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Pride of the South: Risk Analysis for Marine Biosecurity in Fiordland

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Summary

This paper describes a model used to assess alternative scenarios for managing the marine biosecurity risk to Fiordland from vessel traffic. Scenarios are assessed in terms of risk reduction per dollar spent. To keep the analysis manageable, we focus on vessel risks from hull fouling, as this is considered the primary pathway of vessel-related spread. Our analysis includes evaluation of the costs and benefits of different types of vector treatment as well as the possibility of continued vessel monitoring and control of pest populations in Bluff Harbour to reduce the risk of vector infection.

Key words: Fiordland, marine biosecurity, risk reduction, benefit cost analysis, management options, Bluff.

Introduction

Fiordland is an area in the southwest corner of New Zealand's South Island characterised by glacially carved fiords, dense forest and high rainfall. Fiordland's spectacular landscape – dramatic peaks, sheer rock faces, thundering waterfalls and stunning reflections of tranquil fiord waters – is matched underwater by an equally unique environment of outstanding natural values. Very high levels of rain entering the Fiordland catchments result in a dark stained and buoyant low-salinity layer that overlays the oceanic water in the fiords. These conditions support Fiordland's globally unique and highly diverse marine communities. For example, Fiordland is the only place in the world where a species of black coral (*Antipathes fiordensis*) can be found in depths as shallow as 4 m (Grange 1985).

The fiords have become national icons and annually attract large numbers of tourists – Milford alone attracts over half a million tourists per year (GHD Ltd 2005; Booth *et al.* 2007). In economic terms, a range of coastal industries related to the marine environment (*et al* tourism and the hospitality industry) account for significant commercial activity in Fiordland. A study for DOC estimated that Fiordland National Park added $196 million per year to the economies of Southland District and Queenstown Lakes District in 2005 (DOC 2006). The fiords and outer coast also support important commercial and recreational fisheries, notably rock lobster, paua and blue cod, which collectively have total quota (*i.e.* asset) values in excess of $200 million (Batstone, Elmetri et al. 2009). Added to this is the value that New Zealanders derive from Fiordland's unique environment, either directly from non-commercial recreational activities such as boating, diving, and aesthetic enjoyment of Fiordland's natural values, or indirectly by simply knowing that the fiords exist and are being protected.

Concerned to protect the biodiversity values of the area, a range of stakeholders worked collaboratively to produce the Fiordland Marine Conservation Strategy[1]. The Government recognised this strategy through the Fiordland (Te Moana o Atawhenua) Marine Management Act 2005, which gave effect to this strategy for the Fiordland Marine Area (FMA; see Figure 1) in part by requiring government agencies to take into account advice and recommendations of the Fiordland Marine Guardians (the Guardians), an advisory group established under the Act.

The vision of the Fiordland Marine Conservation Strategy is to ensure "*that the quality of Fiordland's marine environment and fisheries…be maintained or improved for future generations to use and enjoy*." The Fiordland Marine Conservation Strategy calls for monitoring, compliance and enforcement, and biosecurity programmes, each of which is led by a different government agency. MAF Biosecurity New Zealand (MAFBNZ) is the lead agency for biosecurity matters.

Working with the Fiordland Marine Guardians and other agencies, MAFBNZ coordinated the development of the Fiordland Marine Biosecurity Strategic Plan 2009/10 - 2013/14, completed in 2008. MAFBNZ then commissioned the Cawthron Institute to work with the Fiordland Marine Guardians and other agencies and stakeholders to prepare an operational plan to achieve the outcomes identified in that strategy.

The scope of the Fiordland marine biosecurity programme mirrors biosecurity management at a national level; it includes activities to prevent biosecurity threats reaching the FMA and activities to deal with biosecurity threats within the FMA. As with national level biosecurity, focus is placed on prevention due to the higher likelihood of success, the range of management options available and value for money.

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[1] Guardians of Fiordland's Fisheries and Marine Environment Inc. 2003: Fiordland Marine Conservation Strategy (138 pages).

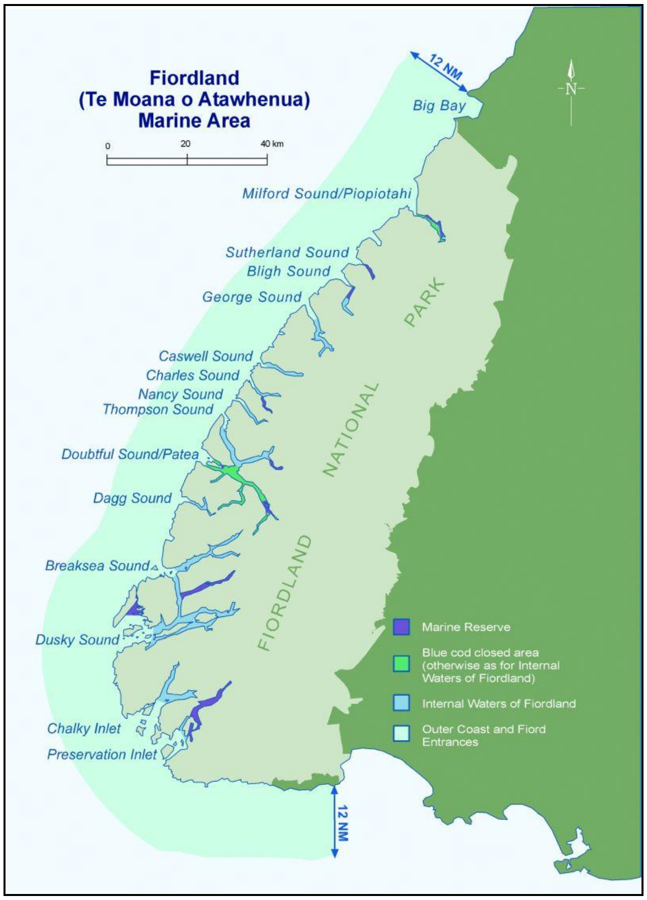

Figure 1. Indicative Map of Fiordland (Te Moana o Atawhenua) Marine Area and Marine Reserves in the Southwest Corner of New Zealand's South Island (Department of Conservation).

Managing Risks to Marine Biosecurity

Risks to Fiordland's marine biosecurity arise primarily from human-mediated movement of "vectors" from outside Fiordland, including from overseas, that can carry pest species into the FMA. The majority of vector movement into Fiordland is vessel traffic comprising recreational boats, commercial fishing vessels, charter boats and cruise ships. Vessels have the capacity to transport invasive marine species through hull fouling, equipment and gear (*et al* ropes, fishing nets, anchors, floats) and bilge water. In addition, cruise ships and larger commercial vessels have the potential to introduce invasive species via the discharge of ballast water, or through species carried in their seachests (water intake chambers recessed into the hull).

Given the types of vessels most frequently visiting Fiordland and the strict regulation of ballast water discharge within internal waters (see e.g. Environment Southland 2001), fouling associated with hulls, seachests and other “niche areas2” on vessels will likely be the dominant mechanism for the transfer of invasive marine organisms into Fiordland. For example, Stuart (2002) found that 35% of vessels (including fishing vessels, yachts, launches and freighters) surveyed in southern New Zealand ports (from Timaru to Otago Harbour) were infected with *Undaria*, even though some of those ports had an active programme to control *Undaria* at the time. Recent MAFBNZ vessel monitoring data from Bluff indicates that at least 10 commercial fishing vessels that are known to visit to Fiordland from Bluff have been infected with *Undaria* on at least one occasion over the past 12 months. In addition to *Undaria*, other organisms that are considered to have a high risk of transfer to Fiordland via fouling, including hydrozoans, bryozoans, and colonial and solitary sea squirts (KML 2006).

Given historic and existing vessel movements into Fiordland, it is likely that a range of non-indigenous marine species, and perhaps invasive marine pests, have already established in the FMA. However, the occurrence and distribution of invasive marine species in the FMA is poorly documented, except for specific locations (*et al* Milford Sound) and groups of species (e.g. macroalgae in Doubtful Sound). In Milford Sound, for example, MAFBNZ commissioned a baseline survey for non-indigenous species as part of a national port baseline survey programme, which identified several species that were new to science (Inglis et al. 2008).

Various management measures can be applied to reduce biosecurity risk, but these invariably come at a cost. One way to compare measures is to assess how much they reduce risk (*i.e.* expected impact) per dollar of cost. If budgets are unlimited, then all measures that have a benefit-cost ratio greater than 1.0 would be adopted. If budgets are constrained, then the measures that provide the greatest risk reduction per dollar should be implemented first, followed by others with the next highest risk reduction, and so on as far as the budget allows.

This type of analysis was conducted to assess the relative merits of alternative measures for reducing risk from vessels visiting Fiordland. To keep the analysis manageable, we focused on vessel risks from hull fouling, as this is considered the primary pathway of vessel-related spread.

Inputs to the analysis included numbers of vessels visiting Fiordland, proportions from Bluff versus other ports, resident times in Fiordland, estimates of the risk of pest introduction to Fiordland given different levels of vector treatment, the costs of these treatments and estimates of the rates of adoption of these different treatments. Previous work on marine biosecurity and expert knowledge were utilised to identify possible

[2] Niche areas are subsurface areas of a vessel's hull (including recessed compartments) which may be favoured locations for settlement of some types of fouling organisms due to: (a) reduced exposure to water flow when the vessel is moving (resulting in sub-optimal performance of self-polishing anti-fouling paints); (b) complete absence of antifouling protection (*et al* on areas that are inaccessible during hull maintenance, such as dry dock support strips); (c) the protection of fouling organisms from removal by shear forces (when vessel is moving); and/or (d) removal of anti-fouling during in-service maintenance. Types of niche areas are listed in Hopkins & Forrest (2009).

treatment measures and recommend which were likely to be the most effective in the Fiordland environment.

As part of the vector management strategy, Cawthron also considered the merits of present interim efforts to control pest populations in Bluff Harbour as a means of reducing vector infection, hence biosecurity risk to Fiordland. The interim programme was started in 2007 due to concerns over an imminent threat of pests spreading to Fiordland. It consists of generic measures (social marketing campaign, vessel monitoring and compliance) and control of source populations in Bluff Harbour to reduce the immediate risk of spread of potential marine pests from Southland into Fiordland. While it was generally accepted that the generic measures would continue in some form, the relative merit of the control programme in Bluff Harbour needed to be assessed.

To assess the various measures that could be undertaken, we built a spreadsheet model to assess alternative scenarios for managing the marine biosecurity risk to Fiordland from vessel traffic.

The Conceptual Framework

The model is based on the conceptual framework described by Forrest et al. (2006). The model estimates the status quo level of risk in terms of an expected annual impact, in dollars, from incursions of marine pests, and then assesses different management scenarios according to how much that risk can be reduced and at what cost.

The model is summarised as follows:

$$RR_{Mi} = (R_U - R_{Mi})/C_{Mi} \qquad (1)$$

RR_{Mi} is the risk reduction per dollar spent on managing risk in scenario *i*;
R_U is unmanaged risk (*i.e.* with no measures taken under this Plan) from all potential pest species;
R_{Mi} is the remaining risk (after management measures) in scenario *i*, and
C_{Mi} is the cost of the risk reduction measures in scenario *i*.

These terms are explained further below.

Unmanaged risk (R_U)

$$R_U = P_I * P_{PD} * V * I \qquad (2)$$

P_I is the probability that at least one non-indigenous marine species will be introduced to Fiordland in any given year[3], and P_{PD} is the probability that an introduced pest will

[3] In principle, where probability is high, more than one introduction can occur per year, in which case P_I should be defined as a frequency rather than a probability.

establish at pest densities (*i.e.* to a spatial extent where it has a measurable adverse impact on the value of the location). P_I*P_{PD} can thus be understood as the frequency of marine pests establishing at pest densities. For example, P_I*P_{PD} = 0.2 suggests that an invasion is expected on average once every five years. For this model, P_I and P_{PD} represent existing levels of risk management, excluding any measures that are seen as "interim" pending the outcome of this Plan. In particular, the source control and vessel monitoring programme in Bluff are not included in "existing risk management measures" because they are part of the risk management scenarios being assessed.

V is the value at risk, *i.e.* the total value of Fiordland to New Zealanders. This is expressed in dollars but represents recreational, cultural, biodiversity, amenity and intrinsic values as well as commercial values from, *et al*, fisheries and tourism.

I is the average percentage impact on these values that would be expected from a representative invasive marine species that establishes at pest densities. V * I is therefore the dollar impact of a marine pest invasion, and $P_I * P_{PD} * V * I$ is the average expect annual impact, in dollars, of marine pest invasions in Fiordland.

With detailed information on the probability of introduction and establishment of each possible marine invasive species, and corresponding detail on the impact that each pest would have on the values of Fiordland, R_U could be estimated for each species, and potential management measures could be prioritised for a given pest species or across a number of high risk species. This information is not available, however, and even if it were it would be difficult to identify a small number of species that present the greatest risk to Fiordland. This Plan, therefore, generalizes across all potential pest species and takes a pathways approach rather than a species approach. In particular, the model described here has been used to assess risk from the vessel fouling pathway, since this is seen as the highest risk pathway for Fiordland (KML, 2006).

Risk Management Scenarios and Costs

For each scenario *i* for managing risk to Fiordland from vessel fouling, we estimate managed risk (R_{Mi}, *i.e.* the amount of risk remaining once additional measures are in place) as follows[4]:

$$R_{Mi} = P_{Ii}' * P_{PDi}' * V * I \qquad (3)$$

P_{Ii}' and P_{PDi}' are simply the new (reduced) probabilities of introduction and establishment at pest densities as a result of specific measures to be implemented in scenario *i*. Thus, the entire expression represents the expected annual dollar value of

[4] Forrest et al (2006) define R_{Mi} to include the possibility that an invasion, were one to occur, could be successfully controlled, thus avoiding the impact of an incursion. For the purpose of this exercise, where the focus is on assessing alternative measures to reduce the risk of an introduction via vessel fouling, and given the challenges of attempting to eradicate or control a marine pest in Fiordland, we assume the likelihood of successful control and the corresponding costs of control to be constant across the management scenarios.

marine invasions under this scenario, and $R_U - R_{Mi}$ is the risk reduction benefit achieved, expressed in dollars per year.

For this application of the model, the cost of a scenario, C_{Mi}, is defined as the additional cost incurred to implement measures for that scenario. This enables us to define RR_{Mi} as the risk reduction per dollar spent (*i.e.* a benefit-cost ratio) for each scenario *i*, and to compare these for alternative scenarios.

Defining the Scenarios

For this project, the management scenarios were defined as agency interventions to improve the compliance with best management practices, as described in Table 3, by those bringing vessels and gear into Fiordland. In practice, there is a range of possible management practices and, for any particular scenario, the population of vessel and gear owners will be distributed across these different practices. For example, under the status quo scenario, 70% of vessel owners might apply anti-fouling annually, 20% bi-annually, and 5% at intervals greater than every two years. The remaining 5% might apply anti-fouling annually *and* take additional measures such as underwater inspection of the vessel prior to each trip to Fiordland, or having the vessel wrapped and treated in between anti-fouling applications.

For each practice, there is a different probability of introducing a marine pest to Fiordland, so it is necessary to specify the "compliance profile" for each management scenario. This in turn requires, to avoid having a model of infinite complexity, defining a small number of discrete levels of practice, even though in reality there is a continuum. The management scenarios are then defined as policy interventions (including education and communications) designed to shift the compliance profile, *i.e.* to motivate vessel and gear owners to adopt more effective practices to reduce risk, and each scenario has its own compliance profile across the range of possible practices.

The scenarios are described in Table 1.

We assumed that scenarios A, B and C would involve additional annual agency costs, compared to the status quo, of $15,000, $40,000 and $65,000, respectively, for communication and planning (A, B and C). These involve a combination of one-off costs, spread over 10 years to get a more realistic view of the annual risk reduction per dollar spent, and on-going costs. For example, the $15,000 for Scenario A comprises $5,000 per year for 10 years to establish the register and $10,000 per year to operate it. Scenario B adds a further $250,000 ($25,000 for each of ten years) to establish the register as a legal requirement. To these costs, Scenario C adds a further $25,000 per year for vessel monitoring.

Table 1. Policy Scenarios for Managing Marine Biosecurity Risk to Fiordland

Scenario	*Policy interventions*
Status quo	Resource consent conditions and Deed of Agreement for cruise vessels remain in place with current level of enforcement. Communications effort continues unchanged.
A	A voluntary Vessel Intentions Register is established and additional communications effort encourages vessel and gear owners to adopt best practice. VHF radio operators are asked to remind skippers of these requirements.
B	Registering intent to bring a vessel or gear into Fiordland is made mandatory. Vessels and gear must be free of macrofouling, and must be made available for inspection upon request. Agencies develop procedures for dealing with fouled vessels or gear found in Fiordland. VHF radio operators are asked to remind skippers of requirements.
C	In addition to Scenario B, vessel monitoring occurs monthly in Bluff and results are entered in Vessel Intentions Register. If a vessel with history of fouling registers its intent to visit Fiordland, the skipper is reminded of biosecurity requirements and enforcement officers watch for the vessel in Fiordland.
Source control	Populations of unwanted marine organisms are reduced to, and maintained at, very low levels in Bluff Harbour to minimise the level of infection of vessels. This scenario is combined with each of the four scenarios above, so that there are 8 scenarios in total.

Estimating the Model for Fiordland

In order to estimate the relative cost effectiveness of alternative scenarios, input values were provided for several parameters. Key inputs to the model are listed in Table 2.

A 1999 study estimated the value of ecosystem services from New Zealand's terrestrial environments at roughly $40 billion annually (Patterson & Cole 1999). That study found less information on non-market value of services from marine environments, but noted an average value from overseas of NZ$400 per hectare. This figure included market revenue from the likes of fisheries and tourism as well as non-market value from, for example, biodiversity, carbon sequestration and amenity values.

Table 2. Input Parameters for Model of Fiordland Vessel Fouling Risk

Input parameter	*Assigned value*	*Comment*
Annual value of Fiordland marine environment	$750 million	Based on a value of $1000/ha (2.5x value cited by Patterson & Cole (1999) for average global value of marine area)
Impact on Fiordland of marine pest incursion	1%	Authors' indicative estimate. Some invasions will have less impact, some far more.
Status quo rate of pest incursions	1 in 5 yrs	Authors' indicative estimate
Risk reduction from annual anti-fouling (compared to "default" of anti-fouling interval greater than 2 years)	100x	Authors' indicative estimate
Risk reduction from annual anti-fouling + underwater inspection prior to departure for Fiordland (compared to default)	1000x	Authors' indicative estimate
Risk reduction from annual anti-fouling plus hull wrapping 3x per year	10,000x	Authors' indicative estimate
Risk reduction from control of pest populations in source ports to near-zero (reduction is additional to that provided by anti-fouling and other measures listed above).	100x	The previous Bluff programme (1997-2004) reduced the reported incidence of *Undaria* on vessels by about 100x. However, the reduction in risk of other pests is unknown, since to date only *Undaria* has been found.

Given the unique biodiversity and special character of Fiordland's marine environment, we put the indicative value to New Zealand at 2.5 times this, or $1000 per hectare, which suggests an annual value of $750 million per year[5]. This compares with an estimated $196 million per year in recreation and tourism revenues that Fiordland adds to the economies of Southland District and Queenstown Lakes District (DOC 2006) and

[5] We have estimated the size of the FMA, using GIS software to mark the boundaries, at 750,000 ha.

fisheries quota values (asset values) in excess of $200 million (Batstone *et al.* 2009). The non-market values cited above are additional to this commercial value.

Because the compliance profile will differ for different types of vessels (*i.e.* cruise vessels versus fishing vessels versus recreational yachts) and because different types of vessels stay in Fiordland for different periods of time, the probability of introducing a marine pest into Fiordland will also differ by type of vessel. For the model, P_I is defined as the probability that one vessel will introduce a marine pest, and each type of vessel is assigned a different value depending on number of trips a typical vessel (of that type) would make to Fiordland in a year, and the number of days per trip.

This is then scaled up by the number of vessels of a given type to obtain the total risk from that category of vessel, and summed across categories to obtain the overall P_I value, which represents the frequency of marine pest invasions in Fiordland. Finally, this overall P_I value is benchmarked to an indicative estimate by the authors of the actual frequency of pest invasions in Fiordland at existing levels of vessel traffic and risk management, set for this project as 1 every 5 years. The P_I values for each type of vessel are then converted to absolute probabilities using this benchmark value.

As noted above, a compliance profile was assigned to each of the scenarios. To specify a different compliance profile for each vessel type adds significantly to the complexity of the model. We therefore first estimated the model assuming all vessels types had the same compliance profile, the same number and duration of trips and the same probability of introducing marine pests to Fiordland. The compliance profiles for each of the four scenarios are presented in Table 3.

Table 3. Assumptions Rgarding Percentages of Vessels with Different Levels of Hull Treatment (for each of the scenarios assessed in the risk management model)

*Hull treatment**	*Status Quo*	*Scenario A*	*Scenario B*	*Scenario C*
AF>1yr	5%	4%	0.5%	0%
AF annually	85%	80%	75%	70%
AF + inspect	10%	15%	22%	25%
AF + wrap	0%	1%	2.5%	5%

* AF>1yr = the interval between anti-fouling applications is more than 1 year; AF annually = the interval between anti-fouling applications is annual or as needed;
AF + inspect = anti-fouling is applied every year or as needed *and* the vessel has an underwater inspection prior to every trip to Fiordland; and
AF + wrap means that anti-fouling is applied every year as needed *and* the vessel is wrapped and chemically treated 2-3 times per year (generally less cost than full anti-foul treatment).

As a result of feedback from the Guardians and other stakeholders, we then specified another version of the model to distinguish between vessel types, for two scenarios, the Status Quo and Scenario B. The compliance profiles used for these scenarios are presented in **Error! Not a valid bookmark self-reference.**.

Table 4. Percentages of Vessels Assumed to Have Each of Four Levels of Hull Treatment (by Vessel Type, for Status Quo and Scenario B)

Hull treatment*	**Type of vessel**				
	Commercial fishing	*Recreational*	*Charters & tourism*	*Research*	*Cruise ships*
Scenario: Status Quo					
AF>1yr	10%	5%	0%	0%	0%
AF annually	90%	94%	55%	50%	100%
AF + inspect	0%	1%	45%	50%	0%
AF + wrap	0%	0%	0%	0%	0%
Scenario B: Mandatory vessel intentions register & clean hull requirement					
AF>1yr	0%	2%	0%	0%	0%
AF annually	85%	96%	40%	0%	90%
AF + inspect	15%	2%	50%	100%	10%
AF + wrap	0%	0%	10%	0%	0%

* See Table 3.

The four scenarios were estimated assuming no control of pest source populations in Bluff Harbour, and another four scenarios were estimated with source control. For these latter scenarios, the compliance profiles were the same as without source control, but the vessel population was divided into two groups, those resident in Bluff and those from elsewhere (see

Table 5). For those vessels resident in Bluff, the probability of introducing a marine pest to Fiordland was divided by 100. The risks associated with resident and non-resident vessels were summed to obtain the overall risk for a given scenario, subtracted from the Status Quo risk to get the dollar amount by which risk has been reduced, and then divided by the costs of the interventions and improved management practices to obtain RR_{Mi}, the risk reduction per dollar spent.

Table 5. Estimated Number of Vessels Visiting Fiordland Marine Area (FMA) Annually

Vessel type	No. of vessels visiting FMA – total	No. vessels – Bluff resident	Trips into FMA/yr (avg)	Avg days/ trip
Commercial fishing	50	25	12	10
Recreational (yachts and launches)	100	10	1.5	5
Commercial charters & tourism	14	4	3	60
Research & Agency	4	0	4	14
Cruise Vessels	18	0	4	1
Total	***186***	***39***		

Sources: consensus view of officials from Ministry of Fisheries, Dept of Conservation, Environment Southland and Fiordland Marine Guardians at a workshop held 1 May 2009.

Results of the Model

Applying the assumptions in the above tables for the status quo, once in every five years Fiordland would expect a marine pest invasion that causes average damages (*i.e.* a reduction in value) equal to $7.5 million per year, *i.e.* the expected annual average loss is $1.5 million.

For the scenarios with no control of pest populations in Bluff Harbour, the benefits and costs of the three management scenarios are shown in Table 6. The analysis suggests that scenario A has a benefit of roughly $10 for every dollar spent. This increases to a per dollar benefit of $20 for Scenario B, even with the additional costs (assumed to be $225,000 spread over 10 years) involved in getting a plan change to the Southland Coastal Plan. Scenario C reduces risk further and still returns benefits of around $10 for every dollar spent. Total net benefits are greatest with Scenario C.

The lower part of Table 6 shows the relative benefits of controlling pest populations in Bluff Harbour. For this analysis, we made a fairly generous assumption that source population control would reduce by a factor of 100 the risk of Bluff-resident vessels introducing marine pests to Fiordland. While the rate of vessel infection by *Undaria* was reduced by nearly this much when the population was being intensively controlled from 1997 to 2004 (Hunt et al. 2009), we do not know by how much such a programme would reduce the risk of infection of other species were they present in the future. For example, *Styela clava* has recently been discovered in Port Otago and can be expected to be transferred to Bluff at some point in the future. *Styela* may well require different control methods, with different costs and a different degree of effectiveness.

Table 6. Risk Reduction Benefits and Costs of Alternative Risk Management Scenarios (Without Differentation of Vessel Type)

Scenario & short description	**Expected annual loss**	**Risk reduction** (change in annual loss)	**Marginal cost of measures***	**Risk reduction per dollar** (RR_{Mi})	**Net benefits** (Risk reduction less costs)
Without source population control in Bluff					
SQ: Status Quo	$1,500,000	na	na	na	
A: Voluntary Register	$1,232,534	$267,466	$26,532	$10.08	$240,934
B: Mandatory Register and "clean hull" policy	$325,661	$1,174,338	$45,274	$20.03	$1,102,532
C: Scenario B + vessel monitoring in Bluff	$185,708	$1,314,292	$81,248	$12.88	$1,161,238
With source population control in Bluff					
SQ′ (w source control)	$1,188,629	$311,371	$550,000	$0.57	-$238,629
A′: Voluntary Register	$976,684	$523,316	$37,134	$14.09	-$63,818
B′: Mandatory Register and "clean hull"	$258,060	$1,241,939	$77,575	$16.01	$577,230
C′: Scenario B′ + vessel monitoring in	$147,159	$1,352,841	$124,058	$10.90	$564,074

* Additional costs compared to previous scenario; includes agency costs and costs for vessel owners and operators.
na = not applicable

Using these assumptions, the risk to Fiordland can be reduced to lower levels, but the costs of source population control of pests exceed the estimated benefits. If the value to New Zealanders were assumed to be $1.5 billion per year rather than $750 million, or the impact of a pest were assumed to be 2% damage rather than 1%, then the risk reduction per dollar spent on source population control would just exceed $1. Changes in other assumptions, *et al* the number of Bluff-resident vessels that visit Fiordland, or the number and duration of those visits, would also directly affect the estimated risk reduction per dollar spent on controlling pest populations in Bluff.

Finally, we specified another version of the model that distinguishes between the different vessel types, assigning different risk levels and compliance profiles to each type. This version was specified only for the status quo and three alternative scenarios, scenario B, scenario SQ′ (in which the only intervention is intensive control of pest populations in Bluff Harbour), and scenario B′ (vessel register, clean hull policy and pest control in Bluff).

The results are shown in Table 7 and are generally consistent with the results from the more general version of the model. The vector control implemented in Scenario B appears to have a high return, about $10 per dollar spent. Pest population control in Bluff looks somewhat better in this version, *i.e.* with risk differentiated by vessel type, but is still marginal in benefit-cost terms under the assumptions used in the model. As before, changes in the assumptions would change the risk reduction per dollar from pest population control at source, but not the relative performance of this measure compared to managing vector risk.

Table 7. Risk Reduction Benefits and Costs of Alternative Rrisk Management Scenarios, with Rrisk Differentiated by Vessel Type (not shown)

Scenario & short description	**Expected annual loss**	**Risk reduction** (change in annual loss)	**Marginal cost of measures***	**Risk reduction per dollar** (RR_{Mi})	**Net benefits** (Risk reduction less costs)
Without source population control in Bluff					
SQ: Status Quo	$1,500,000	na	na	na	na
B: Mandatory Register and “clean hull” policy	$322,617	$1,177,384	$120,080	$9.80	$1,057,304
With source population control in Bluff					
SQ′ (w source control)	$944,842	$555,159	$550,000	$1.01	$5,159
B′: Mandatory Register and “clean hull” policy	$3,226	$941,615	$120,080	$7.84	$821,535

* Additional costs compared to previous scenario; includes agency costs and costs for vessel owners and operators.
na = not applicable

Conclusions

Marine biosecurity risks arise from a wide variety of human-related vectors, and the degree of risk from each individual vector varies depending on how it is managed by its human owner or operator. The effectiveness of a biosecurity risk management measure, therefore, depends not only on the biological effectiveness of the treatment, but also upon the measure's ability to alter human behaviour, e.g. to apply anti-fouling to a vessel's hull at least annually and to inspect the hull prior to visiting an area with high biodiversity values.

Biosecurity measures can be prioritised by applying a model that combines both biological and behavioural parameters to estimate the risk reduction per dollar achieved. While the absolute dollar value estimates obtained in this study are indicative only, due to the lack of firm estimates of the value of Fiordland's marine biodiversity, the relative values of alternative measures are much more robust. The analysis in this study indicates that measures that address all vessels entering Fiordland generate a much higher net benefit than does a measure that targets control of a significant population of an unwanted marine organism in a port in close proximity to Fiordland.

References

Batstone, C., Elmetri, I., *et al.* (2009). Economic Value Mapping: Mapping the economic value of New Zealand's marine systems. Cawthron Report to MAF Biosecurity New Zealand.

Booth, K.L., Espiner, S.R., Higham, J.E.S. (2007). Fiordland (Te Moana o Atawhenua) Marine Area User Study 2007. Report prepared by Kay Booth and Associates for Biosecurity New Zealand, Department of Conservation, Environment Southland, Fiordland Marine Guardians, Ministry for the Environment, Ministry of Fisheries, New Zealand.

Department of Conservation (DOC) (2006). The value of conservation: What does conservation contribute to the economy? http://www.doc.govt.nz/upload/documents/conservation/value-of-conservation.pdf [Accessed 21 June 2009].

Environment Southland (2001). Deed of Agreement between Environment Southland and the New Zealand Cruise Ship Industry. Environment Southland, Invercargill, New Zealand.

Forrest, B.M., Taylor, M.D., Sinner, J. (2006). Setting priorities for the management of marine pests using a risk-based decision support framework. Biological invasions in New Zealand. R. B. Allen and W. G. Lee. Berlin & Heidelberg Springer-Verlag: 299-405.

GHD Ltd (2005). Milford Sound Transport. Issues and Options. www.southlandnz.com.

Grange, K. (1985). Distribution, Standing Crop, Population Structure, and Growth Rates of Black Coral in the Southern Fiords of New Zealand. New Zealand Journal of Marine and Freshwater Research 19: 467-475.

Hopkins, G., Forrest, B.A. (2009). Vessel biofouling as a vector for the introduction of non-indigenous marine species to New Zealand: Slow-moving barges and oil platforms. Biosecurity New Zealand Project ZBS2005-02. Draft Report Prepared for Post-Border Directorate by the Cawthron Institute.

Hunt, L., Chadderton, L., Stuart, M., Cooper, S., Carruthers, M. (2009). Results of an attempt to control and eradicate *Undaria pinnatifida* in Southland, New Zealand, April 1997 - November 2004. Department of Conservation, Invercargill, New Zealand. 48 p.

Inglis, G., Gust, N., Kospartov, M., Peacock, L. (2008). Milford Sound: First baseline survey for non-indigenous marine species. Research Project ZBS2005/19. MAF Biosecurity New Zealand Technical Paper 2008/01.

KML (2006). BPO/221/2005: Marine ecological risk assessment for Fiordland (Tier one: problem formulation). Prepared by Kingett Mitchell Ltd for Biosecurity New Zealand (draft, June 2006). 37 p.

Patterson, M.G., Cole, A.O. (1999). The economic value of New Zealand's biodiversity. Occasional Paper Number 1, School of Resource and Environmental Planning, Massey University. 88 p.

Stuart, M.D. (2002). Translocation of *Undaria pinnatifida* by vessel fouling: analysis of the Department of Conservation vessel monitoring database, May 1999-May 2001. Prepared for the Ministry of Fisheries, Wellington, New Zealand. Project ZBS2001-04. 55 p.