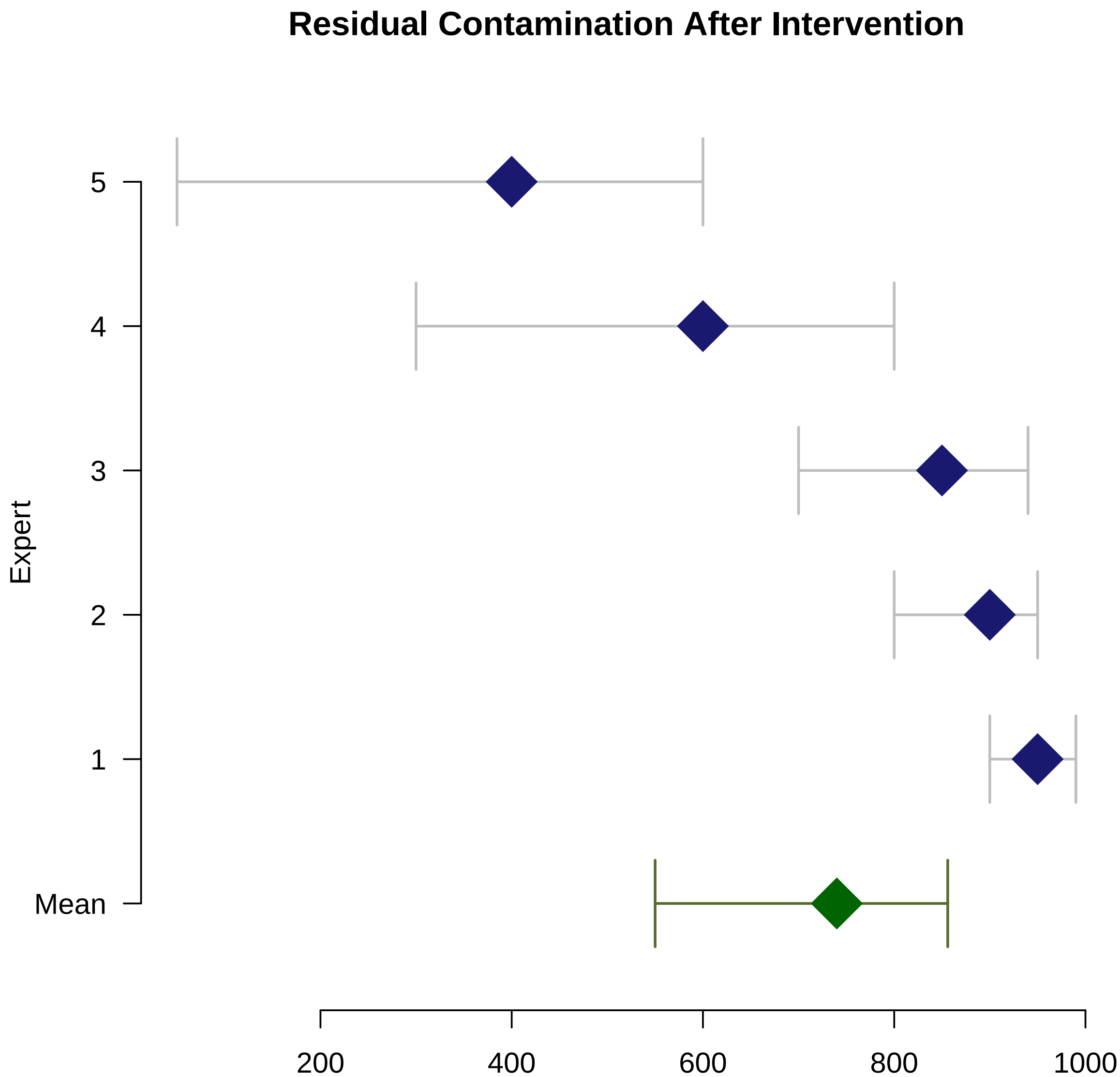

Figure C.10: Question 2a; Commercial vessels profiling and inspection.

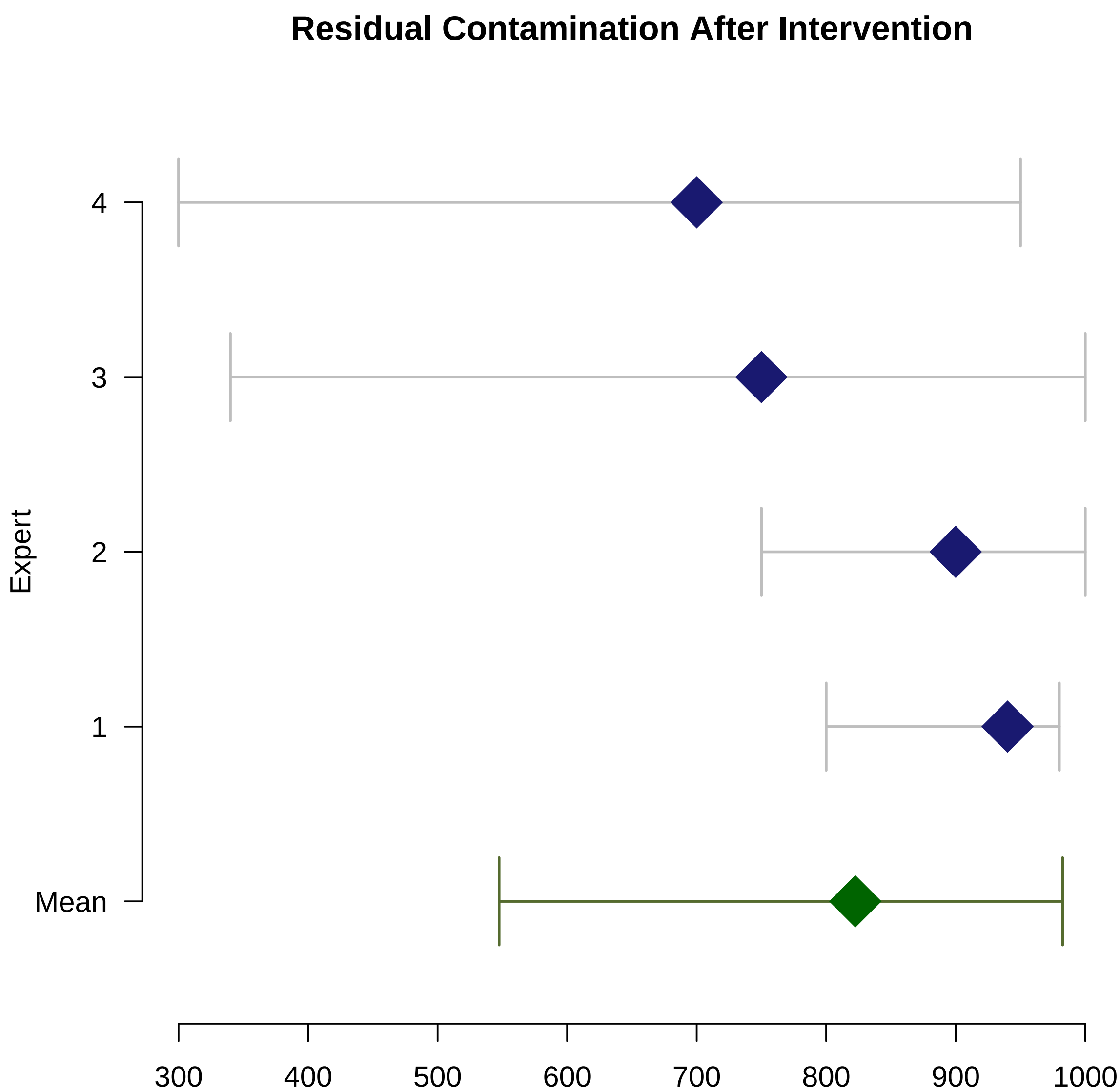

Figure C.11: Question 2b; Offshore discharge.

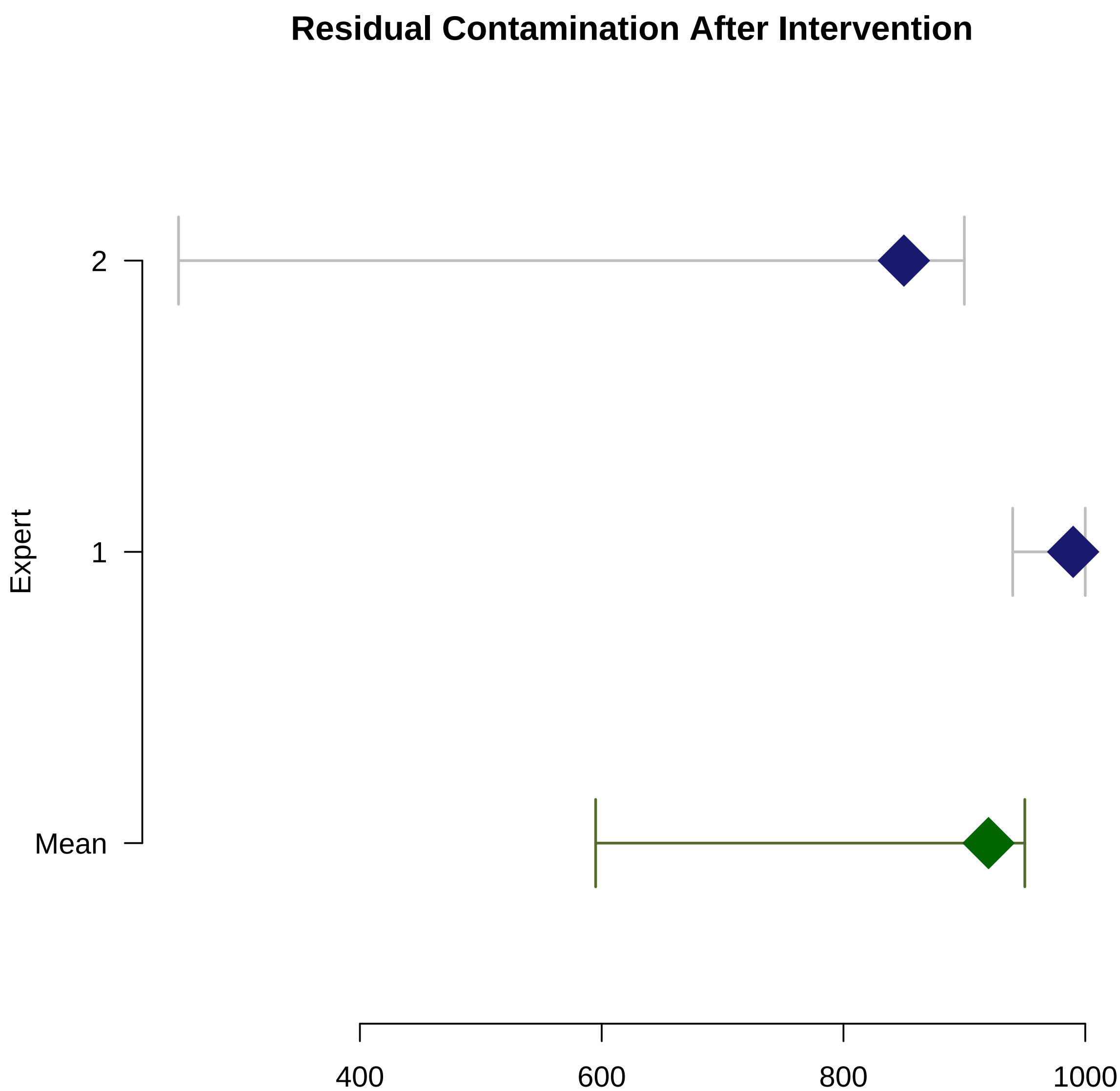

Figure C.12: Question 2c; Yachts profiling and inspection.

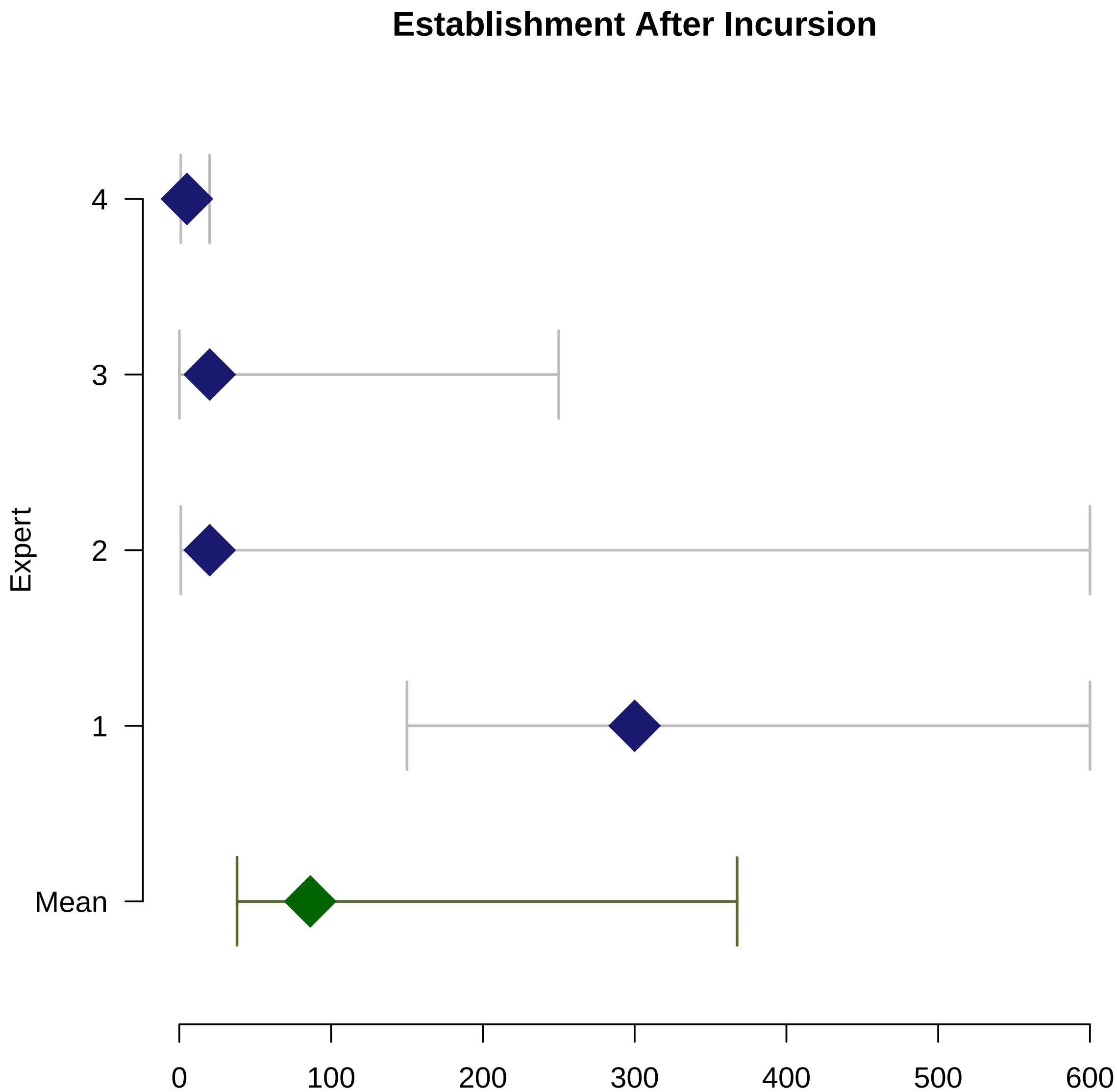

Figure C.13: Question 3a; Establishment from biofouling.

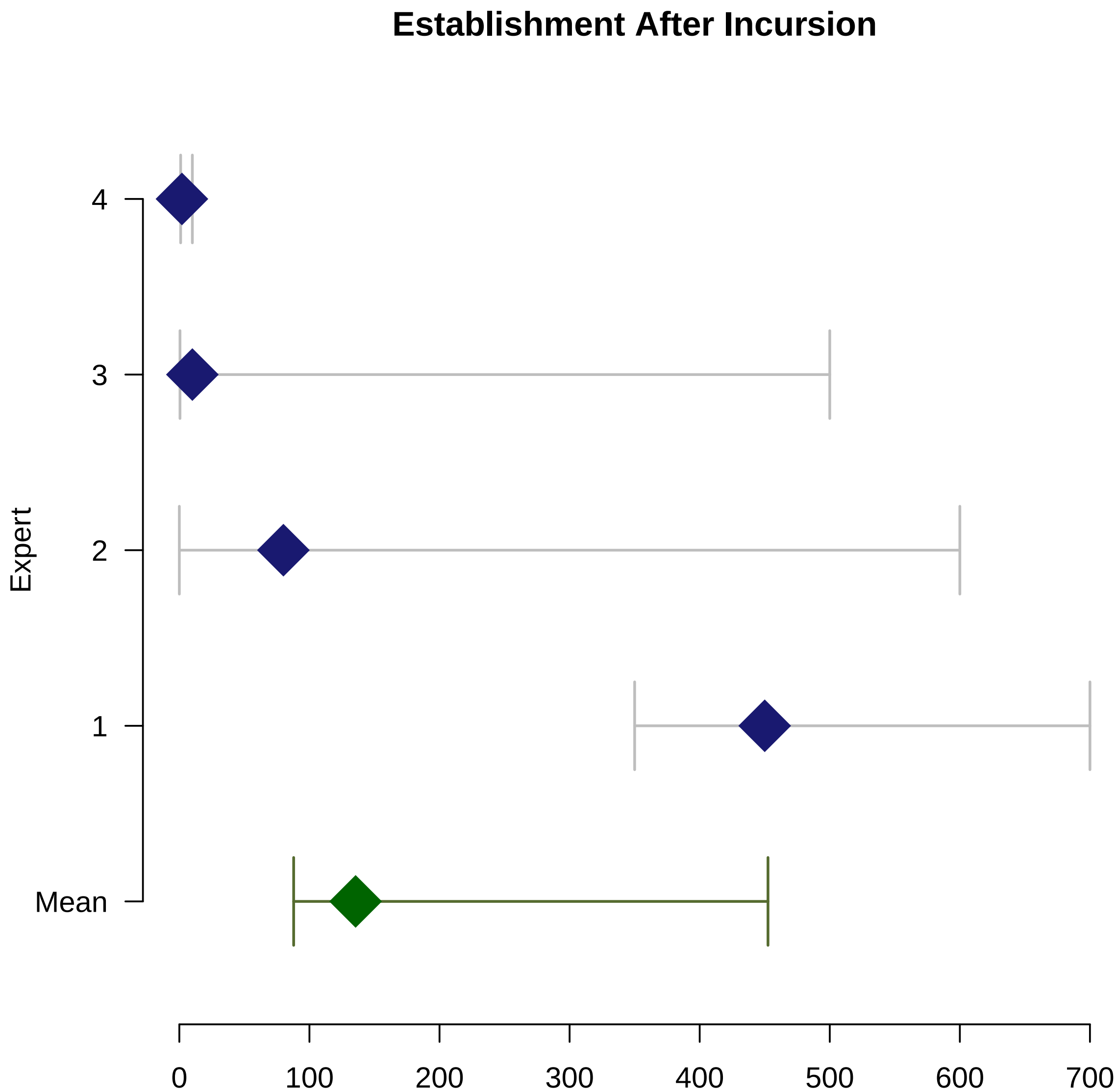

Figure C.14: Question 3b; Establishment from ballast water discharge.

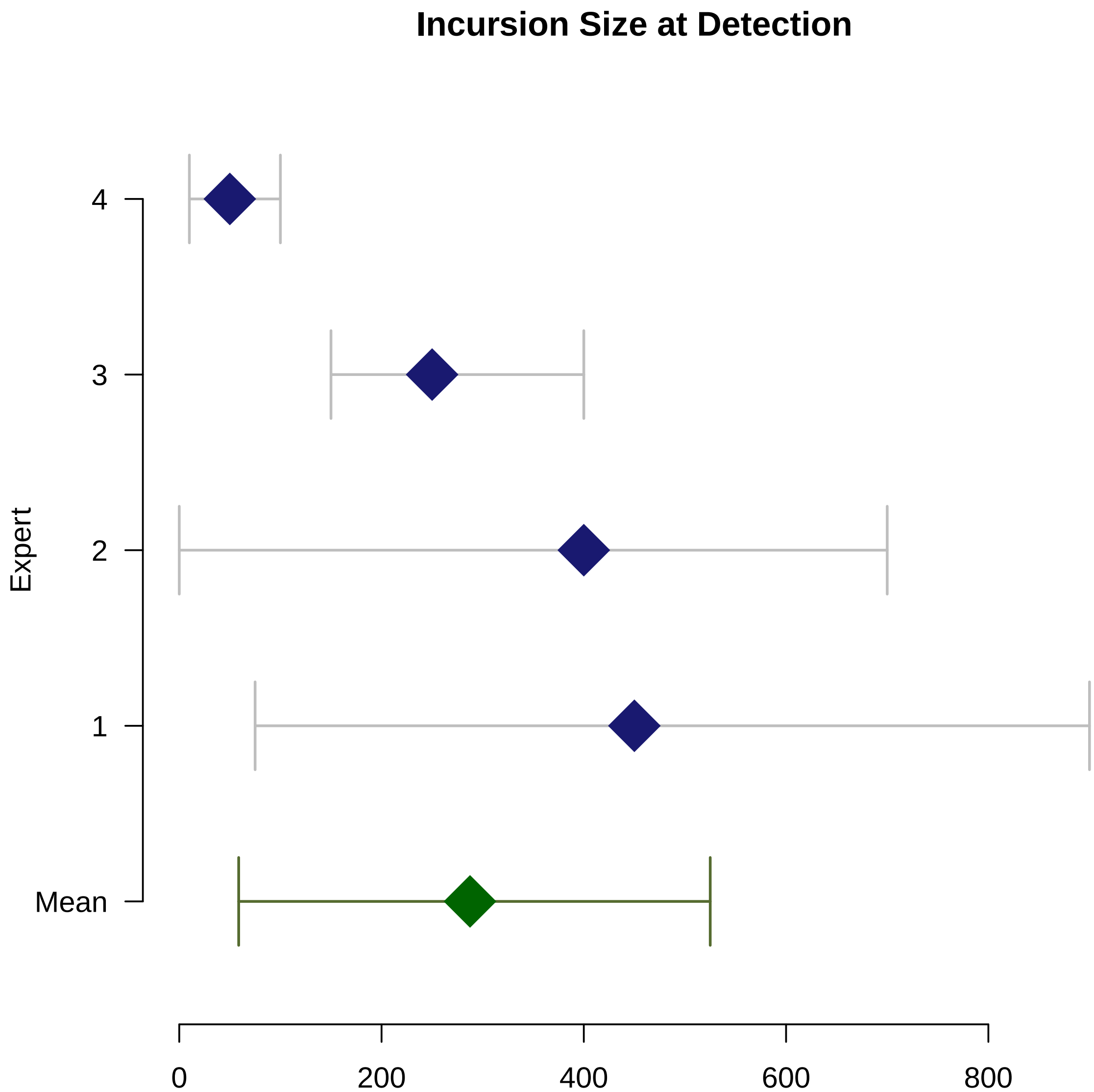

Figure C.15: Question 4a; Incursion Size at detection under current surveillance.

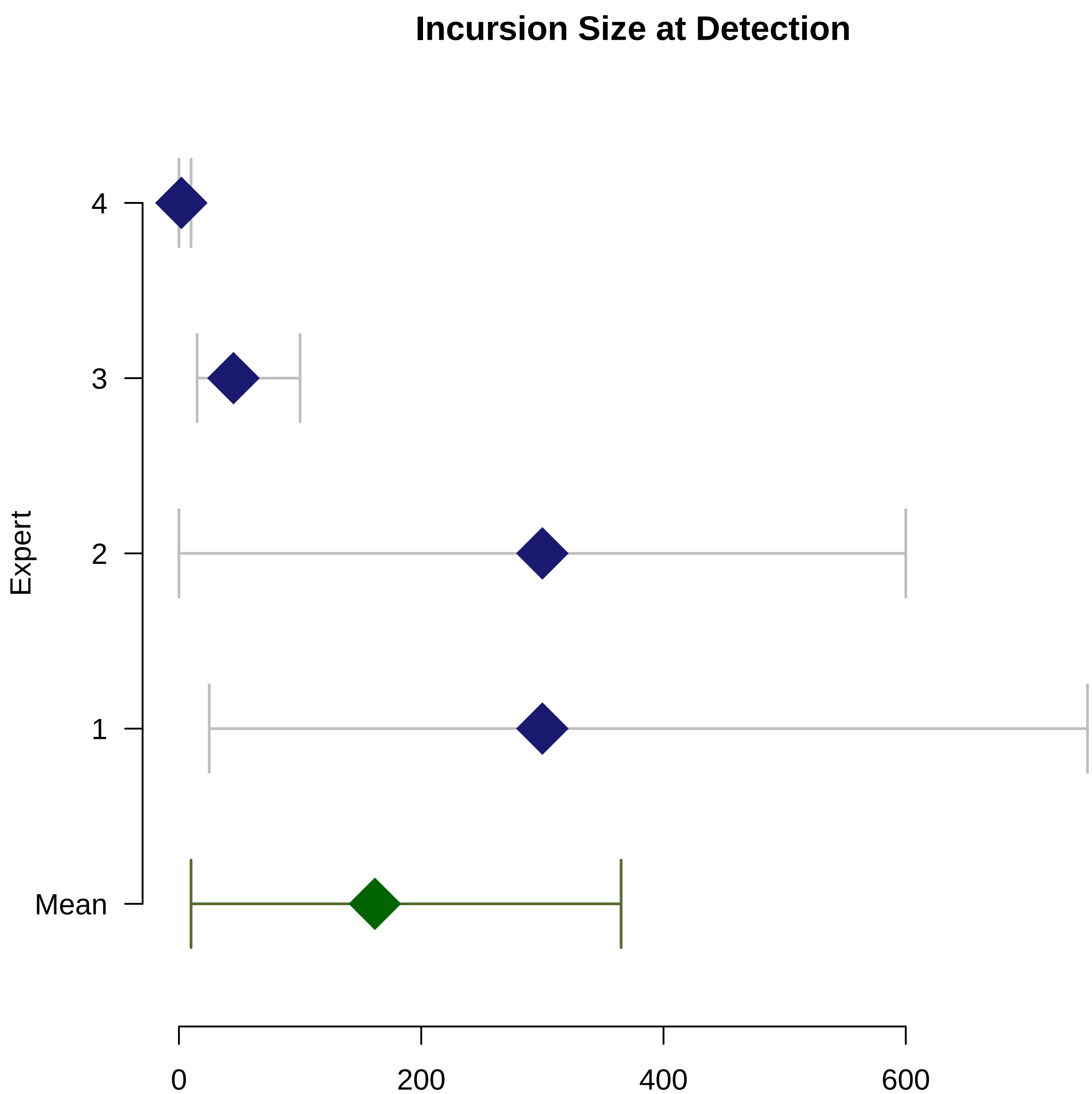

Figure C.16: Question 4b; Incursion Size at detection under no surveillance.

Appendix D

Review by Biofouling Solutions

As noted earlier, two reviewers provided extensive and thoughtful commentary, which has been very much appreciated. The report is considerably improved because of their careful work. The review by Biofouling Solutions provides considerable useful insight for future biofouling modelling exercises; this review is reproduced entirely here.

Detailed Scientific Review of CEBRA Project 17062102: Marine Pest Structural Risk Model Applied to *Perna perna*

Date: 31 August, 2021

Prepared for: University of Melbourne

  

Report prepared by

BIOFOULING SOLUTIONS

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Document Review and Distribution

Document Review

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31 August, 2021	Dr Pat Lewis	Biofouling Solutions Pty Ltd.	Accuracy and Content	0.3

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Date	Name	Company	Type	Version
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Executive Summary

This report provides a scientific review of the draft final report for CEBRA research project 17062102: Marine Pest Structural Risk Model. The reviewers recognise the advantage in developing a biosecurity risk framework that can be applied across multiple pathways to understand the impact of interventions and the cost of biosecurity policy implementation (or the lack thereof). It is also recognised that in the absence of specific data, expert elicitations are increasingly being applied to better understand complex problems. However, it should be noted that the outcomes of expert elicitation processes ultimately reflect the nature of the questions posed and the applied experience of the respondents that are involved in the process. While details on both questions presented and the applied experience of respondents where not provided in the draft report, the outcome seems strongly influenced by the small pool of experts, uncertainty expressed by experts and the effect of outliers.

The reviewers consider that the model and approach would benefit substantially from structural revisions ensuring the model is applicable to marine species, improving the nature of questions to ensure they focus on relevant selective filters, by resolving errors or uncertainty in the application of expert elicited data, and through consulting a broader pool or experts with a higher applied experience in biofouling and ballast water management. To assist readers in being able to understand the interpretation of the model, the authors should include all raw data, should present the specific questions posed to experts and should update all figures to include a key and an explanatory figure description. Furthermore, the report would have increased relevance to biosecurity outcomes if it was framed in the context of existing New Zealand maritime biosecurity policy such as the Craft Risk Management Standard – Biofouling (CRMS).

Specific recommendations or comments include:

- Pathways relevant to marine pest transportation could be better conceived. The reviewers recommend avoiding the use of administrative definitions for subcategories and replacing these with functional pathway components (e.g. ballast water, general hull, niche area etc.).
- The likelihood module considers a range of components but would be more effectively structured if the components corresponded to stages in the invasion pathway. This would allow experts to better assess the impact of selective filters on the biotic and abiotic tolerances of a particular species.

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- The Minimum Viable Populations (MVPs) of *Perna perna* used in the draft are not equivalent across the pathways examined (i.e. three adults in hull fouling versus 100,000 larvae in ballast). This is likely to have resulted in a bias in the expert elicited responses. The reviewers consider that a MVP of three individuals in a biofouling community has a low likelihood of resulting in a self-sustaining population of *P. perna* establishing during typical vessel operations.
- The model applies high risk status to bulk carriers and container ships without justification, and this seems to have a strong influence on expert elicitation results for Raw Approach. The reviewers consider that a vessel's operational history and maintenance history is a better predictor of risk status, and that in the absence of this data, the CRMS long and short-stay categories would be a better categorisation of risk than that applied.
- While the model appropriately uses exposure to contaminated ports as a means of categorising risk, this is applied unevenly across pathways. Yachts are unreasonably lumped into a single high-risk category despite exposure to *P. perna* within their recent voyage history being unlikely. The advantage of expert elicitation processes it that this approach can facilitate reasonable estimates despite data paucity, yet this does not seem to be the outcome here.
- The expert elicited values for the "Residual Contamination Following Intervention" (i.e. profiling and inspection of commercial vessels, offshore discharge of ballast water, profiling and inspection of yachts) are in general higher than expected considering the stringent biosecurity policy setting of New Zealand.
- The interventions assessed for ballast water risk mitigation seem limited to offshore exchange despite the increasing prevalence of Type D-2 ballast water treatment systems.
- The Raw Approach values provided through expert elicitation have a very strong influence on the outcome of the model. However, these are obtained by a very small pool of four experts. The indicated error margin provided by experts coupled with the considerable variability in some critical responses do not provide a high level of confidence in the outcome. Furthermore, due to the small number of respondents, outlier estimates have a strong degree of leverage on the mean values used in the model. Increasing the pool of respondents participating in the process and ensuring that experts are suitably experienced would improve the outcome.
- The effect of Interventions is described in the text, tables and figures of the report as being an indication of "Residual Contamination following Intervention". However, these values are used in the model inversely. In other words, this is not used as a residual contamination

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following intervention, but rather an indication of pests intercepted and prevented from entering New Zealand (see Table 2.3). This source of confusion needs to be resolved as if this is an erroneous use of expert elicited data, all outputs produced by the model are incorrect.

- The report provides no data about the specific set of questions presented to experts during the elicitation process. As a result, interpreting the expert responses is difficult.
- No raw data regarding expert responses is presented in the results or elsewhere to assist in understanding some of the ambiguity and potential error in the model.
- Figures presented in Appendix A are poorly labelled and are not presented with any keys to assist in interpretation. The labels on the second y-axis on all graphs (i.e. "90") were not understood by the reviewers.
- The responses relating to establishment after arrival are considerably higher than available data would predict. The reviewers consider that experts might have misinterpreted this as colonisation within the recipient location rather than the establishment of a self-sustaining population. Removing this ambiguity and incorporating a more structured focus on selective filters in the transportation pathway would improve the outcome.
- The estimate of cost of eradication are the result of only one expert opinion and it seems substantially lower than expected for a 100 ha incursion.
- The impact of monitoring and readiness on cost of eradication are not well addressed by the single respondent that replied to this question. Irrespective of this distinction, the respondent's indication of 95% eradication success probability for a 100 ha incursion does not seem to be consistent with real world eradication attempts.

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BACKGROUND

Biofouling Solutions was engaged by the Centre of Excellence for Biosecurity Risk Analysis (CEBRA) to provide a scientific review of the draft final report for CEBRA research project 17062102: Marine Pest Structural Risk Model. The request for review pertains to a CEBRA report that applies a framework summarizing the actions of the biosecurity system against a specific pest to an example of a marine pest species (as detailed in Robinson et al. [2018, 2020]). The CEBRA Framework had previously been applied to a terrestrial species (the Asian Gypsy Moth - *Lymantria dispar*). The draft final report provided for review examines the development and parameterisation of the structural risk management model for a marine pest, namely the brown mussel (*Perna perna*). The model comprises a likelihood module (which represents pre-border and border exposures and risk management), and a consequences module (which represents impacts and post-border activities).

This scientific review does not seek to validate the underlying framework model initially presented in in Robinson et al. (2020) nor the assumptions of Crombie et al. (2007) that are used in the model. Instead, the review addresses the factual basis for conclusions presented in the draft final report, the practical considerations underpinning various assumptions used in the report, and biological considerations relevant to both the species in question (*P. perna*) and the marine pest transportation pathways assessed that might affect the interpretation of the results. Calculation errors are identified and the expert elicitation process and the general approach to gaining expert estimates is examined to understand the deviation of the model's outcome from the observed rate of incursions for *P. perna*.

1. INTRODUCTION

1.2 Risk-Return model likelihood component: pathway categorisation

In Recommendation 1, the authors suggest that the application of the model would benefit from defining pathways in terms of readily available classifications used within MPIs existing data resources. This would clearly assist in gaining more valuable expert elicitation outcomes. However, additional fundamental concerns exist regarding the pathways presented and their equivalence from a risk assessment perspective applied to the marine environment.

The pathways presented in Section 1.2 present four major categories of pathways (Cargo, Mail, Passengers and Vessels) with numerous sub-categories presented within each. For categories relevant to the terrestrial system, sub-categories are defined primarily in units relevant to biological

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transportation. This results in an ability to intuitively consider the likely risk for each sub-category. For example, within "Cargo" assessing the operation of the sub-category "containers" allows an assessor to consider the relevant functional pathway stages and the resulting likelihood of pest transmission. However, the pathways sub-categories applicable to marine pests (i.e., "Vessels – fully cleared" and "Vessels – under surveillance") are defined by administrative status not functional status. While the indicated administrative status might result in more information being available to the assessor, it is unlikely to affect the actual rate of contamination and resulting biosecurity risk status. As a result, this sub-categorisation does not seem to be a meaningful distinction for the purpose of the framework (though notably the reviewers may not be familiar with some of the considerations leading to the designation of these categories).

To meaningfully consider the operation of a pathway for marine pests, the model would benefit from including a different selection of sub-categories for "Vessels". It should also be clarified whether or not the "Vessel" category is distinct from other categories that are transported onboard the vessel (e.g., cargo or passengers transported on-board a ship). Presuming that the category is designed to encompass the vessel independent of other categories, more meaningful sub-categories might be (for example):

- Vessel (ship)
    - Onboard (i.e., pests on the deck, within accommodation and internal spaces, or entrained within the general superstructure)
    - Ballast water
    - General hull
    - Niche areas (e.g. sea chests, rudder pintles, etc.)
    - Internal seawater systems

These (or similar) sub-categories would assist in the delivery of more meaningful expert elicitation outcomes, as the operation of each subcategory could be more accurately considered for an individual species (and in some cases subcategories could be quickly excluded). By adopting this approach pathway dependant considerations that affect the operation of each sub-category could be considered independently through the expert elicitation process to gain a more accurate assessment of risk. Furthermore, use of these or similar sub-categories would better align the framework with current regulatory instruments governing the operation of each vessel-based pest pathways in the

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New Zealand marine environment (e.g. the ballast water regulations implementing the 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments, and the Craft Risk Management Standard – Biofouling (CRMS)). This would ensure the output provides the best value possible in terms of evaluating the implementation of existing policy, as well as effectively allocating resources to both compliance assessment and surveillance.

Finally, to assess marine transportation pathways to a similar level of detail to those considered for terrestrial pathways (e.g. nursery stock versus plant products etc.), it might be useful to consider shipping sectors as being distinct in regards to the likely risk of marine pest transportation. Given that vessel arrival data should provide basic information on the vessel type, it might be useful to distinguish at the category level for the major shipping sectors (e.g. bulk carriers, container ships, offshore support, passenger vessels, etc.). Different shipping sectors have dramatically different operational parameters and standard management practices, and thus interact with potential marine pests in different but broadly identifiable ways. For example, as identified by the experts consulted in this study, the risk associated with importing a Mobile Offshore Drilling Unit (MODU) into New Zealand waters is dramatically different to a typical bulk carrier that operates in New Zealand waters for less than 21 days (i.e., shortstay under the CRMS).

Addressing these sectors at the highest level within the framework would remove some of the ambiguity apparent in assessing the broader category of "Vessels" and would allow experts to quickly identify the higher risk pathways and ultimately providing a more meaningful end-result. However, the reviewers do recognise that this approach would require greater effort and a larger model. Furthermore, the effect of sector specific considerations can be less important in some cases than recent management history and operational profiles. An alternative and perhaps simpler approach would be to avoid sector specific considerations completely and apply the same risk factors considered under the CRMS (i.e., short-stay and long-stay vessels).

1.2 Risk-Return model likelihood component: measures influencing the operation of a pathway

The framework considers a range of actions in moderating a risk associated with a pathway prior to any particular risk arriving within a "Port" (see Figure 1.1 and associated text in the final draft report). However, it is unclear to the reviewers how the "measures" considered correlate with the operation of a pathway in the context of marine pests. For example, the report considers a range of International Agreements, Bilateral Agreements, Import Health Standards and Border Interventions as the primary "measures" affecting the operation of the pathway. When this logic is applied to

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marine pests, the primary measures in place would relate to New Zealand policies implementing the 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments, and the CRMS. Notably, current New Zealand requirements for ballast water treatment and the adherence to the CRMS "clean hull" threshold essentially creates a policy environment where vessel operators are expected to demonstrate that *Perna perna* is not present on the vessel prior to arrival[1]. These policy requirements should be addressed in the report as it clarifies, for the benefit of the expert elicitation process, the expected status of compliant vessels, the management measures considered acceptable, and the likely proportion of non-compliant vessels that are not detected in standard compliance assessment processes.

For example, in the context of ballast water, failure of these policy mechanisms would primarily be attributable to:

a) Undeclared discharges of ballast water drawn from a port contaminated with *P. perna* at a time where viable larvae were present in the water column; or
b) Failure of the type D-2 ballast water treatment system (or exchange process if applicable) affecting ballast water drawn from a port contaminated with *P. perna* at a time where viable larvae were present in the water column.

In the context of biofouling, the primary source of policy failure is likely to relate to:

a) Vessels that are seeking to enter New Zealand waters as short-stay vessels demonstrating compliance through best practice management (e.g. a vessel maintains an acceptable biofouling management and complies with the recommended inspection frequency for its coating age but has still been exposed to a recruitment event in a port contaminated with *P. perna*);
b) Vessels operating under a Craft Risk Management Plan which allows them to adopt a short-stay threshold despite not meeting CRMS short-stay requirements (e.g. a cruise ship that visits New Zealand multiple times within a season including ports that are not a listed destination port, but which also visit ports contaminated with *P. perna*);
c) Vessels which either provide false declarations or have contracted inspection or cleaning services that have fraudulently declared compliance status with the CRMS;

[1] Any vessel with biofouling communities that include any species of mussel would not meet the "clean hull" threshold under the CRMS.

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d) Naval vessels that are exempted from biosecurity compliance requirements.

2. Likelihood Model

The draft final report includes four components within the likelihood model to assess the probability of any *P. perna* establishing within New Zealand waters:

1) Raw exposure
2) Interventions (NB: this is not addressed in the introduction to this section)
3) Pathway risk estimations
4) Attenuation (from incursion to establishment)

The reviewers consider that this approach would be better justified if framed in the context of the known stages in the invasion pathway for marine organisms (see Figure 1). Preferably, this would be applied to each identifiable sub-category as discussed in Section 1.2 (i.e., Ballast water, general hull, niche areas, etc.). this would enable experts to consider the likely contamination of each subcategory, and the operation of pathway dependant filters at subsequent stages of the transportation pathway (see Figure 1). While various stages are addressed in the approach used, they are frequently confounded (i.e., Raw Exposure incorporates both a risk rating attributed to interaction with an infected port, an assumed survival rate upon arrival in New Zealand and an overlaid risk analysis for vessel types) and make it difficult to assess each stage on the basis of available information.

Adopting a systematic pathway-oriented approach to the risk assessment framework would avoid the ad-hoc categorisation of risk apparent in the draft. For example, the draft uses risk categories that are created without apparent justification (i.e., high risk versus low risk vessels) or applied unequally across pathways (e.g., yachts are excluded from the analysis of exposure to infected ports). A systematic approach would assist in applying the model quickly and effectively to other species and pathways and assessing the impact of policy interventions.

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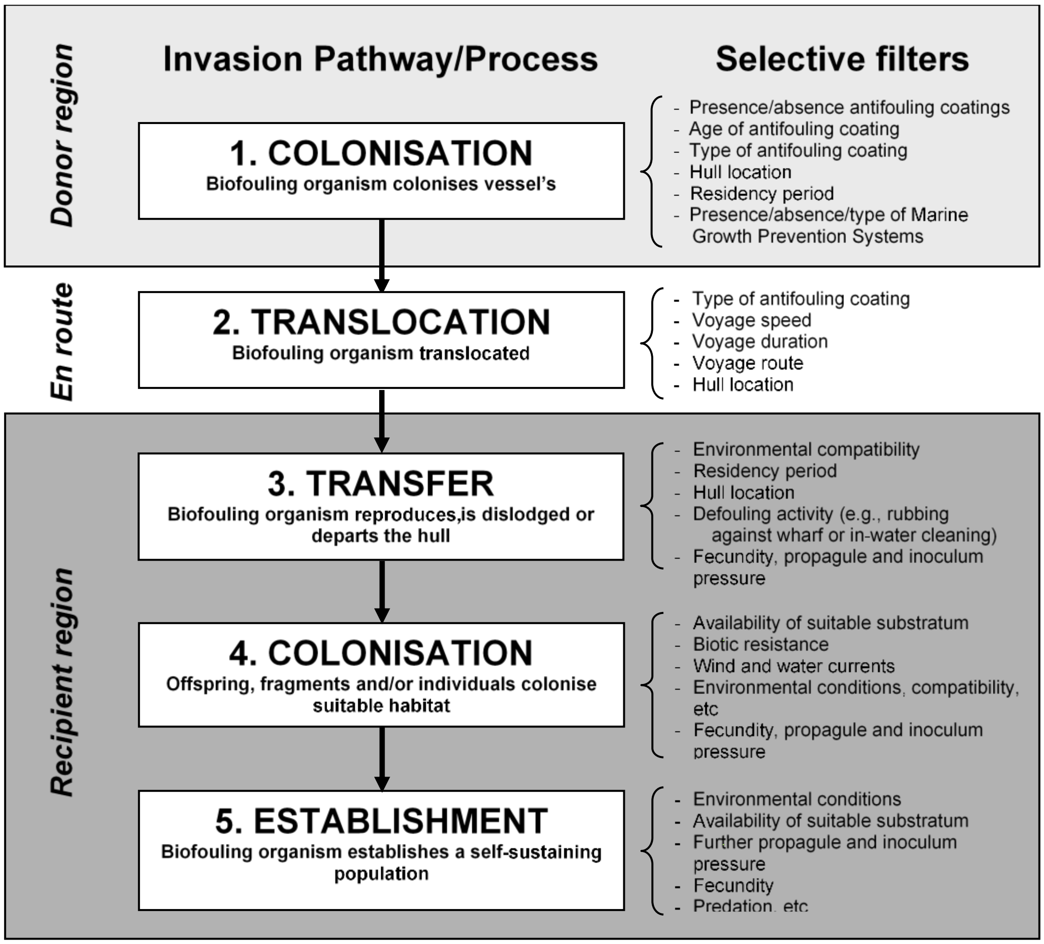

Figure 1. General invasion pathway and associated selective filters or pressures in which biofouling organisms must overcome in order to be successfully translocated from one location to the next. Figure reproduced from Coutts et al. (2009).

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2.1 Raw Exposure

The report provides limited information about the considerations applied to the Raw Exposure component and how these were used by experts to arrive at an estimate of the rate per 1,000 vessels contaminated by *P. perna.* Effectively, the paper seems to apply the following logic:

1) Vessel are categorised as either:
    a. High risk (bulk carriers and container ships) or
    b. Low risk (all other vessel categories?)
    c. Yachts (Although, no justification or categorisation is provided, there appears to be an assumption of high-risk status)
2) While it is not addressed clearly within the text of the paper, the analysis also incorporates high risk and low risk ports based on the distribution of *P. perna* reported on the Smithsonian NEMESIS webpage[2].
3) The paper assumes that a minimal viable population for *P. perna* is three adults in a biofouling community or at least 100,000 larvae within ballast.

While various comments from experts presented in Appendix B (Conference Call Notes) and Appendix C (Workshop Notes) address substantive considerations relevant to the assumptions used for assessing raw exposure, it is unclear how the categories used were arrived at. Furthermore, there appears to be significant uncertainty in the assessment of Raw Approach Rate provided by experts and presented in Appendix A (expressed both in the spread of estimates and the indicated error margins for each estimate). In particular, the spread of estimates for critical questions such as contamination on High-Risk Vessels and yachts make it difficult to interpret the results with any confidence, especially with such a small respondent group. It would be beneficial to indicate the experience of the experts consulted as a means to validate the veracity of estimates. As the primary input from the experts relates to likely contamination and the impact of policy intervention, it would be useful, for example, to indicate how many physical vessel inspections each of the respondents have participated in so that critical estimates can be put in the context of experience. For example, in over 1,600 biofouling inspections for marine pests, Biofouling Solutions inspectors have only detected eight vessels contaminated with *P. perna*. This real-world detection rate stands in significant contrast to the estimated rates of contamination per 1,000 vessels provided by the experts used in this study (though notably this is not filtered according to visits to ports contaminated with *P. perna*).

[2] https://invasions.si.edu/nemesis/species_summary/568077

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2.1.1 Vessel categorisations

While there is some discussion regarding bulk carriers and container ships within Appendix B and C, it is difficult to reconcile these comments with the assessment that these vessel categories are high risk. Presumably this is based on the outcome of a scientific study, but as the study is not referenced, the assumption is therefore not supported. Furthermore, compared to other vessel categories discussed in the Appendices (e.g. Mobile Offshore Drill Units), available data would indicate that these are relatively low risk in relation to *P. perna*, particularly considering that these vessels would typically fall into the short-stay category (i.e. visiting for less than 21 days). Without having access to the details regarding the >1,300 low risk vessel types visiting New Zealand presented in Table 2.3, it is difficult to understand the assumptions underlying the relative risk of biofouling associated with vessel types entering New Zealand. Because the allocation of high risk status for vessel types has a significant effect on respondent raw exposure estimates (i.e., means of 92 for low risk vessels versus 375 for high risk vessel visiting contaminated ports), the paper should provide clear and validated justification for this categorisation. Considering that more low risk vessels (17) than "high risk" vessels (4) enter New Zealand waters after visiting an infected port (see Table 2.3), providing a good justification for this categorisation seems critical.

As an alternative, it would be useful to integrate the same risk assumptions applied in the CRMS to ensure consistency with New Zealand biosecurity policy. For example, irrespective of vessel type, it would be constructive to assess any vessel staying >21 days, or visiting areas not designated as a first port of call, as "high risk" while vessels staying <21 days would be considered "low risk"[3]. Overlaying this with distributional data for *P. perna* would be a sound basis for Raw Exposure categorisation and would result in an outcome that is well aligned with the policy environment and useful for evaluation and review of both the model and relevant biosecurity policy.

2.1.2 High risk ports

The reviewers find no fault in allocating higher risk status for vessels that visit ports in which *P. perna* is known to have an established population (both native and introduced). While a precautionary approach of allocating all vessels visiting such ports a "high status" is reasonable in the face of non-

[3] BFS is aware that significant additional data is available to MPI when completing vessel screening. For example, alternative risk categorisations could relate to antifouling coating age or other information elicited from incoming vessels. Clearly integrating this data into the risk model would require more work and access to more extensive data than assessed in the current report.

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existent or limited data, a more robust risk assessment outcome would be provided by integrating readily available data to assess likely contamination risks during visits to such ports. For example, vessels that have recently dry-docked and have a relatively new application of a biocidal antifouling coating, including within all niche areas, or alternatively vessels that have completed an in-water inspection and/or clean (to an acceptable standard), would be likely be have a relatively low risk of contamination while visiting infected ports, provided port residency is limited to an acceptable threshold[4]. At the very least, such visits by nominated "high risk" vessels (i.e. bulk carriers and container ships) would be unlikely to present a greater risk when compared to "low risk" vessels that visit the same ports for longer durations, without inspections and with depleted biocidal antifouling coatings. As discussed above, in the absence of vessel operational and management data, a more constructive approach might be to avoid arbitrary risks categories for vessels and default to risk categories inherent in the logic of the CRMS (i.e., short-stay versus long-stay vessels).

2.1.3 Minimum viable population size

The basis for the definition of minimum viable population size is not justified within the report, nor are they applied in a manner which addresses relative risks of vectors (i.e., ballast versus biofouling) in a proportional manner. With respect to biofouling, the report considers a "high risk" as a single vessel with a at least three individuals of *P. perna*. For ballast water, the report considers "high risk" as a single vessel with at least 100,000 larvae (presumably discharged upon arrival). While it is acknowledged that this is based upon the propagule pressure considerations (though it is not well described in the paper), it is doubtful that three mature individuals on a single vessel could produce 100,000 fertilised larvae[5] and thus represent an equivalent risk. As *P. perna* requires successful external fertilisation to produce viable larvae, a low-density distribution of three adults on a single vessel is unlikely to result in a significant spawning event. For successful reproduction to occur there would need to be both sexes present and individuals would need to be in close enough proximity for successful fertilisation to occur in the water column to produce viable larvae.

[4] Any such "acceptable" residency period would need further research and justification. For example, some jurisdictions (Western Australia Department of Infrastructure and Regional Development) nominate seven days as an acceptable port residency.

[5] As a sexually dimorphic broadcast spawners with fertilisation occurring approximately 8-hours after gamete release, density dependant effects on a founding population have a strong impact on successful reproduction and subsequent establishment.

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In regard to the minimum viable population for ballast water, it should also be noted that larval viability for this species is typically 10-20 days. As a result, the expectation of vessels arriving with 100,000 viable larvae in the ballast should be considered in the context of typical journey durations (>20 days for a vessel travelling at 20 knots via the Panama Canal). This would likely significantly affect the estimates of rates of contamination provided by the experts consulted. Once again, addressing each vector's sub-category independently and considering the operation of selective filters associated with the entire pathway in a systematic manner would assist in ensuring that the expert elicitation process identifies fundamental selective filters that have a strong influence of likelihood.

2.2 Interventions

The report considers the effect of three regulatory interventions on the rate of *P. perna* introductions and asks experts for their considered opinion on the effect of each intervention on the rate of introductions of *P. perna* to New Zealand (i.e., estimate the number of infected vessels per 1,000 following intervention). No details are provided regarding the nature of such intervention events or the rate at which they are applied to visiting vessels. The reviewers have assumed that for commercial vessels, interventions are applied to all incoming vessels and documentation is required to demonstrate compliance with existing policy mechanisms.

The review has proceeded based on the assumption that the expert elicitation results for interventions reflect the residual contamination of 1,000 vessels following intervention (as stated in the title of the Appendices A.9 – A.11). This assumption is supported by the heading of Table 2.2. It is noted, however, that the impact of interventions provided by experts are consistently higher than expected. As a result, the reviewers did begin to question whether these estimates were intended to indicate the "effectiveness" of intervention measures as opposed to the residual contamination. This interpretation would explain the confusion of the model identified in Section 2.3.4.

2.2.1 CV Prof. and Inspection (Biofouling)

All incoming vessels to New Zealand are required to submit documentation verifying that they are compliant with the relevant clean hull threshold under the CRMS, and as a result it is surprising that all experts consulted indicted that more than 40% of vessels (mean of 74%) will be contaminated with at least three *P. perna* following compliance intervention examining biofouling management measures. It is difficult to reconcile this assumption with the available documentation for scrutinising

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compliance and the harsh penalties applied to non-compliant vessels (including ejection from New Zealand waters). Considering that many of the experts involved in the expert elicitation process are actively involved in developing and implementing CRMS policies, it is surprising that vessels flagged as non-compliant in the intervention process currently implemented in New Zealand are levied with significant penalties (including ejection from New Zealand waters) despite policy experts believing that on average 74% of other vessels represent analogous risks which have not been effectively identified and contained during compliance processes. As noted previously, the reviewers consider that a greater emphasis on current policy mechanisms in the elicitation process would likely assist the experts consulted in framing responses that are more closely aligned with applied management measures and actual detection trends.

2.2.2 Offshore discharge

The report uses offshore discharge of ballast as the only intervention applied to ballast water despite the 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments coming into force on 8 September, 2007, and an increasing reliance on Type D-2 ballast water treatment systems to manage ballast water biosecurity risks. The reviewers have not been provided with data regarding the rate of uptake in Type D-2 systems for vessel entering New Zealand but considering that vessels are expected to phase out exchange as a means of treatment by 8 September, 2024, it is likely that such systems are already prevalent amongst vessels visiting New Zealand.

The experts consulted in the study estimated that following offshore discharge and exchange of ballast water the residual rate of contamination was between 55 - 98% (mean of 82%) which shows a very low level of confidence in exchange as a treatment approach (i.e. Type D-1 under the Ballast Water Convention). This is not aligned with contemporary studies which estimate that when completed in accordance with the rules of the convention, both empty re-fill exchange and flow-through exchange can deliver between 66 to 99% efficiency (see Molina and Drake, 2016). Interestingly, a recent paper commissioned by the Australian Commonwealth assessed the failure rate of type D-2 ballast water treatment systems and found a 33% overall failure rate (SGS, 2021). While the reviewers have no significant experience in ballast water management, it seems that the identified failure rates for ballast water management are higher than expected.

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2.2.3 Profiling and inspection of yachts

Only two experts provided a response to this question (compared to four of five for other intervention measures). The reviewers were confused by the application of a 74.67% mean value for the residual contamination after intervention (profiling and inspection of yachts) presented in Table 2.2. The apparent mean value displayed on Graph A.12 seems to be greater than 90%. If this is an error, it will have further impacts upon the subsequent interpretation of the results. Alternatively, some data might not be reported in the appendices. Preferentially raw data would be provided to assist in the review process.

The low confidence in the effectiveness of intervention (i.e., mean of >90% residual contamination) may be linked to the limited compliance scrutiny applied to yachts in New Zealand, though the reviews do not have sufficient information to provide comment on this. The low response rate from experts regarding yachts in this question does reduce confidence in the outcome and preferably should be justified in the discussion.

2.3 Pathway Risk Estimates

2.3.1 Impact of "Approach values"

The outcome of the pathway risk estimate (i.e., residual risk following intervention) is strongly influenced by "Approach Value" estimates, despite the low number of experts (4) consulted in the expert elicitation process. Furthermore, the indicated error margin on many estimates coupled with the considerable variability in responses (e.g., yacht contamination estimates range from close to 0% to close to 80%) do not provide much confidence in the veracity of expert elicitation. This impact is particularly evident for the higher Approach Values. For example, the second highest raw approach value (28.18%) was provided for yachts, yet this outcome is strongly influenced by a single respondent who indicated that nearly 80% of yachts would be contaminated with *P. perna*. Furthermore, the error margins associated with many higher estimates indicate significant uncertainty relative to some of the other respondents. Additionally, for all vessel categories with an Approach Value greater than 1%, the Approach Value outcome is either strongly influenced by a single outlier (e.g. see graph A2 [Biof.: LR Ships (BM)], A5 [Biof.: Yachts], A6 [BW: HR Ships (BM)] and A7 [BW: LR Ships (BM)]), and/or presents a spread of responses greater than 40% indicating a strong lack of consensus from respondents (e.g. see graph A1 [Biof.: HR Ships (BM), A5 [Biof.: Yachts] and A6 [BW: HR Ships (BM)]). The model could compensate for the influence of outliers by weighting responses based on indicated

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uncertainty, or by weighting according to the relevant experience of respondents, but preferably the study should be improved by consulting a larger panel of suitably qualified experts.

2.3.2 Specific considerations applied to yachts

One of the key differentiators from the model is whether a vessel has transited through a port known to be contaminated with *P. perna* (i.e., "BM" ships versus "not BM" ships). The reviewers agree that this is an appropriate method of screening risk, though note that vessel management status and port residency periods could be used to further refine the model (see discussion in Section 2.1). A history of exposure to contaminated ports has been applied in the model to Low-Risk and High-Risk vessel categories and has enabled a realistic application of "Approach Values" to the reported vessel traffic (i.e. identifying four High Risk vessels that have been exposed to *P. perna* from a total of 886; and identifying 17 Low Risk vessels that have been exposed to *P. perna* from a total of 1,338 vessels).

Unfortunately, this logic is **not** applied to yachts resulting in a very high "Approach Value" being applied to all yacht entries irrespective of their exposure to *P. perna*. While the authors acknowledge the lack of data regarding yacht transit through infected ports and indicate that yacht values are highly speculative, the report still concludes that yachts are one of the primary sources of risk. Lack of data should not default to high risk. One of the advantages of an expert elicitation process is that subject matter experts can apply logic when considering risk independent of available data. However, despite valuable considerations regarding yacht exposure presented within Appendix B and C, this logic does not seem to have been incorporated into the "Approach Values" provided for yachts. For example, the Appendices indicate that most yachts visiting New Zealand pass through the Panama Canal and subsequently cruise the Pacific Islands prior to arrival in New Zealand. While the reviewers do not necessarily agree with the assertion that freshwater exposure during transit through the Panama Canal will kill all *P. perna*, other considerations can be applied. For example, the vast majority of yachts crossing the Pacific will visit multiple destinations meaning that passage is typically over a long period between the months of June to November (to avoid the cyclone season). As a result, few yachts would be likely to proceed directly from a contaminated port to New Zealand, and many yachts will be hand cleaned between destinations to facilitate better passage time. Additionally, it is likely that a reasonable number of yachts access New Zealand from other regions including Australia and South-East Asia, in which case exposure to *P. perna* is further reduced.

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2.3.3 Apparent errors noted in the model

The reviewers are confused about the way the expert elicited results for "residual contamination following intervention" are used in the model in Table 2.3. To use the example of Biofouling, the experts indicated that following intervention, a mean of 74% of vessels with biofouling will still be contaminated (see Table 2.2 and graph A.10). Thus, an impact of 74.00 is applied to all relevant biofouling scenarios in Table 2.3. If we take the example of "Biof.:HR Ships (BM)" the following is applied in the model:

- The volume of vessels is 4 (data not provided)
- The Approach Value is 37.5 (see A.1: experts estimate that 37.5% of vessels are contaminated)
- The model thus assumes that 1.5 vessels in this category are infected with *P. perna* each year and subsequently enter New Zealand (i.e., 37.5% of 4).

Applying the "Impact" value of 74% for biofouling (i.e., following intervention 74% of vessel are still contaminated, see A.10) the estimated number of infected vessels per year should be 1.11 following intervention (i.e., 74% of 1.5 = 1.11). However, the report applies this value to the category of "Reduction" and then creates another category of "Residual" which equals the total number of estimated infected vessels arriving each year (1.5) minus the adjusted value that incorporates the effect of interventions (1.11). This "Residual" value is subsequently used in the model to calculate the estimated number of *P. perna* established each year in association with the pathway. The justification for this logic is not apparent as the "Residual" value used applies to the estimated number of vessels that are NOT contaminated according to expert elicitation (or at least that is how the data is presented). This error is applied across all path categories.

As a result of this apparent error, the established rate for all pathways is not reported correctly in relation to expert elicitation. For example, for the path category of "Biof.:HR Ships (BM)", the rate of established *P. perna* associated with this pathway each year is obtained incorrectly by calculating the expert elicited establishment rate for biofouling (8.62%) from the "Residual" value (i.e., 8.62% of 0.39 = 0.03). If the correct value of 1.11 is used, the "Established" rate would be 0.09 (i.e., 8.62% of 1.11 = 0.09). Alternatively, the interpretation and labelling around Impact values is not correct and should be amended throughout the report.

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2.4 Establishment after arrival

Both estimates of establishment rate based on the minimum viable population are affected by an outlier estimate (expert 1) significantly higher than other respondents (see A.13 and A.14). As noted in Section 2.3.2, the report would benefit from greater number of suitably qualified experts to reduce the impact of outliers.

It is typical when examining invasion pathways in the marine environment to distinguish between colonisation in a recipient environment and the establishment of a self-sustaining population. For example, it is possible that three *P. perna* in close proximity on a hull could spawn and create viable larvae and, provided the abiotic and biotic conditions in the recipient environment are suitable, that the larvae could find suitable habitat and settle (i.e., colonise). However, larval competencies in the genus *Perna* typically extend from 8 – 20 days. As a result, any viable larvae are likely to be widely dispersed prior to settling, resulting in large distances between any settled individuals and a low likelihood of successfully establishing a F2 population and subsequent generations (i.e., establish). This distinction is critical and likely to shape the outputs from expert elicitation. The estimates for establishment given by experts seem more closely aligned with likely rates of colonisation than establishment.

2.4.1 Establishment from biofouling

The expert elicitation process estimates that 8.62% of vessel arrivals with biofouling that include at least three mature *P. perna* will result in an established population. The reviewers consider this an implausibly high estimate that is not well aligned typical rates of marine pest establishment, or those reported for *P. perna* in New Zealand (i.e., no reported established populations in New Zealand). Indeed, if nearly 10% of infected vessels resulted in an establishment, it would be assumed that the species would have been well established by now. As noted above, this high rate is strongly affected by an outlier in the estimation process, which if removed would result in lower rate of establishment. Considering that this is an annual figure, the reviewers consider that the expert elicitation outcome is better aligned to a successful colonisation event rather than the frequency of established populations developing.

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2.4.2 Establishment from ballast

The very different interpretations of minimum viable population size between biofouling (3 mature individuals) and ballast water (10,000 viable larvae) have a strong impact on the likelihood of *P. perna* colonising and subsequently establishing. Biofouling mediated introductions under this interpretation require a range of density dependant processes as well as stochasticity regarding in-water fertilisation. On the other hand, releasing 10,000 viable larvae in the water column could conceivably result in a rapid settlement of individuals within close proximity.

Despite the differences in minimum viable population densities between ballast and biofouling, and the impact of pathway dependant facts could be applied to create a more informed estimation of colonisation/establishment risk. For example, typical voyage durations from contaminated ports to New Zealand are likely to exceed the maximum larval competency period for *P. perna* meaning that ballast water is unlikely to be a viable transportation mechanism for this species to New Zealand (unless unreported populations establish in closer proximity). As a result, the reviewers believe that the establishment estimates provided by the experts are likely higher than expected for this species.

2.4.3 Final establishment Rate

Table 2.5 should be updated to correct the errors noted in Section 2.3.4 regarding the use of "Residual" values and the error in the "Impact" value for yachts identified in Section 2.3.2.

2.4.4 Distribution of risk between ports

Table 2.7 should be updated to reflect the corrected Establishment rates for each pathway.

3. CONSEQUENCE MODEL

3.1 Cost of eradication

The data produced through expert elicitation for "Cost of Eradication" is limited to a single respondent (see A.17 and A.18) despite a range of response values and a mean being produced in Table 3.3 (these seem based on the single respondent's margin of error). Furthermore, the text of Section 3.2.3 seems to omit any reference to the figures produced through this process (see line 339). As a result, it is difficult to provide meaningful comment on the cost estimates for eradication, though

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it is assumed that the costs provided range from NZ$2 – 3 million based on the appendices and table. The reviewers agree with the suggestion of the authors that, in fact, eradication costs are likely much higher than indicated by the expert for a 100 ha incursion, especially considering the need to incorporate ongoing monitoring to determine success.

The authors identify that the data for this section is of marginal value due to the single respondent and also identify that the counterfactual scenario of “no readiness” was underspecified and thus the response process was compromised by uncertainty. While the authors point out that the absence of a well defined “no readiness” model might ultimately be negligible in the context of the Crombie model, the reviewers disagree. The goal of early detection is to detect an established pest prior to the species establishing a broad range. Presuming that monitoring is able to identify the species in the early stages of colonisation, (i.e., <1 ha distribution) savings in eradication costs could theoretically be significant (though notably there are few examples of effective monitoring leading to early detection and eradication). It is also noted that the quoted value of $200,000 to eradicate a 12.5 ha incursion is likely a gross underestimate, particularly considering that ongoing monitoring would be required for at least 5 years in order to demonstrate success.

3.2 Estimated probability of eradication success

Once again, only one expert contributed to this elicitation process and as identified by the authors, this is of limited value. However, in the experience of the reviewers an estimate of 95% confidence to eradicate a 100 ha incursion is wildly optimistic. Very few examples of successful marine eradication programmes exist in relation to established marine pests and most successes are predicated on species with significantly limited distributions in constrained environments such as locks or lagoons (e.g., Fergerson, 2000, Creese et al., 2004), or species that are host dependant (Culver & Kuris, 2000).

4. RESULTS

The results table presented in Chapter 4 presents the final calculations incorporating previous results presented in other sections of the report. While some supporting graphs are provided in Appendices, the report does not provide any real results or raw data (e.g., from the elicitation process) to enable a meaningful review. These results are affected by a number of influences that are not described or justified in the paper. For example:

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- The values for Intervention for yachts seem incorrect (see Section 2.2.3) which influences subsequent interpretation.
- The model appears to incorrectly apply the intervention output (see Section 2.3.4) meaning that the values presented here are incorrect.
- Later stages in the assessment are reliant on a single data point (i.e., 1 expert elicitation) which is then applied multiplicatively to more robust outcomes diminishing their value.
- The overall sample size for expert consensus is extremely low in general (i.e., maximum of 4-5) and uncertainty, errors and outliers have a strong influence on the outcome.

5. Discussion

The authors point out that the outcome of the model is a much higher estimate of establishment than observed. As discussed in Section 2, the reviewers believe that the approach would be better framed by identifying two discreet stages in the establishment process: 1) colonisation (i.e., individuals successfully colonise suitable habitat and survive) and 2) establishment (i.e., individuals are able to establish a self-sustaining population). The current study (or at least the expert elicitation outcomes) seems to produce a realistic estimate of post-border colonisation likelihood rather than establishment likelihood. This could be addressed by clarifying the questions presented to experts.

Recommendation 2 presented by the authors suggests that CEBRA develop a guide to assist in experts providing realistic results. This would be an advantage, but the reviewers feel that for a third party examining the report, greater confidence would be provided by a more transparent assessment of the relative quality of expert elicitation data. For example, this might include a weighting system that incorporates expert uncertainty or potentially expert experience. More importantly, a group of four experts is a small pool of expertise, especially when all are well acquainted with each other and operating within the same general research/policy environment. The approach would greatly benefit from an expanded pool of experts with a particular focus on individuals with experience in inspecting biofouling and ballast water communities.

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5.1 Caveats

The lack of data regarding the movement of yachts has introduced significant uncertainty into the process and resulted in an outcome that likely overestimates the risk of these vessels. Considering the proximity of potential source populations for *P. perna*, the typical speeds and voyage itinerary of incoming yachts and likely influence of transit on survival, this risk outcome should be significantly less when applied to this species. In the context of a species-specific risk assessment, this outcome serves to mask other risks that might be of more serious concern.

5.2 Interpretation

The authors identify exposure to established *P. perna* populations is critical to understanding risk and recommend that the exposure model is updated to account for vessel transit through infected ports. This is endorsed by the reviewers, but it is also noted that gathering exposure data for yachts would significantly improve the assessment and would have a high likelihood of completely readjusting the outcome.

5.3 Conclusions

Despite the authors identifying that exposure to infected ports is the dominant factor contributing to relative risk, the conclusion proceeds to indicate that the generalised outcome could be applied to other species. This is clearly erroneous considering the strong role that visiting infected ports played in the expert scoring.

6. Reviewer summary

The reviewers recognise the advantage in developing a biosecurity risk framework that can be applied across multiple pathways to understand the impact of interventions and the cost of biosecurity policy implementation (or the lack thereof). It is also recognised that in the absence of specific data, expert elicitations are increasingly being applied to better understand complex problems. However, it should be noted that the outcome of expert elicitation processes ultimately reflects the nature of the questions posed and the applied experience of the respondents that involved in the process. While details on both questions presented and the applied experience of respondents where not provided

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in the draft report, the outcome seems strongly influenced by the small pool of experts, uncertainty expressed by experts and the effect of outliers.

The reviewers consider that the model and approach would benefit substantially from structural revisions ensuring the model is applicable to marine species, improving the nature of questions to ensure they focus on relevant selective filters, by resolving errors or uncertainty in the application of expert elicited data, and through consulting a broader pool or experts with a higher applied experience in biofouling and ballast water management. To assist readers in being able to understand the interpretation of the model, the authors should include all raw data, should present the specific questions posed to experts and should update all figures to include a key and an explanatory figure description. Furthermore, the report would have increased relevance to biosecurity outcomes if it was framed in the context of existing New Zealand maritime biosecurity policy such as the Craft Risk Management Standard – Biofouling (CRMS).

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REFERENCES

Coutts, A. D. M., Piola, R. F., Hewitt, C. L., Connell, S. D., and Gardner, J. P. A. (2010). Effect of vessel voyage speed on survival of biofouling organisms: implications for translocation of non-indigenous marine species. *Biofouling*, 26: 1–13.

Creese R.G., Davis A.R. and Glasby T.M. (2004). Eradicating and Preventing the Spread of Caulerpa taxifolia in NSW. NSW Fisheries Final Report Series No.64. 124 pp.

Crombie, J., Knight, E., and Barry, S. (2007). Marine Pest Incursions. A Tool to Predict the Cost of Eradication Based on Expert Assessments. Technical report, Australian Government, Bureau of Rural Sciences.

Culver, C.S., Kuris, A.M. (2000). The apparent eradication of a locally established introduced marine pest. *Biological Invasions.* 2: 245-253.

Ferguson, R. (2000). The effectiveness of Australia's response to the black striped mussel incursion in Darwin, Australia. A report of the Marine Pest Incursion Management Workshop, 27-28 August 1999. Department of Environment and Heritage, Commonwealth of Australia, Canberra, Australia, Research Report, 13

Molina, V., Drake, L.A. (2016). Efficacy of open-ocean ballast water exchange: a review. Management of Biological Invasions. 7(4): 375–388.

Robinson, A., Brockerhoff, E., and Ormsby, M. (2018). Scoping the value and performance of interventions across the NZ biosecurity system. Peer-Reveiwed Technical Report 1606E, CEBRA.

Robinson, A. and Ormsby, M. (2021). Proportional value of interventions across pathways and layers of the biosecurity system. Final Report 170621, CEBRA.

Robinson, A., Welsh, M., Ormsby, M., Brockerhoff, E., and Reed, C. (2020). Proportional Value of Interventions across Pathways and Layers of New Zealand's Biosecurity System. Technical Report 170621, Centre of Excellence for Biosecurity Risk Analysis.

SGS. (2021). Study on the implementation of the Ballast Water Management Convention in Australia: 2019-2020. Report prepared for the Australian Government Department of Agriculture, Water and the Environment. 23 pp.

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