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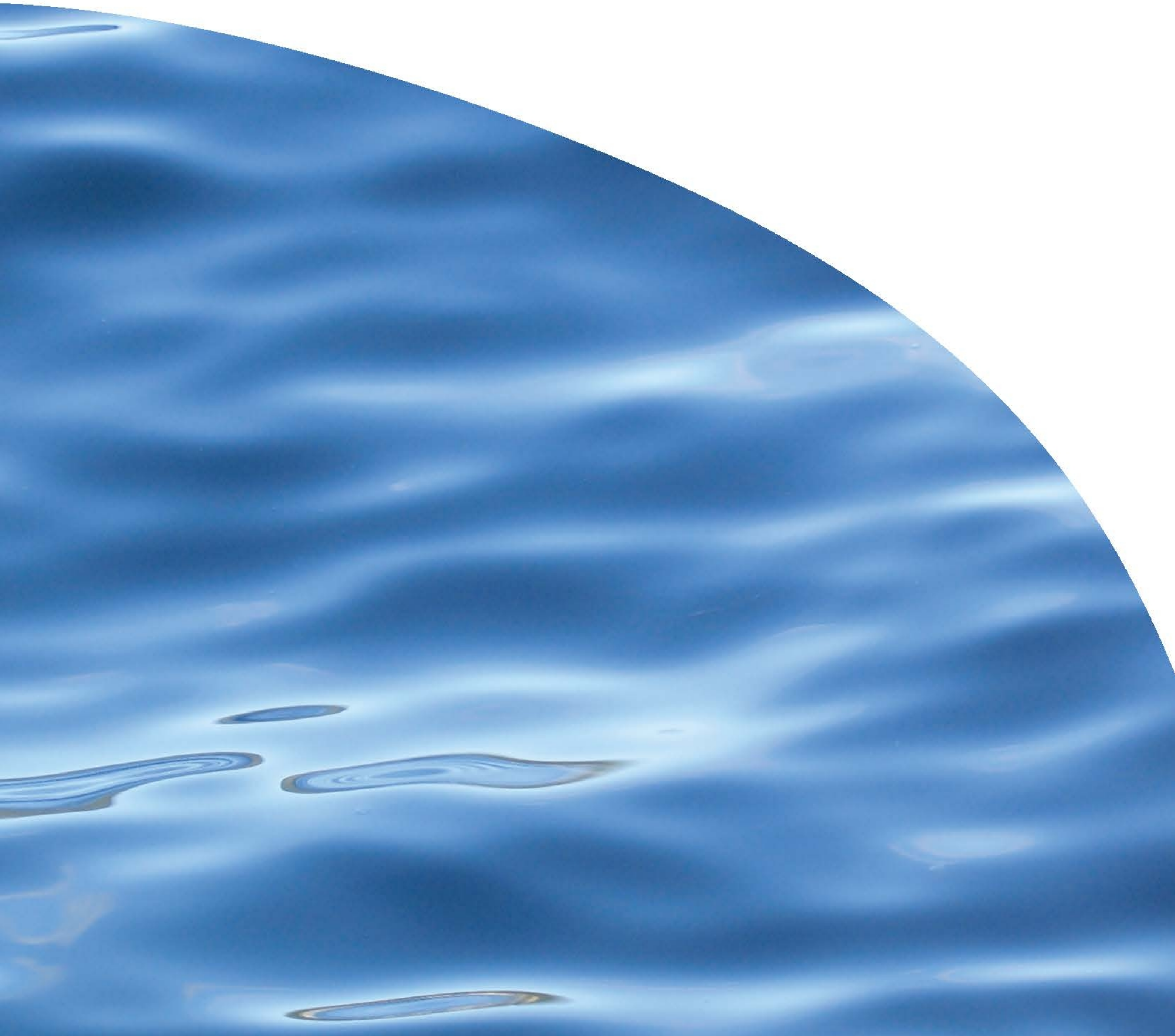
A BENEFIT-COST MODEL FOR REGIONAL MARINE BIOSECURITY PATHWAY MANAGEMENT



A BENEFIT-COST MODEL FOR REGIONAL MARINE BIOSECURITY PATHWAY MANAGEMENT

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Prepared for Northland Regional Council

Envirolink Grant 1605-NLRC186

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EXECUTIVE SUMMARY

Northland Regional Council (NRC) is considering developing a 'regional pathway management plan' under the Biosecurity Act 1993 (BSA), in order to manage the human-mediated spread of marine pests into and within the Northland region. Among other things, the BSA requires an analysis of the benefits and costs of such a plan. Recently, the Top of the South (TOS) Marine Biosecurity Partnership (which comprises the three TOS councils, MPI, local ports, the aquaculture industry, tangata whenua and other regional stakeholders in marine biosecurity) has produced a draft benefit-cost model for pathway management that is broadly suitable for NRC's needs. This report is part of an Envirolink Medium Advice Grant project (Regional Council Advice number 1605-NLRC186) that further builds on and refines the TOS benefit-cost model, to facilitate application by NRC. Beyond the term of the Envirolink, it is expected that NRC will continue to revise and adapt the model to suit their evolving needs.

The model provides a framework for assessing risk according to the likelihood of marine pest introduction and spread with and without pathway management, and the consequences in terms of impact on regional values. The pathway management scenario considered in this report is based on reducing hull biofouling on vessels to a low level, according to a defined 'level of fouling' scale. The benefit of pathway management is determined, in dollar terms, as the difference between unmanaged and managed risk. The ratio of this benefit to the cost of implementing management measures over a 10 year time-frame (the assumed operational time-frame of a regional pathway management plan) gives the expected value of damage reduction per dollar spent on management.

The model is populated using data from the TOS, with results being illustrative rather than definitive; the purpose of this report was to describe the mechanics of the model to NRC, with reference to accompanying spreadsheets. We demonstrate how the input parameters used, and the various assumptions made, may have a significant bearing on model outcomes. Among the key considerations for NRC in terms of application to Northland are:

- Determining values at risk and the magnitude of impact on those values.
- The pathways focused on for management, and the 'package' of management measures implemented.
- The likely risk reduction achieved by the management measures (based on both technical effectiveness and conceivable levels of uptake or compliance).
- Management costs and the optimal combination of management effort/cost vs risk reduction achieved.

A particular challenge is to reliably ascertain the nature and extent of pest impacts, and to characterise effects that cannot readily be assigned a monetary value. For example, it can be demonstrated that delaying pest spread can have a tangible economic benefit for industries such as aquaculture, but the benefits of delaying spread for values such as biodiversity are less clear. A related issue is that the 'average' outcome from pathway management might be

delay of pest spread, but implementation of improved practices could lead to even greater gains. For example, improved pathway management may prevent the spread of a pest that would otherwise have had catastrophic effects; however, there is no way to measure this type of 'success'.

Provided NRC are explicit about the base assumptions and input values, the model will provide a useful framework to enable evaluation of the benefits and costs of pathway management, in a systematic and transparent way, accounting for uncertainty in estimates of key input parameters. The model can easily be tailored to suit the specific needs of NRC; for example, there is scope to include terms in the model that relate to the management of specific pest populations. In this way, the benefits and cost of pathway management can be compared with pest management approaches, such as NRC is currently undertaking.

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1. INTRODUCTION

1.1. Background

Since 2012, Northland Regional Council (NRC) has directed more than three quarters of a million dollars towards managing marine pests that have become established in the Northland region. NRC, as well as a number of other councils and the Ministry for Primary Industries (MPI), recognises that managing risk pathways (*e.g.*, vessel biofouling) that introduce or spread marine pests is critical to achieving effective marine biosecurity. For this purpose, NRC is considering developing a 'regional pathway management plan' under the Biosecurity Act 1993 (BSA). Under Section 90 of the BSA, an analysis of the benefits and costs of such a plan is required as an early step in plan development.

The Top of the South (TOS) Marine Biosecurity Partnership (Tasman, Nelson and Marlborough councils, along with MPI, Department of Conservation, local ports, the aquaculture industry, tangata whenua and other stakeholders) has produced a draft benefit-cost model for pathway management analysis that is broadly suitable for NRC's needs (Lawless & Forrest 2014), although it requires further refinement and region-specific adaptation. The model used by the TOS is itself based on a risk-based approach for marine biosecurity management that was developed by Forrest *et al*. (2006) and later applied to consider regional biosecurity management in Fiordland (Sinner *et al.* 2009). The TOS work expanded on these earlier approaches to specifically consider risk pathways.

This report is part of an Envirolink Medium Advice Grant project that further builds on and refines the TOS model and develops an approach that is 'fit-for-purpose' for both the TOS and NRC. The model provides a starting point for evaluating pathway management benefits and costs in a systematic and transparent way that accounts for uncertainty in estimates of key input parameters.

The focus of the Envirolink project was to further develop and refine the existing TOS model by way of knowledge transfer to NRC, and collaboration with their staff. As such, this report focuses on providing guidance for NRC on the methods, along with key rationale and assumptions and limitations. Beyond the term of the Envirolink, it is expected that NRC will continue to revise and adapt the approach to suit their evolving needs.

1.2. Scope of this report and key project steps

The project progressed as follows:

- Cawthron prepared a briefing document for NRC that described the model developed by Forrest *et al*. (2006), and its adaptation for the TOS Partnership.

The document described the methodology and the underlying rationale, and model assumptions with respect to key parameters. An Excel spreadsheet accompanied the briefing document that contained the model and its functions. This information was provided to NRC in August 2015.

- Cawthron subsequently visited NRC, and worked with NRC staff to adapt the model to suit their purposes.
- A revised model was produced by Cawthron, and reviewed by NRC in January 2016. Cawthron has produced this final report that describes the model and its associated Excel worksheets.

The draft input parameters estimated for the TOS study are used to demonstrate the mechanics of the model, as NRC staff are still undertaking separate further work to estimate these for Northland. Note that TOS study estimates are likely to be further refined at some later date, hence should be regarded as illustrative rather than definitive.

2. BENEFIT-COST MODEL AND ADAPTATION TO REGIONAL PATHWAY MANAGEMENT

2.1. Model

The model described by Forrest *et al*. (2006) was developed as a decision-support tool to prioritise management actions for the protection of geographically-defined high value areas (or resources) from target marine pests. The model in its entirety is based on a four-step risk management process consisting of risk identification, risk assessment, analysis of risk treatment options, and risk evaluation. These steps are all relevant to NRC, but of most relevance for this Envirolink project are the middle steps involving risk assessment and analysis of risk treatment options; these steps use a 'chain-of-events' risk model as summarised in Box 1. The base model includes parameters that reflect measures to reduce the spread of specific pests, as well as measures to control new incursions of established populations.

2.2. Model adaptation for regional pathway management

As NRC's focus is pathway management, the terms in the model that relate to the likelihood of successful control of a pest incursion in a defined area (P_{SC}) and the associated costs (C_{SC}) can be assumed to be zero. NRC may wish to include non-zero values for these terms at a later date; for example, to compare the efficacy of pathway management vs pest incursion response.

With respect to the remaining parameters in the model, a suggested general improvement to the original model described by Forrest *et al*. (2006) relates to the terms for pest introduction and pest density (terms P_I and P_{PD} in Box 1, respectively). For regional application we suggest that these terms are expressed as a single parameter. As the notion of 'pestiness' or 'invasiveness' is implicit in the estimated level of impact (the 'I' term in the model), the term P_{PD} is largely redundant. As such, we use the term Pi to simply reflect the introduction risk of an actual or potential pest.

2.3. Process of regional model application

The approach to regional model application largely followed Box 1 in that it involved:

- Assessing (in a simplistic way) the expected value of damage from marine pests under the present management regime (*i.e.*, in the absence of specific measures to reduce the likelihood of pest introduction through pathway management). This is the unmanaged risk term (R_U) in Box 1.

Box 1. Overview of model developed by Forrest et al. (2006)

The model developed by Forrest *et al*. (2006) was based on protection of geographically-defined high value areas (HVAs) from target marine pests. The model first requires assessment of risk to HVAs in the absence of any specific management activities; *i.e.*, in the absence of management activities above and beyond the baseline or 'status quo'. This term is referred to by the authors as 'unmanaged risk', which was represented in simplistic terms in the original model (notes that the syntax below is simplified from that used by Forrest *et al*. 2006) as:

$$\mathbf{R_U = P_I \times P_{PD} \times V \times I}$$ where:

R_U = unmanaged risk from a pest, which is the expected value of damage from the pest in the absence of specific measures to reduce the likelihood of introduction or to respond to an incursion;

P_I = the probability of introduction of a pest to a defined area;

P_{PD} = the probability that, once introduced, a pest will reach 'pest density' in a defined area;

V = the total value at risk in a defined area; and

I = the impact resulting from establishment at pest density, in terms of the proportion of the values at risk that are lost due to a pest.

The next main step involves assessing the level of managed risk and associated management costs, to enable evaluation of which measures provide the best value for money. The level of managed risk and associated costs were expressed as follows:

$$\mathbf{R_M = P_{I(M)} \times P_{PD} \times V \times I \times (1 - P_{SC})}$$

$$\mathbf{C_M = C_{SM} + [P_{I(M)} \times P_{PD} \times C_{SC}]}$$ where:

R_M = managed risk from a pest, or the expected value of damage from a pest despite measures to reduce the likelihood of introduction and respond to any incursion (*i.e.*, residual risk);

$P_{I(M)}$ = the reduced probability of the introduction of a pest to a defined area, after feasible measures to manage spread have been implemented;

P_{PD}, V and I are defined as per the unmanaged risk equation;

P_{SC} = the probability of successful control of an incursion of a pest in a defined area;

C_M = the expected cost of management measures to reduce the risk from a pest in a defined area;

C_{SM} = the cost of measures to manage spread that could be implemented to reduce the likelihood of introduction of a pest to a defined area; and

C_{SC} = the expected cost of incursion response in a defined area, *i.e.*, the cost of incursion response discounted by the probability of an incursion.

The expected value of damage reduction per dollar spent on management can be expressed as $[R_U - R_M] / C_M$. Implied in the management model are measures to reduce the spread of specific pests, as well as measures to control new incursions of established populations. However, the approach is hierarchical in that each main component can be expanded or deleted as necessary. For the purposes of considering the efficacy of pathway management for the TOS and NRC, the model terms relating to pest introduction and spread have been expanded, and the terms related to pest incursion response have been assumed as zero. Further changes are described in the main text.

- Estimating risk under a pathway management strategy that aims to reduce the incidence of 'heavily fouled' vessels, by specifying a maximum allowable level of hull fouling (see below). This gives the managed risk term (R_M) in Box 1.
- Assessing the benefit of risk reduction in dollars per year, as the difference between R_U and R_M. The ratio of this benefit to the annual cost of implementing management measures (C_M) gives the risk reduction per dollar spent on management (RR_M).

The model input parameters that were used to calculate R_U, R_M and C_M are described in subsequent sections, with the illustrative input values taken from the TOS study. NRC have the base spreadsheets and can readily undertake their own assessment once they have estimates for each of the model input parameters.

Note that, in the TOS case, a conservative approach was undertaken to estimate input parameters based on judgements (sometimes 'guesstimates') by the TOS authors (Lawless & Forrest), with supporting data used where possible. However, as already noted, the TOS assessment is a 'work in progress' and the parameter estimates should be regarded as illustrative at this stage. To provide a sense of how different input values affect model outcomes, we present some lower and upper bounds for many of the estimates. Lower and upper bounds in the values of R_U and R_M (and benefit, R_U - R_M) reflect the arithmetic product of the lower or upper bounds in their input parameters.

Clearly, a more rigorous approach to estimating the bounds of each parameter would ideally be undertaken; for example, using structured elicitation methods with multiple experts. With a more rigorous approach, the upper and lower bounds could be considered to reflect some of the uncertainty inherent in model input parameter estimates and modelling outcomes. In the meantime, the rough estimates that we use from the TOS study illustrate how the model can be used to determine whether (and to what extent) pathway management might be worthwhile.

3. MODEL PARAMETERS FOR ESTIMATING R_U IN THE TOP OF THE SOUTH

3.1. Overview

The parameters of unmanaged (*i.e.*, baseline or 'status quo') risk, R_U, and the methods that were used to derive lower and upper bounds in the TOS study are described below. R_U in the modified model can be described as follows:

$$R_U = Pi * V * I$$

Definitions of V and I are as per Box 1. As already noted, in this regional model Pi represents pest introduction risk from external sources.

3.2. Estimating the rate of pest introduction (Pi) to the TOS from external regions

To estimate Pi requires clarification as to what is meant by the term 'pest'. A simplistic approach would be to define any non-indigenous species (NIS) as a pest; for example, because New Zealand's indigenous biodiversity is permanently changed by such a species being present. However, we adopt a more usual approach and consider pests to be NIS that have adverse effects (actual or potential) because of their high abundance or dominance (MPI 2012).

When considering Pi as the rate of introduction, the time-frame over which historic data are considered is clearly important. The TOS assessment used data for the last 15 years (since 2000) on the basis that this represented a period of heightened biosecurity awareness. Relevant events in the TOS leading up to and during that period include:

- The incursion and small scale management (in Nelson) in the 1990s of the Asian kelp *Undaria pinnatifida*.
- The 2001 introduction and subsequent spread and eradication attempts (2003, 2006-2008) of the sea squirt *Didemnum vexillum* in Marlborough.
- Port baseline surveys undertaken in Golden Bay, Nelson, Picton and Port Underwood (between c. 2001 and 2006).
- Ongoing six-monthly Marine High Risk Site Surveillance by NIWA, which involves surveys for target marine pests in Nelson and Marlborough ports.
- The formation of the TOS Marine Biosecurity Partnership in 2008.

Since 2000, seven marine species[1] are known to have become established in the TOS that are either formally designated as marine pests, or can be considered as potential pests (*e.g.*, by virtue of their high abundance and/or studies reporting actual or potential adverse effects). Seven species in 15 years equates to an annual introduction rate of close to 0.5 species per year. As such, the TOS study used a baseline value of 0.50 as an estimate of Pi, and for illustrative purposes in this report we use nominal lower and upper bounds of 0.40 and 0.60, respectively. Actual introductions could be greater due to undetected pests in areas outside ports and marinas where there is no formal surveillance.

3.3. Estimating values impacted (V and I)

Estimating values at risk and the proportional level of impact on those values poses considerable challenges, in part because of the need to consider non-economic values, but also due to considerable uncertainty about the impacts of most pest species. In a recent analysis for development of a pathway management plan for Fiordland, Harris (2015) considered the regional value of commercial fisheries and tourism, and discussed ways to value biodiversity. Examples cited included work for MPI by Branson (2012) and a study by Patterson and Cole (1999) on 'The economic value of New Zealand's biodiversity'. NRC may wish to consider these documents for ideas on assigning values to the region.

The TOS study took a simplistic approach, and derived some rough estimates to use as an initial guide, as follows:

- **V:** The value at risk was 'ballparked' for the TOS as follows:
    - The lower bound was conservatively based on ten times the value of marine farming production in the region of c. $200M per year, giving $2B. As marine farming occupies c. 1% of the coastal marine area, the lower bound assumes that other attributes of the region have a considerably lower per unit area value than does aquaculture. Clearly, this approach doesn't reliably account for aspects of the environment that are vulnerable to harmful marine organisms but cannot be reduced to monetary values.
    - The upper bound was derived from a Cawthron-Massey University project (unpublished) on coastal ecosystem services, which reviewed global studies to derive values for comparable habitats in Tasman and Golden Bays. It suggested an annual value of c. $2B for ecosystem services in these areas. If it is assumed that the value of ecosystem services for the

[1] These species are Mediterranean fanworm *Sabella spallanzanii*, sea squirts *Didemnum vexillum*, *Styela clava* and *Clavelina oblongifolia*, seaweed *Grateloupia turuturu*, bryozoan *Zoobotryon verticillatum*, and brown mussel *Perna perna* (which was eradicated) (Hopkins *et al*. 2011).

Marlborough CMA is comparable to Tasman and Golden bays, the value of the entire TOS region would be roughly $4B.

- **I:** Estimating the proportional impact on the value at risk in the status quo situation is difficult and highly subjective. Quantitative data exist on the impacts of some marine pests for industries like aquaculture, for which it is reported that economic impacts attributable to biofouling (or specific pests) range from c. 50–30% of production costs globally (Adams *et al.* 2011). However, the impacts of specific pests are usually highly location- and species-specific. Additionally, there is no simple way to assign a monetary value to ecological impacts or impacts on other non-economic values. It is even more challenging to quantify the proportion of value at risk that is potentially lost to a pest. In the absence of reliable information, the TOS study modelled scenarios of impact in an unmanaged situation based on lower and upper values for parameter I of 1% and 5% of the value at risk. It was assumed that this level of impact could be realised gradually over a period of 10 years[2].

[2] NRC anticipate that a pathway management plan would initially be put in place for 10 years, so this is a logical time-frame over which to consider potential risks and management benefits.

4. MODEL PARAMETERS FOR ESTIMATING R_M IN THE TOP OF THE SOUTH

4.1. Overview of risk management approach

Managed risk, R_M, is given by the following equation:

$$R_M = Pi_{(M)} * V * I_{(M)}$$

$Pi_{(M)}$ is the probability of introduction of an NIS after implementation of pathway management measures for hull fouling (the subscript 'M' is used to denote the management regime). It was conservatively assumed in the TOS study that model parameter V (total value) would remain the same. However, the value of the parameter '$I_{(M)}$' is expected to differ to the baseline parameter I, which represented the proportion of V that was lost to marine pests. As well as decreasing $Pi_{(M)}$, the introduction rate of marine pests, a regional pathway management approach is also expected to decrease the subsequent rate of human-mediated spread from new regional populations. Accordingly, the proportion of value impacted in a given period of time will be reduced compared with the unmanaged situation. The way this situation was addressed in the model is described below (see Section 4.3), as it was not made explicit in the original conceptual approach of Forrest *et al*. (2006).

The management regime being considered for both the TOS and Northland is to reduce or eliminate 'conspicuous' biofouling from vessels, the rationale being that increased fouling is associated with increased marine pest risk. This outcome will likely be achieved by defining a maximum permitted fouling threshold according to a 'level of fouling' (LOF) scale developed by Floerl *et al*. (2005); see Table 1.

Table 1. Level of fouling (LOF) ranks (source: Floerl *et al*. 2005).

Rank	Description	Visual estimate of fouling cover
0	No visible fouling. Hull entirely clean, no biofilm[a] on visible submerged parts of the hull.	Nil
1	Slime fouling only. Submerged hull areas partially or entirely covered in biofilm, but absence of any macrofouling.	Nil
2	Light fouling. Hull covered in biofilm and 1–2 very small patches of macrofouling (only one taxon).	1–5 % of visible submerged surfaces
3	Considerable fouling. Presence of biofilm, and macrofouling still patchy but clearly visible and comprised of either one single or several different taxa.	6–15 % of visible submerged surfaces
4	Extensive fouling. Presence of biofilm and abundant fouling assemblages consisting of more than one taxon.	16–40 % of visible submerged surfaces
5	Very heavy fouling. Diverse assemblages covering most of visible hull surfaces.	41–100 % of visible submerged surfaces

[a]Biofilm: Thin layer of bacteria, microalgae, detritus and other particulates that is required for settlement of the larvae of many species of marine invertebrates. Refer to (Todd and Keough 1994, Keough and Raimondi 1995).

One scenario being considered is a hull fouling standard based on a maximum permitted LOF of 2 (*i.e.*, LOF ≤ 2, comprising ≤ 5% fouling cover on the hull). At greater than LOF 2, hull fouling is often considered conspicuous, at least in the case of recreational vessels (Forrest 2013). The next section describes the process used to calculate $Pi_{(M)}$, based on the extent to which Pi would be expected to reduce if an LOF 2 standard was in place.

4.2. Estimating the reduced rate of pest introduction, $Pi_{(M)}$, as a result of hull fouling management

4.2.1. Assumptions regarding the relative importance of hull fouling to Pi

Hull fouling is implicated as a key pathway for the spread of marine pests. However, it is not the only pathway, as other vessel-related mechanisms (*e.g.*, ballast water) and non-vessel pathways (*e.g.*, aquaculture) may be important in some circumstances. As such, the risk assessment process incorporates model terms to account for these other human-mediated pathways, and also the process of natural spread. Even when the Pi value for each of these other pathways is not well understood, incorporating terms for them serves as a reminder of residual risk that is not being addressed under a hull fouling management regime (Forrest *et al*. 2006). To estimate how Pi would reduce under an LOF 2 standard, it is necessary initially to:

- Make an assumption regarding the proportion of status quo/baseline risk that is attributable to hull fouling compared with other potential pathways.
- Combine the probabilities from the different pathways in a mathematically defensible way, as the total Pi value does not reflect the sum of Pi values for each pathway.

In the TOS study, the estimated Pi was assumed to be 90% attributable to hull fouling (HF). In that case, the TOS Pi was derived based on seven species, for which hull fouling was strongly implicated as the causal pathway. However, other pathways may be important for ongoing pest introductions, and for illustrative purposes, the other pathways were defined as ballast water (BW), aquaculture (AQ), other human-mediated pathways (OT), and natural spread (NS). There are various reasons to justify setting the Pi values for the non-hull fouling mechanisms at a low level. For example, whereas hull fouling is important for all vessels (which number in their thousands), mechanisms such as ballast water are important for only some large vessel types (*e.g.*, merchant ships), which are a minority in New Zealand waters compared to smaller types.

Assuming the Pi values for each pathway are independent of each other, but not mutually exclusive, the probability of at least one 'event' is one minus the probability that none of them will occur (Snedecor & Cochran 1980). Thus, the Pi for all pathways defined above can be represented as:

$$Pi = 1 - [(1 - Pi_{(HF)}) \times (1 - Pi_{(BW)}) \times (1 - Pi_{(AQ)}) \times (1 - Pi_{(OT)}) \times (1 - Pi_{(NS)})]$$

Calculations are given in Table 2, based on illustrative values for the non-hull fouling pathways. The associated spreadsheets provided further comment on the relative importance of these non-hull fouling pathways.

Table 2. Illustrative Pi values for each pathway used in the TOS model*.

Pi bounds	Pi HF	Pi BW	Pi AQ	Pi OT	Pi NS	**Pi**
Lower	0.360	0.005	0.050	0.005	0.001	**0.40**
Upper	0.540	0.010	0.100	0.010	0.002	**0.60**

* Note that the overall Pi value (bold type) is not the sum of individual Pi values for each pathway (see text). The hull fouling (HF) Pi value ($Pi_{(HF)}$) for the TOS is based on all recorded introductions since 2000 by any pathway (c. 0.50 pests per year, bounds 0.40–0.60), with an assumption that hull fouling represents 90% of that risk. For illustrative purposes, the remaining risk (grey shade) is spread across ballast water (BW), aquaculture (AQ), other human-mediated pathways (OT) and natural spread (NS).

The next section considers the reduction in overall Pi under an LOF 2 management regime in which hull fouling Pi is reduced, but the Pi for other pathways is assumed to remain the same. NRC may choose to alter these values; for example, if it is considered that pathways other than hull fouling could have a greater relative importance and/or if a broader management and awareness programme is implemented to address these pathways.

4.2.2. Proportion of hull fouling risk theoretically eliminated with management

Overview

$Pi_{(M)}$ reflects the level of residual risk that remains after eliminating all conspicuously fouled vessels to a target LOF of 2 (*i.e.*, by eliminating LOF 3-5), weighted by an efficacy factor to reflect that management is unlikely to be completely effective. To determine $Pi_{(M)}$, it is necessary to determine:

- The proportional contribution to risk reflected by vessels in each LOF category in the absence of management. This requires consideration of vessel risk in relation to the presence of risk species.
- The cumulative decrease in risk that is achieved by reducing fouling to LOF 2, for vessels that are fouled at LOF 3, 4 or 5 (it is assumed that management has no effect on vessels that are already LOF 2). This component requires a means to evaluate how species risk is altered by a management approach that focuses on levels of fouling (*i.e.*, does not target any particular species).

The calculations that enable this assessment are summarised in Table 3, and the key steps described below. For cross reference, the calculations for each step are cross-referenced to column labels A–H in Table 3.

Table 3. Calculation of risk represented by each LOF*. These figures are used with data in Table 4 to calculate risk reduction in relation to management measures. Note that, by definition, LOF 1 does not contain visible macrofouling.

A	B	C	D	E	F	G	H
LOF	Mean proportion boats in LOF*	P (risk species present)*	Raw risk	Weighting (median % cover)	Adjusted risk score	Target residual risk (≈ LOF 2)	Risk eliminated (F - G)
1	0.09	0.000	0.000	0.000	0.000	0.000	0.000
2	0.55	0.330	0.183	0.030	0.005	0.005	0.000
3	0.17	0.843	0.145	0.105	0.015	0.005	0.010
4	0.11	0.856	0.090	0.280	0.025	0.005	0.020
5	0.08	0.969	0.078	0.705	0.055	0.005	0.050
				TOTALS	**0.101**		**0.079**

* Column letters are used to facilitate cross reference from the main text. The risk eliminated assumes vessels of LOF 3-5 are reduced to LOF 2, such that the target residual risk in column G is equivalent. Hence, the total risk eliminated (across LOF 3-5) from column H can be estimated as 78.27% of the total adjusted risk from column F (*i.e.*, 0.079/0.101).

Vessels in each LOF category and associated risk indicator taxa

The first step requires assessment of the percentage of vessels in each LOF category and likelihood that risk species are associated with a given LOF. For the TOS, the proportion of vessels in each LOF category (Table 3, columns A & B) was determined as the mean value from two recent hull fouling surveys of recreational vessels (Forrest 2013, 2014). In addition to LOF, the TOS surveys simultaneously recorded the occurrence of species or taxa that were considered to be indicative of a biosecurity risk, either because they:

- Were known pests (*e.g.*, MPI 2012) or were similar (functionally and/or taxonomically) to known pests, or
- They were 'late successional' fouling species that can be considered indicative of boats whose antifouling coat is no longer effective; based, for example, on raw data from a TOS study by Lacoursière-Roussel *et al.* (2012).

Three taxa were recorded in the TOS surveys that met these criteria, namely solitary ascidians, bivalves and brown macroalgae (the only example being the Asian kelp *Undaria pinnatifida*). Column C of Table 3 indicates the proportion of vessels in each LOF category that had at least one of these risk indicator taxa present, and illustrates that the occurrence of such taxa increases with vessel LOF. Columns B and C are multiplied together to provide a raw risk score for each LOF category (column D).

Determining risk eliminated by hull fouling management

Recognising that risk relates not just to the presence of a species but also its prevalence (among many other factors), the TOS study applied as a weighting factor the median cover of hull fouling within each LOF category (column E). For example, a vessel of LOF 4 by definition has a percent cover of 16–40%, in which case a weighting factor of 0.28 (reflecting a median cover of 28%) was applied to the raw risk score for LOF 4 to give an adjusted risk score in the absence of management (column F). Assuming vessels of LOF 3–5 have their fouling reduced to LOF 2 by management, the risk eliminated can be determined (column F – column G). The total risk eliminated by targeting a maximum LOF of 2 is therefore 78% (0.78 = 0.079/0.101) under a theoretical scenario of 100% management efficacy.

4.2.3. Accounting for management efficacy

In reality, management will not be 100% effective. There are two main reasons for this. The first is that management measures themselves (*e.g.*, hull cleaning) may not, for a given vessel, reduce fouling to LOF 2, and the second is that there is unlikely to be complete uptake by vessel owners (and not all non-compliant vessels will be detected). As such, a 'management efficacy' term was defined as the product of these limitations, with illustrative lower and upper bounds based on the low and high efficacy figures shown in Table 4. In a more refined model, NRC may wish to account for some level of improvement in management efficacy over time (*e.g*. following a phase-in and education period).

4.2.4. Determining reduction in hull fouling Pi and residual risk for calculating Pi(M)

The product of proportional risk eliminated (*i.e.*, 0.78 based on Table 3) and management efficacy values from Table 4 gives the reduction in $Pi_{(HF)}$ that would occur under the LOF 2 management strategy. Thus, the following reductions are estimated:

- Low efficacy: 64% elimination of c. 78% of hull fouling risk = proportional reduction in $Pi_{(HF)}$ of 0.50 **(*i.e.*, residual risk = 0.50)**
- High efficacy: 86% elimination of 78% of hull fouling risk = proportional reduction in $Pi_{(HF)}$ of 0.67 **(*i.e.*, residual risk = 0.33)**.

Table 4. Calculation of management efficacy based on illustrative likelihoods that treatments will be successful and owners will comply with management regime (and non-compliant vessels will be detected).

Elements of efficacy	Low efficacy	High efficacy
P (treatment success)	0.85	0.95
X		
P (uptake/detection)	0.75	0.90
=		
Efficacy score	**0.64**	**0.86**

The residual risk values are multiplied by the lower and upper Pi values for hull fouling, $Pi_{(HF)}$, to obtain $Pi_{(M)}$ for hull fouling. After including the illustrative residual risk for the other pathways, the lower and upper bounds for $Pi_{(M)}$ for all pathways combined can be recalculated (Table 5). As noted above, for present purposes, we have assumed that residual risk on other pathways is that same as in the unmanaged scenario. In reality, education and awareness conducted in relation to a hull fouling campaign would provide an opportunity to raise awareness of feasible risk reduction practices for other pathways; accordingly, their $Pi_{(M)}$ values may decrease as well.

Table 5. $Pi_{(M)}$ estimates for target LOF 2, calculated by multiplying $Pi_{(HF)}$ from Table 1 by the residual risk following management. Estimates are shown for illustrative low efficacy and high efficacy management scenarios*.

a. Low efficacy

$Pi_{(M)}$ bounds	$Pi_{(M)}$ HF	$Pi_{(M)}$ BW	$Pi_{(M)}$ AQ	$Pi_{(M)}$ OT	$Pi_{(M)}$ NS	**$Pi_{(M)}$**
Lower	0.180	0.005	0.050	0.005	0.001	**0.23**
Upper	0.270	0.010	0.100	0.010	0.002	**0.36**

b. High efficacy

$Pi_{(M)}$ bounds	$Pi_{(M)}$ HF	$Pi_{(M)}$ BW	$Pi_{(M)}$ AQ	$Pi_{(M)}$ OT	$Pi_{(M)}$ NS	**$Pi_{(M)}$**
Lower	0.119	0.005	0.050	0.005	0.001	**0.17**
Upper	0.178	0.010	0.100	0.010	0.002	**0.28**

* Pathway codes (HF, *etc*) are as indicated for Table 2. $Pi_{(M)}$ values for pathways other than hull fouling (grey shade) are assumed unchanged from the baseline scenario (see text).

4.3. Estimating proportion of value impacted, $I_{(M)}$

Values (V) are assumed to remain the same in a managed scenario, and the original model described in Box 1 made no assumptions regarding how the proportion of V adversely impacted under management, $I_{(M)}$, might change. However, a pathway management scenario that reduces the introduction (and subsequent spread) of pests will delay the timeframe over which impacts are realised. A simple approach that we adopted to calculate $I_{(M)}$ by reducing parameter I by the same amount that Pi was reduced, given a management timeframe of 10 years. Hence, lower and upper bounds for I of 5 and 10% of V, respectively (see Section 3.3), would reduce by 50 and 67% under the low and high efficacy management scenarios, respectively.

5. CALCULATION OF RISK REDUCTION AND BENEFIT-COST

5.1. Management costs, C_M

For the TOS, ongoing costs of pathway management measures to reduce vessel fouling to LOF 2 were estimated to total c. $1.5M per year, reflecting estimated agency costs of c. $0.4M and exacerbator costs of c. $1.1M. The latter reflected the estimated costs of haul-out, clean and antifouling of non-compliant boats[3]. These estimated costs are based on known current costs in the TOS, and the scale of costs incurred in similar programmes in other regions; however, the TOS costs are fairly ballpark at this stage. Upper and lower bounds were set at ± $0.25M. It is likely that there will be additional set-up costs in the initial years of a management programme. Accordingly, the benefit-cost calculations below assume (for illustrative purposes) an extra $0.2M per year for the first two years.

5.2. Overview of benefit-cost calculations and modelling outcomes

Values of R_U and R_M, together with management costs C_M, can be used to calculate the expected value of damage reduction per dollar spent on management; *i.e*. 'risk reduction' per dollar spent on management, RR_M, as:

$$\mathbf{RR_M = (R_U - R_M) / C_M}$$

The calculations described below were made for a 10 year management programme whose goal is to achieve vessel hull fouling LOF ≤ 2. The distribution of both benefits and costs changes over the 10 year management timeframe, and had to be accounted for in the calculation of RR_M.

One of the cost assumptions noted above for the TOS was that there would be additional set-up costs of $0.2M for each of the first two years of a management programme. As such, total costs over 10 years were calculated as the sum of costs per year, determined on a present value basis, using a discount rate of 7.5%.

Benefits were more complex to calculate, due to the need to cater for the fact that the realisation of adverse effects will occur incrementally as marine pests spread; *i.e.*, the full extent of model parameter 'I' is not realised in year 1, in fact it is not expected to be realised until year 10. Accordingly, it is necessary to include in the model an estimate of the rate at which adverse effects are realised. Our simplifying assumption, reflected in the calculations in Table 6, was that spread occurs in even linear increments; *i.e.*, 10% of I is realised in year 1, 20% in year 2, and so on.

[3] Note that the TOS cost estimate reflected recreational boats only. Costs may in fact be considerably greater if hull fouling was addressed for all non-compliant vessels.

Under this assumption regarding the rate of spread, the method for calculating R_U and R_M involved estimating these parameters for each year of a 10 year management programme, given the same probability Pi of a new introduction every year. Thus, the estimated impact in year *y* is the impact of a species that arrived *y* years ago, plus the impact of a species that arrived *y* + 1 years ago, and so on. Applying this approach resulted in a triangular matrix of estimates of R_u and R_M, which were summed for each year[4]. Total values for R_U and R_M over 10 years of management were determined on a present value basis as described above for costs.

Table 6 presents modelling outcomes for a scenario of low management efficacy, for which the level of reduction in Pi is c. 50% as described in Section 4.2.2. The 'incursion rate' in Table 6 reflects the estimated frequency (in years) of a new marine pest arrival. For the TOS this frequency was estimated at one pest every 1.7 to 2.5 years under the status quo, which decreases to one pest every 2.8 to 4.3 years under a low efficacy hull fouling management scenario.

In terms of the overall ratio of the benefit to the annual cost of implementing management measures (*i.e.*, RR_M), the lower bound is conservatively assumed as the combination of lower bound of benefit and upper bound of cost. In the illustrative outcomes derived from the TOS, the lower bound of the RR_M ratio was c. 6 and the upper bound c. 112. A figure of > 1 indicates situation where management may be worthwhile. In this illustrative scenario the net benefit of hull fouling management in the most conservative case is c. $60M per year.

5.3. Effect of key assumptions and parameter estimates on modelling outcomes

Values of R_U and R_M may differ greatly under different assumptions regarding the input parameters. Achieving a more substantial reduction in Pi than in the illustrative case presented above could be realised in part by ensuring a very high level of uptake of a hull fouling standard (*e.g.*, by a comprehensive awareness, inspection and enforcement programme). However, if a stringent LOF ≤ 2 standard was achieved in practice, it still leaves 1–5% macrofouling cover on vessel hulls. From the TOS recreational vessel monitoring data (see Table 3), the likelihood of a risk species being present (albeit at low prevalence) is estimated at 0.33. This situation reflects that many vessels accumulate fouling in niche areas (*e.g.*, base of keel, rudder), even when the main hull is well-antifouled and relatively free of macrofouling. Additionally, even with completely effective hull fouling management, residual risk will remain from unmanaged pathways.

[4] The calculations are evident in the Excel worksheets provided to NRC.

Table 6. (a) Unmanaged risk input parameters, (b) managed risk input parameters, and (c) calculation of hull fouling pathway management benefits and costs*, based on a **low efficacy scenario** for a strategy aiming to achieve LOF ≤ 2.

a. Parameters of unmanaged risk, R_U

Bounds	Pi	V	I	Psc	Incursion rate
Lower	0.40	$2,000,000,000	0.01	0.00	2.5
Upper	0.60	$4,000,000,000	0.05	0.00	1.7

b. Parameters of managed risk, R_M

Bounds	$Pi_{(M)}$)	V	$I_{(M)}$	Psc	Incursion rate
Lower	0.23	$2,000,000,000	0.005	0.00	4.4
Upper	0.36	$4,000,000,000	0.025	0.00	2.8

c. Benefits and costs

Bounds	Sum R_U - Sum R_M (benefit)	Cost	RR_M (benefit/cost)	Net benefit
Lower	$72,093,943	$9,405,972	5.6	$59,255,931
Upper	$1,057,326,979	$12,838,012	112.4	$1,047,921,008

* Note that in each of (a) to (c) the lower bound for benefit per dollar in part c is determined from the combination of least benefit and greatest cost (and vice versa for the upper bound).

Different assumptions regarding values and impacts may also lead to large changes in lower and upper estimates of benefits. For example, the realisation of impacts may follow a different pattern to our assumption of even incremental spread, depending on pathway management success (and depending on whether population management is conducted in tandem). Pest spread following introduction may initially be slow, but later rapidly escalate as an increasing number of regional source populations establish. Such a pattern may be better reflected by a geometric distribution that assumes the proportion of regional value adversely impacted is initially very small, but doubles with each consecutive year (Figure 1). In this scenario, the benefits are less than indicated in Table 6, with a low efficacy benefit-cost ratio ranging from 2–39.

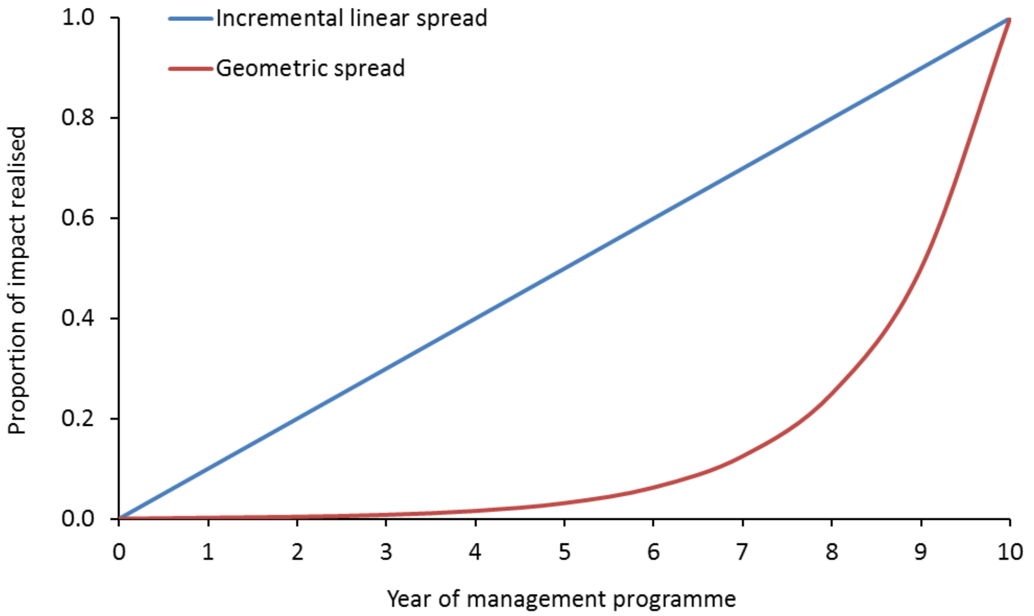

Figure 1. Two illustrative scenarios of the proportion of the estimated impact (I) that is realised each year over the duration of a 10-year pathway management programme. The figure simplistically illustrates that the nature of the spread trajectory influences the timeframe to realisation of impacts, and therefore the benefit-cost model outcomes. Note that the impact is expected to increase during management, as hull fouling is the only pathway managed, and management is not expected to be 100% effective.

6. SUMMARY AND FURTHER CONSIDERATIONS

The risk model described in this report provides a relatively simple tool for rapidly assessing the costs and benefits of marine pest management based on pathway risk reduction, with a specific consideration of hull fouling. Our illustrative assessment of hull fouling management, based on the TOS data, suggested that a management strategy that seeks to reduce fouling to LOF 2 or less, has the potential to delay the regional introduction and spread of marine pests. Under various assumptions and parameter estimates, an illustrative benefit-cost ratio of c. 5–112 was realised in a situation of low management efficacy. However, as discussed above, the input data and assumptions can have a significant bearing on model outcomes. Among the key considerations for NRC in this regard are:

- Determining values at risk (V), and potential impacts (I).
- The pathways focused on for management, and the 'package' of management measures implemented.
- The likely risk reduction achieved by the management measures (based on both technical effectiveness and conceivable levels of uptake or compliance).
- Management costs, and the optimal combination of management effort/cost vs risk reduction achieved.

A particular challenge is to reliably ascertain the nature and extent of pest impacts. The invasiveness of marine pests is notoriously variable in space and time. Prior knowledge of invasiveness and impacts is often a poor reflection of what might happen in a new location or at some future time. There is also the additional issue of how to characterise the magnitude of impacts given their species-specific nature. For example, the majority of NIS have no known adverse other than their presence as non-native species, but a handful have had catastrophic impacts overseas. By contrast, the impact of some species may be judged as 'beneficial' in certain circumstances. For example, when the non-indigenous Asian kelp *Undaria pinnatifida* establishes in impoverished rocky habitats, it can provide habitat for a range of other species and enhance local-scale biodiversity.

Similarly, the inherent difficulty in characterising effects that don't have a monetary value presents challenges in terms of making management decisions. Ongoing research is expected to provide some guidance in this respect. For example, the Ministry for Business Innovation and Employment recently funded a four-year collaborative study (NIWA, Cawthron and Waikato University) that is trying to understand the types of impacts from marine pests and their magnitude, and consequences for ecosystem services.

In terms of 'selling' the benefits of pathway management, it is relevant to consider that the expected outcome from management is to delay rather than prevent pest spread. From the perspective of some stakeholders, this situation can be perceived as making pathway management fairly pointless (Elvines *et al.* 2013). However, as discussed by Forrest & Fletcher (2015), although the 'average' outcome from pathway management might be delay of spread, implementation of improved practices could lead to even greater gains. For example, improved pathway management may in fact prevent the spread of a pest that would otherwise have had catastrophic effects. Of course, there is no way to measure this type of 'success'. An additional consideration is that considerable economic benefits may result from delay of spread, evident from this report and other studies. For example, it has been demonstrated in various New Zealand studies that delaying the spread of biofouling pests can have a tangible economic benefit to an industry such as aquaculture (NZIER 2008; MPI 2013).

Provided NRC are explicit about the base assumptions and input values, the model will provide a useful framework to enable evaluation of the benefits of pathway management and other management approaches, and can be easily tailored to suit the specific needs of NRC. For example, as mentioned earlier in this report there is scope to include the model terms in Box 1 that relate to the management of specific pest populations. In fact, the pest response terms in Box 1 could be further partitioned into parameters that separately account for the efficacy of surveillance (in terms of pest detection) and pest response, as described in a report considering management options for *Undaria pinnatifida* (Sinner *et al.* 2000). In this way, the cost and benefits of pathway management can be compared with a pest population management approach (e.g., Sinner *et al.* 2009). Clearly, there are a number of issues for NRC to address as part of applying the model to determine the costs and benefits of a regional pathway management plan. However, with a relatively small additional effort, the model can be applied to suit NRC's needs.

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