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An Economic Framework for Biosecurity Decision Making in New Zealand

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Abstract

Exotic pests and diseases continually threaten New Zealand's indigenous biodiversity. These incursion events often require rapid responses. Therefore, the success of New Zealand's Biodiversity Strategy depends not only upon knowledge of these exotic species incursions, the damage they may inflict and efficient response programmes, but also on the use of management tools to better allocate the resources to respond to these incursions. Currently, considerable work is going into risk assessment of incursions, but the link in the chain between good science and policy implementation is weak. This paper outlines an economic framework for a decision support system (DSS) to strengthen management systems for risks to indigenous biodiversity from alien invasive organisms. The primary focus of the research reported on here is to create a sound basis for allocating biosecurity resources that can be applied by Biosecurity New Zealand (BNZ) to rapidly and accurately evaluate and rank projects aimed at protecting indigenous biodiversity from incursions of exotic pests and diseases. The DSS model will be developed so that it can be operationally implemented by BNZ staff.

Key words: decision support, economic optimising, biosecurity, indigenous biodiversity

Biosecurity in perspective

Alien invasive organisms (AIO) including both pests and diseases can cause major costs to society through a variety of mechanisms. As an island nation isolated from major natural movements of organisms, but now increasingly exposed to such movements through increased trade and tourism New Zealand is more vulnerable than most other nations. This isolation and now exposure means New Zealand has more to loose than most countries, particularly from

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those AIOs that threaten the country's primary industries, the mainstay of New Zealand's exports. Increasingly important to many New Zealanders is also the country's indigenous biodiversity, which because of isolation, has a unique character in the world.

The damage that can be done to agriculture and forestry by AIOs has been well recognised (MAF 2003), but wide recognition that indigenous biodiversity is valuable and needs protecting is a more recent phenomenon. The increasing realisation that indigenous biodiversity has value has come about through the reduction of native ecosystems through human pressure (clearing of bush and draining of wet lands for agriculture for example) and the realisation that what is left is vulnerable. Also factors are the increased wealth of the nation with more leisure time to enjoy the outdoors and the demand from tourists who wish to visit New Zealand because of the unique nature of the environment here.

Biosecurity New Zealand (BNZ) is charged with protecting New Zealand from unwanted incursions and the structures and processes that have been developed over the years are world class, but the focus has been on protecting the primary export industries. A key reason for this is that the benefits from incurring costs are relatively easy to quantify and therefore demonstrate that there is a net benefit from taking action so that society will be better off. When it comes to indigenous biodiversity the benefits are much harder to quantify and thus be able to demonstrate that benefits exceed costs as well. When competing for scarce funds, being able to demonstrate monetary benefits exceed costs makes it much easier to jump Treasury hurdles and obtain funding.

New techniques for quantifying the values of non-market goods, such as indigenous biodiversity, are increasingly being accepted by funding authorities. These techniques are based on the premise that value is based on how they contribute to human welfare (Cork, Shelton et al. 2001). This in turn is based on perceptions of value. Such perceptions can be measured through peoples' willingness to pay for positive changes to indigenous biodiversity or willingness to accept compensation for its degradation. Willingness to pay for non-market goods can be inferred by asking people directly what they are willing to give up to keep it, or how much compensation they would accept to lose it through a process called contingent valuation (Boyle 2003). Complex choices involving economic, social, cultural and environmental values can be analysed using choice modelling, also called attribute based methods (Holmes and Adamowicz 2003).

Economic assessments must be considered in the context of the comparisons and decisions being made and care should be taken in extrapolating beyond that context (Bockstael, Freeman et al. 2000). This is relevant to decisions on indigenous biodiversity as the value of loss needs to be related to the scarcity and vulnerability of the area at risk. The value of the loss or degradation of the last hectare of native beech forest is obviously hugely greater than the loss of the first hectare.

This paper develops a framework for analysing expendture biosecurity at three levels. The first of these is the decision on how much to spend on biosecurity in aggregate. Secondly, how much to spend on the particular components of New Zealand's biosecurity system (pre-border, border, surveillance, response and management). And thirdly, how much to spend on specific incursions. At this detailed level we will focus on incursions that attack indigenous biodiversity (i.e. whole ecosystems such as the coastal marine environment) and the integration of these into the decision making process for biosecurity.

Biosecurity decision making in aggregate

A role of government is to allocate funding to the various services demanded by the people. These are complex political decisions that involve tradeoffs between areas such as health, education and biosecurity to ensure that welfare is maximised given a limited budget.

The political process resolves many of the issues related to funding, but the Treasury is also charged with assisting the government with these decisions. It does this through the application of various economic tools and decision aids which compare the economic and social returns from different areas. The first requirement for new spending is that the net benefits to society exceed the costs. As far as possible these benefits and costs are quantified, but there are many areas where qualitative information is all there is and this must be weighed up along with the quantitative information. The more quantitative the analysis the easier it is to demonstrate that benefits exceed costs and therefore obtain approval. This brings us to the second level of decisions: how much to spend on the various components of biosecurity? Here we focus on protecting biodiversity.

Optimising biosecurity services across components

The high level framework is based on the premise that New Zealand wants to protect its primary industries and retain its unique biodiversity by managing exotic pests and diseases that may threaten them, subject to a budgetary constraint. There is not unlimited money to spend on protection and therefore priorities need to be set.

The objective is to maximise the welfare of New Zealanders by optimally allocating resources to biosecurity generally i.e. across the different phases of biosecurity: pre-border, border, surveillance, response and management.

Optimising the response to incursions

At the next level down, once an incursion of an invasive species has occurred determine the optimal level of resource to respond to it. The response is further broken down into protecting against impacts on income generating activities, human health and the environment. At the most detailed level we are interested in optimally allocating resources to incursions impacting on indigenous biodiversity, assets that have non-market values.

This framework can be conceptually explained algebraically.

BNZ is faced with a budget constraint	=	\$Xm
To allocate across	x_1	pre-border
	x_2	border
	x_3	surveillance
	x_4	response
	x_5	management

The objective is to find a set of values for x_1, x_2, x_3, x_4, x_5 that maximises the utility of the nation.

Ut Max	V	=	$?_i\ NB_i\ (x_i)$
Subject to	$?_i\ x_i$	=	X
Where	V	=	well being of all NZders
	NB	=	Net Benefit over time (NPV)
		=	$?_t\ NB_t\ .\ 1\ /\ (1-r)^t$
Where	r	=	discount rate

In practical terms the aim is to invest in biosecurity services until the benefit from the last dollar spent in each area just equals the cost i.e marginal revenue equal marginal cost, in cost benefit analysis terms Net Benefit equals zero i.e.

$$NB_{x1} = NB_{x2} = NB_{x3} = NB_{x4} = NB_{x5} = 0$$

There are likely to be more projects that meet the criteria of positive Net Benefit than there is funding. In this case projects within each area should be ranked according to the highest Net Benefit divided by the Cost of biosecurity inputs (C) as this ensures the most valuable projects are funded first.

$$NB / C = 0$$

At the margin, a project in one area that has a higher NB/C ratio than in another area should be funded first. If there are a number of projects that significantly exceed the hurdle rate and the budget is not large enough to fund them, then this is a signal to government that increased funding should be considered for allocation to biosecurity in aggregate – the decision at level one.

Because we are dealing with an uncertain future, portfolio theory offers us some additional insights. Markowitz (1952) showed that diversification based on consideration of the mean and variance of alternative investments gave the most efficient portfolio. If we consider the areas of pre-border, border etc that make up our portfolio of investments then there is a set of mean variance projects that maximise welfare. There is a trade-off between risk and return and the optimal portfolio is determined by society's appetite for risk.

Individual preferences for Biosecurity Services

From the individual's point of view it is a basic premise of neoclassical economics that people have preferences for goods (both market and non-market) and that these can be ordered to maximise the individual's utility. This can be specified by the individual's utility function (Flores 2003). The optimal amount of biosecurity services, which are non-market goods, is determined in conjunction with market goods based on the individual's utility function (p28).

Utility function	X	=	$[x_1, x_2, x_3, \ldots\ldots, x_n]$	for market goods
	Q	=	$[q_1, q_2, q_3, \ldots\ldots, q_k]$	for non-market goods

The utility function assigns a single number U(X,Q) for each bundle of (X,Q).

For any two bundles (X^A, Q^A) and (X^B, Q^B) the respective numbers assigned by the utility function are such that $(X^A, Q^A) > (X^B, Q^B)$ if and only if (X^A, Q^A) is preferred over (X^B, Q^B).

Money is relevant because it is scarce and people are limited in how much they can spend on the things they enjoy. For market goods individuals choose how much they spend on each good based on their preferences, relative prices of market goods $P = [p_1, p_2, p_3, \ldots p_n]$ and available income Y.

Non-market goods are rationed as individuals cannot unilaterally choose the level of these goods.

People make choices to maximise utility from their income purchasing market goods subject to a rationed level of non-market goods.

(1) Max wrt X $U(X, Q)$ subject to $P \cdot X = y, \quad Q = Q^o$

The X that solves (1) depends on y, P and Q.

For each market good there is an optimal demand function.

$x_i^* = x_i(P, Q, y)$ and the vector of demands is

$X^* = X(P, Q, y)$ the demand function for the list of goods

Putting the optimal demands into the utility function obtains the indirect utility function:

$$U(X^*, Q) = v(P, Q, y)$$

Demand functions provide the quantity of goods demanded for a given price vector and income level.

Demand functions can also be interpreted as marginal value curves since consumption occurs up to the point where marginal benefit equals marginal cost. Thus demand has social significance (p29).

Adapting Flores' basic model to biosecurity there are two ways of looking at whether the benefits exceed the costs where non-market goods like indigenous biodiversity are involved. The first is **compensating** welfare which is the amount of income an individual would be willing to give up after the project has been implemented that would exactly return him or her to the previous level of utility. This can be shown algebraically:

(2) $$v (P^o, Q^o, y^o) = v (P^1, Q^1, y^1 - C)$$

The superscript ^{o} identifies the initial conditions and ^{1} the conditions after implementation. C is the amount of income willing to be given up to return the individual to the position before the project was implemented. C could be positive or negative depending on how relative prices change and / or the size of any additional taxes paid. If costs are less than C then the project should be implemented as the individual is better off. If costs are more than C then the individual is worse off.

The second measure is the **equivalent** welfare measure and is the amount of additional income an individual would need before the project was implemented to have the same utility as after it was implemented i.e.

(3) $$v (P^o, Q^o, y^o + E) = v (P^1, Q^1, y^1)$$

"The two measures differ by the implied assignment of property rights" (p30). For the compensating measure the initial conditions (status quo) are the basis of comparison and for equivalent welfare the subsequent conditions (the change) are relevant. Which measure is appropriate depends on the situation. When considering a new policy to improve a situation compensating welfare is used, for example, restoring indigenous biodiversity after a long period of possum damage. Alternatively, when the property right already exists and the project would return the situation to that level then equivalent value is appropriate, for example, response to a new pest invasion.

There are two other terms that are often used to substitute for compensating and equivalent measures, these are willingness to pay (WTP) and willingness to accept (WTA) compensation. WTP is usually associated with a positive change and WTA with a negative change. These terms are used to describe impacts on individuals. Benefits in CBA are the sum of WTP for changes that are perceived as gains and WTA for changes that are perceived as restored losses. On the other hand, costs are the sum of the WTA changes that are perceived as losses and WTP changes that are perceived as foregone gains.

When aggregating information to make collective choices, as in biosecurity, the Kaldor-Hicks potential compensation test forms the basis and justification for using CBA (Kaldor 1939) and (Hicks 1939). This test focuses on efficiency and does not consider equity. In order for the project to be in the national interest aggregate benefits must exceed aggregate costs. If there are losers as well as winners from the project, then the test merely requires that winners have the potential to compensate losers and still be better off for there to be a net benefit. Furthermore, the benefits and costs relate to non-market as well as market values.

People decide how to spend their income after the allocation to biosecurity (as part of the tax take). Through the exercise of their vote political decisions are made as to the level of biosecurity services provided. Thus people can influence the level of biosecurity services provided. However, general taxation is a very blunt instrument and funds a bundle of services including biosecurity. Politicians are more likely to exercise the will of the people if the people are involved in the decisions. This is increasingly recognised through the use of surveys, focus groups and citizens juries to provide information for use in decision support tools such as deliberative modeling, mediated modeling and choice modeling to help decision makers involved in public choice.

Conceptual framework for valuing non-market goods and services over time under uncertainty

Flores (2003) provides a conceptual framework for the valuation of non-market goods and services over time (p50). This starts with the premise that utility over time equals the sum of the utility functions for each period.

The time preference factor is assumed to be the discount rate factor.

$$ß = 1/(1-r)$$

(29) $$U = ?\ ß^t\, u\,(X_t, Q_t)$$

$$X = [x_1, x_2, x_3, \ldots\ldots, x_n]$$

Where X is a vector of all the market goods an individual chooses.

$$Q = [q_1, q_2, q_3, \ldots\ldots, q_k]$$

Where Q is a vector of non-market goods.

Let $\quad Y \quad = \quad ? \; \text{ß}^t \, y_t$

The consumer allocates income to the choice of market goods over time, and

X_t is the composite of all expenditures on market goods in period t.

The individual efficiently allocates income between periods when the marginal benefit of spending on market goods in each period is equated in present value terms.

$$(30) \qquad \frac{?\mu\,(X_o, Q_o)}{?\,X} \quad = \quad \text{ß}^t \quad \frac{?\mu\,(X_t, Q_t)}{?X}$$

The above equality must hold for all t for optimal income allocation.

A marginal change in Q_t in and period t is given by

$$p_t^v \quad = \quad \frac{?\mu\,(X_t, Q_t)}{?\,Q} \quad / \quad \frac{?\mu\,(X_t, Q_t)}{?X}$$

and the marginal change over time is given by

$\text{ß}^t \; P_t^v$ (where P_t^v is the vector of marginal changes p_t^v)

Thus the marginal value of Q in the time dependent model is the discounted value of the marginal value in respective periods.

The level of non-market goods provided by a policy maybe uncertain, prices of market goods after the policy is implemented may be uncertain and the cost of the policy may be uncertain.

Uncertainty regarding the distribution of Q

Individuals allocate income to purchase market goods according to expected utility maximisation.

$$\text{Max } E_Q \quad [\,U(X, Q)\,] \quad \text{subject to} \quad p\,.\,X = y$$

When F = the probability distribution of X, the maximum expected utility is given by the indirect utility function

$v^E(P, y, F)$ $P = [p_1, p_2, \ldots, p_n]$ the vector of relative prices of market goods

y = available income

Using the concept of Option Price (OP) defined as "the amount of income given that makes the individual indifferent between the status quo level of expected utility and the new expected utility under the changed distribution" (p52).

$$v^E(P, y - OP, F^1) = v^E(P, y, F^0)$$

In this case, option price is very close to the concept of compensating surplus. Contingent valuation and attribute (choice) surveys generally measure option price since some uncertainty almost always exists[2].

This framework provides the theoretical basis for using contingent valuation and choice modeling to determine the value of ecosystem goods and services.

Before moving on, mention should be made of multi-criteria analysis (Proctor and Qureshi 2005). MCA has been put forward by analysts who are not convinced that economic values can be inferred for non-market goods such as the environment, human health, culture etc. MCA places relative values on different components making up a multi-criteria function. These are expressed as scores in a range, for example, 1 to 100. The scores for each component are added up to form a composite score. Sometimes the scores are given equal weights and sometimes unequal. The analytical hierarchy process (AHP) is a technique for determining weights based on the pair wise preferences of individuals.

While having appeal as an easily understood and easily applied technique MCA suffers from a number of deficiencies compared with economic tools such as choice modeling. Firstly, it tends to result in black box type decisions where the underlying basis for scores is hidden. Secondly, the technique is open to double counting particularly where a rigorous economic evaluation has been conducted using a tool such as choice modeling. This is because the economic values expressed by individuals embody more than just market values as expressed through WTP and WTP concepts. Thirdly, there is no satisfactory way of determining weights that is not open to criticism regarding their

[2] see Freeman Freeman, A. M. I. (1993). The measurement of environmental and resource values: theory and methods. Washington DC, Resources for the Future. for an overview

stability. Lastly, in practice, the scores for different projects particularly when they are close offer little insights for decision makers to differentiate between projects in practical decision making (Wansbrough *pers. com.* 2006).

The optimal level of control over an incursion

Optimal control theory provides a basis for determining the optimal level of control to exert over an incursion of an exotic pest or disease (Olson and Roy 2002), (Horan, Perrings et al. 2002) and (Pitafi and Roumasset 2005). Kaiser, Burnett *et al* (2006) demonstrate the application of the theory for an invasion of Miconia (a woody shrub) on the islands of Hawaii.

The problem is defined by Kaiser, Burnett *et al* as minimising the expected costs and damages from the presence of the pest and control activities undertaken against the incursion, with the objective function as shown below:

$$\text{Max} \quad ?^{8}{}_{0} - e^{-rt} \left(?^{n}_{n\text{-}x}\, c(?)d? + D(\text{n}) \right) dt$$

Subject to:

(1) $? = g(n) - x$

(2) $0 = x = n$

(3) n_0 given

Where			
	n	=	population of the invasive
	?	=	associated time derivative of n
	n_0	=	starting population
	$g(\ )$	=	growth function of the invasive
	x	=	number of removals of the invasive
	$c(\ )$	=	marginal cost function of removals, which varies with the population level
	$D(\ )$	=	damage at population n

Optimal control of the invasive species will result in a steady state population when $x' = ? = g(n) - x$ and thus

(10)	$-c\ (n)$	$-\ D'(n)$	=	$[\,g(n) - \text{r} - 1]$	c	$(n - x)$
	marginal cost	& damages	=	growth	. cost	. (pop. – removals)

> "In other words, the marginal costs and damages of the steady state population (LHS) must be just equal to the marginal opportunity costs of maintaining that population (RHS). If the LHS is greater than the RHS, we should be increasing the harvest rate (*the number of removals*), while if the LHS is less than the RHS, we should be decreasing the harvest rate (page 4).

Kaiser, Burnett *et al* summarise the optimal control policy as follows: "consider first where the population is in relation to an optimal steady state population, as determined by minimising the present value of damages and control costs across an infinite time horizon. If the population is currently at this steady state population, new growth should be continually harvested at the steady state, generating a stream of minimised economic costs and damages indefinitely, unless eradication or accommodation has a lower expected present value of costs and damages. If the population is currently above the steady state population, control costs should be extended to reduce the population to its steady state and then maintain that population unless, again, a corner solution is preferable. If the population lies below the steady state population, damages should be accumulated as the population grows which are lower than the cost of maintaining these lower populations, until at the steady state population maintenance is initiated as described above" (page 4).

Consider the case of possums. The above theory would tell us to determine the minimum control costs and damage that result in a steady state population. If that total cost is less than the cost of doing nothing (i.e. the damage from accommodation) and less than the total cost of eradication, then that is the optimal policy.

Summary

Where does all this theory take us?

We have seen that optimal resource allocation to biosecurity is attained by equating marginal benefit and marginal cost over the different phases of biosecurity – a level two decision. When the marginal project in each phase just exceeds the criteria of a positive net benefit then optimum allocation is achieved. In practical terms this is not usually attainable because of the budgetary constraint. When there are more projects than funding the rule is to allocate funds on the basis of the net benefit to cost ratio, funding the highest first as this will lead towards the optimum. If there are consistently more projects that exceed the funding constraint then this is a signal that the allocation to Biosecurity is under funded in aggregate – a level one decision.

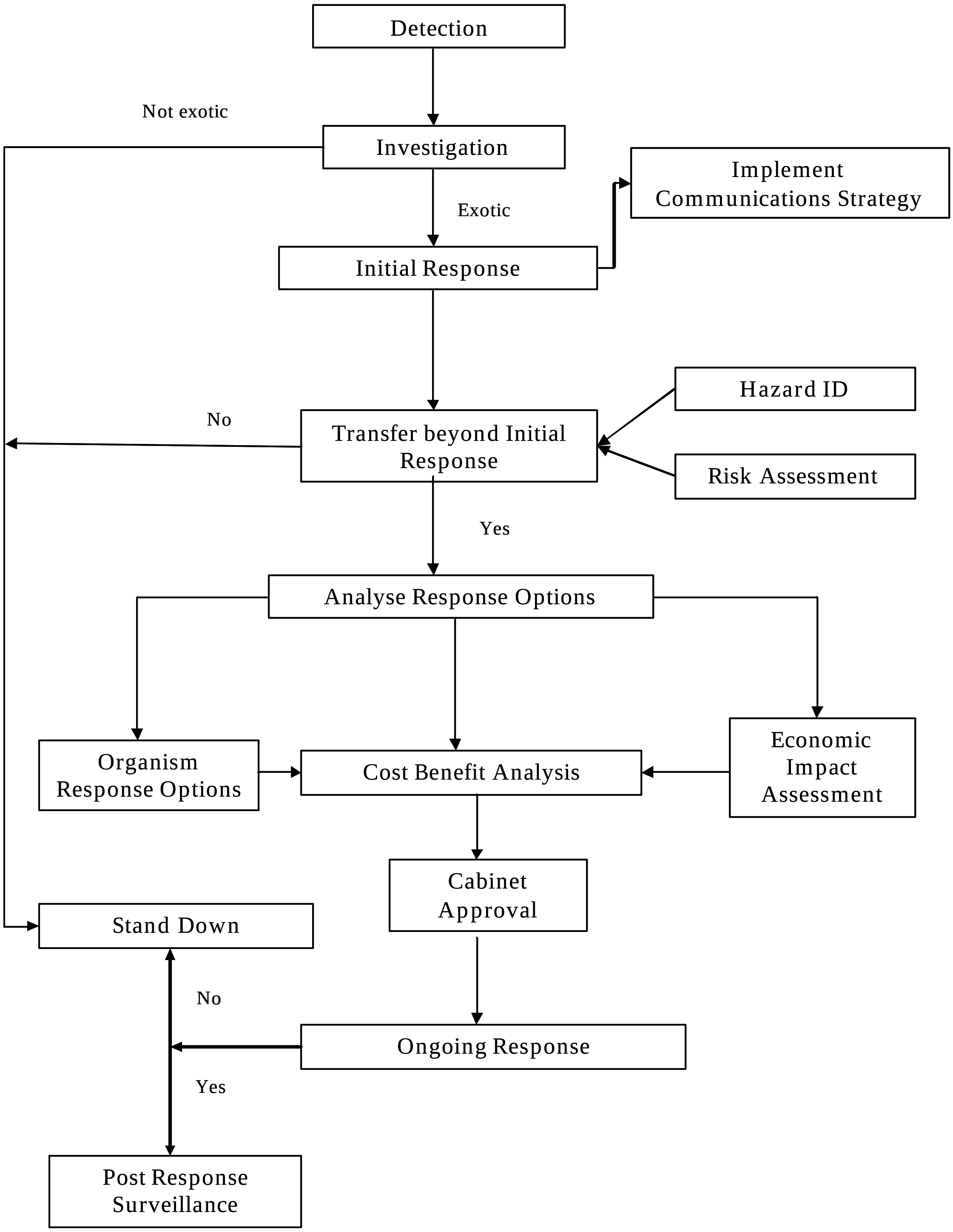
For each project (level 3 decisions), Net benefit is assessed over time and discounted to a net present value based on a discount rate that reflects the national time preference rate. Uncertainty can be taken into account by assigning probability distributions to key variables and using the Excel add-in @RISK to simulate the overall probability distribution for the project. Nimmo-Bell has developed a standardised framework called Quantitative Risk Analysis (QuRA®) to undertake this analysis in a consistent way that has been tested rigorously in the evaluation of research and development projects at the industry level (Bell 2000).

The response process for an AIO is depicted in Figure 1 below (BNZ, 2006).

In the case of indigenous biodiversity the benefits associated with a response are estimated by surveys of experts and properly informed lay people using tools such as choice modeling to determine marginal changes in the value of an ecosystem under different scenarios of damage. When there is insufficient time to undertake this type of analysis information will be drawn from a database of studies and incorporated in the analysis using benefit transfer methods.

The methodology to undertake this analysis will be developed in four case studies, two undertaken in 2007 and two in 2008. The aim is to learn by doing. In the first year we will look at the South Island high country using wilding pines as the AIS and the coastal marine ecosystem using invasive crabs in estuarine areas. In the second year indigenous forest and the fresh water habitat will be the areas of focus. To complete the project the theory and the knowledge gained from the practical application of the case studies will be brought together to form a decision support framework.

Figure 1. Response Top Map Summary



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