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Summary

MoRST is performing an evaluation of the funds invested in environmental research. The two case studies discussed in this paper contribute to the ongoing decision-making about this investment. Substantial funds have been invested in both research programmes identified. Because the main benefits associated with research output are environmental, they are difficult to value monetarily. Preliminary analysis suggests that at a discount rate of 6%, annual future benefit flows of $7 - $10 million will justify the water quality/clarity research. The expenditure on possum biocontrol will be justified if the research generates an annual future benefit flow of $20 million.

Keywords: Cost benefit analysis, returns to research, environmental research.

Introduction

The Ministry of Research, Science and Technology (MoRST) is performing an evaluation of the *Environmental Research* output class and will report to the Minister of Science in June 2004. An important focus of the overall evaluation is identifying the impacts of environmental Research, Science and Technology (RS&T) spending. MoRST is interested in determining whether the research is having a positive effect by delivering real benefits to New Zealand, particularly to the environment. They would also like to determine how effective the funding on environmental research has been. Finally, they would like to begin to identify what influences the link between environmental research and tangible positive benefits. This paper reports on two case studies that shed light on those issues.

The Government's total investment in Vote: RS&T is divided into 14 Output Classes, of which six are referred to as Public Good Science & Technology. Environmental research (Output Class 014) contributes primarily to the Government's Environmental Goal, which seeks to increase our understanding of the environment, including the biological, physical, social, economic and cultural factors that affect it. A total of $88.6 million in research funds were allocated through this Output class in 2003/04. There are 13 portfolios in the Environmental Output class, which support four Environmental Strategic Portfolio Outlines (SPOs).

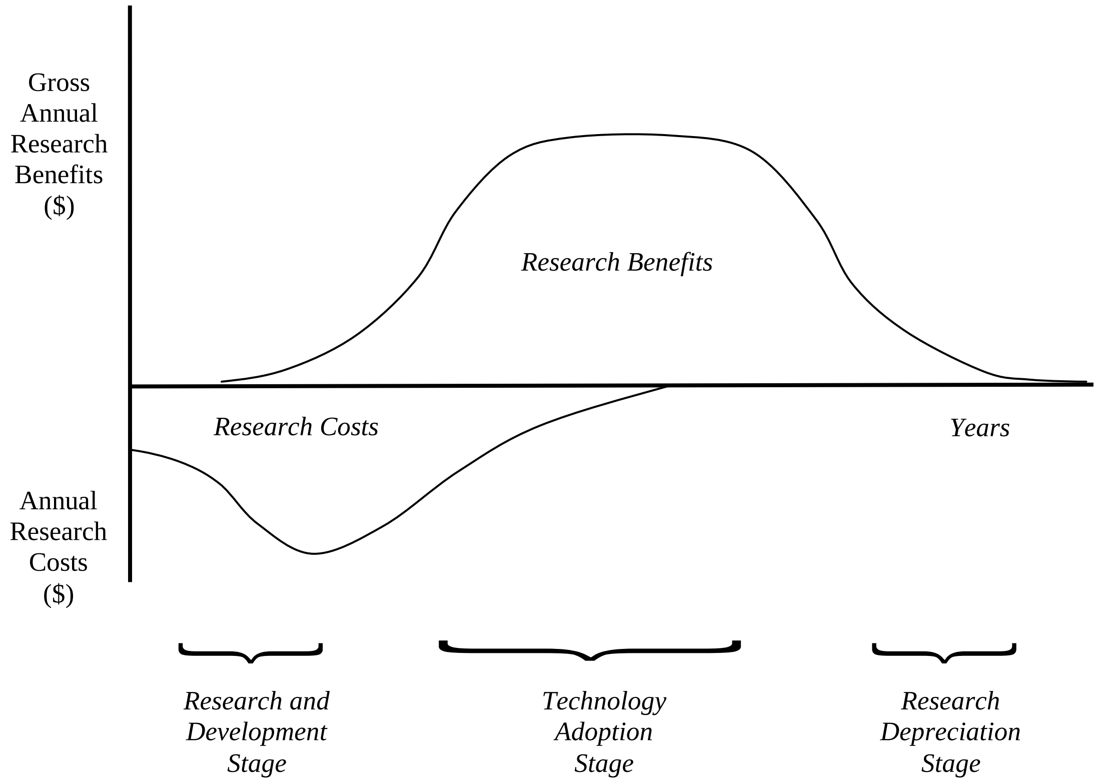
By definition, the benefits of Public Good Science Fund (PGSF) research are diffuse. As a result, there are generally a number of funding partners facilitating this kind of research. The Environmental Output Class is no exception. Major funding partners in environmental research include the Department of Conservation, the Ministry of Agriculture and Forestry, the Ministry of Fisheries, Regional Councils, industry organisations such as the Animal Health Board and AGMARDT. The financial contribution that these groups make to environmental research varies by research output area, but overall it is significant. In many cases the Output Class 014 money supports the higher-risk, more fundamental research that underpins subsequent applied research. The multiple sources of funding makes it impossible to calculate the returns specifically to Output Class 014 as the impact of the individual funding streams cannot be separated.

A considerable amount of research has been completed investigating the social returns to R&D since early work by Griliches (1958) and others. Researchers have used two approaches to estimate the returns to these investments: econometric analysis and case studies. The former approach uses statistical techniques to examine the relationship between R&D and production processes in individual firms, industries or national economies. R&D may impact production processes by way of production costs, output levels or productivity. Total factor productivity (TFP) studies are an increasingly popular means of investigating the relationship between R&D and national economies. The high level of aggregation in this approach avoids the need to identify project specific effects on beneficiaries. In New Zealand a recent study by Johnson (2000) uses econometric approaches to estimate the rate of return to New Zealand R&D investment. The study finds low rates of return to public investment in R&D and promising rates of return to private R&D.

Case study research traces the investments made in a selected research programme and the flow of benefits deriving from the research. Analysts then complete a cost benefit analysis of the research programme by calculating the present value of the investments and the present value of the additional benefits the research has delivered compared to a counterfactual of no research investments. An Australian review of the merits of the two evaluation approaches commented that case studies have advantages of transparency, the methodology is readily understandable and the beneficiaries of the research can be clearly identified (Industry Commission 1995: QA.15).

Many research programmes in agriculture have been studied using case study evaluations and often they have reported very high returns to the R&D (Marshall and Brennan and 2001). These studies have demonstrated that there is often a substantial time lag between the initiation of the research, and an actual research output or innovation, and again between innovation and adoption by end users. In addition, it is important to remember that the stream of benefits produced from a research programme will decay as new research is initiated which will have superior outputs. The time-path of research costs and benefits is depicted in Figure 1. It is important to account for this time-path when evaluating a research programme. Time lags can be substantial, and their length can have a large impact on the present value of research benefits when a discount factor is used.

Figure 1. The time path of research costs and benefits



Source: Adapted from Alston, Norton, and Pardey.

Marshall and Brennan (2001) have raised a number of caveats for those who are evaluating research using a case study approach. They note that it may be difficult to model the benefits from research if they are influenced by stochastic events. In addition, the full identification of research benefits requires that a future 'with research' be compared to a counter-factual 'without-project' scenario. The counter-factual must therefore be accurately accounted for. Other issues for case study evaluations include the possibility of selecting highly successful research programmes that are not representative of all R&D, and the difficulty of identifying and measuring the additional investment costs that may be required after the R&D is completed to achieve adoption. These items may lead to overestimation of the returns to the R&D. Another possibility is the knowledge generated by the R&D may have public good characteristics and be used widely or have spillover benefits that are hard to quantify, and hence the returns to the R&D may be underestimated.

There are clearly strengths and weaknesses of both evaluation methodologies. An additional challenge associated with the evaluation of environmental research, is the fact that research output can be extremely difficult to value in monetary terms. Many environmental research programmes will not lead directly to increases in aggregate productivity. The econometric approach to calculating the returns to research is therefore substantially less useful in this setting. Research output may be easier to identify in a case study approach, but valuing the output in monetary terms can still be problematic. For the research reported in this paper, the case study methodology was judged to be viable. No claim is made that the projects selected for study are representative of the complete suite of investments in environmental RS&T.

A workshop held in Christchurch in 2004 considered how the returns to RS&T might be evaluated. The Workshop identified two methodologies that could potentially be used to identify and quantify the benefits from environmental research. Methodology One identifies the major research programmes, and then attempts to identify and quantify the benefits the research has created. Methodology Two identifies a particular sector or industry that has benefited from environmental research and attempts to trace the link back to the research that contributed to the benefit.

In this paper, the results of two case studies employing Method One are presented and discussed (See Cullen *et al.* in this conference for an application of Method Two). The first case study involves research into water clarity/quality of Lake Taupo. The second involves research into the biological management of possums. The application of this methodology involved several steps. First, a list of research programmes relevant to each case study was assembled. The outcome of each research programme was then determined, followed by an assessment of the counter-factual – which considers what would have occurred if the research had not existed. The difference between the actual outcome with the research results and the counter-factual provides an indication of the net benefits of the research. Finally, these research benefits were compared to the costs of the research programmes in present value terms, to make a preliminary statement about the overall desirability of the research programmes.

Case 1: Water Clarity/Quality in Lake Taupo

Assembling a complete list of research programmes directly related to water quality in Lake Taupo was nearly impossible. Not only are the policies implemented today based on research conducted over 20-30 years ago, but there have also been multiple funding organisations contributing to this research over a long time horizon. With the help of scientists who have been involved in research related to Lake Taupo a rough compilation of research and costs has been compiled (Table 1).

From the mid 1970s to early 1990s there was a continuous series of interlinked lake water quality research projects, many of which were carried out on a wide range of central North Island lakes with Taupo as one of the series. There were also specific studies on the Taupo Lake and catchment. Most of this research was aimed at more fully understanding the issue of eutrophication of freshwaters. As detailed in Table 1, this research received funding from a wide range of providers. Among the government bodies funding such research were the Department of Scientific and Industrial Research (DSIR), the Ministry of Works and Development (MWD), Environment Waikato (EW), and Ministry for the Environment (MfE). Industry funds were received from Mighty River Power Ltd, Genesis Power Ltd and the Dairy Industry. The Ngati Tuwharetoa have also contributed funds to the research on quarter quality, water clarity and algal biomass in Lake Taupo.

Subsequent to the formation of the CRIs, FRST funding for lake research was reduced drastically. Consequently, the National Institute of Water and Atmospheric Research (NIWA) as also supported the work with Non-specific Output Funding for several years. There are currently three major research programmes relevant to water quality/clarity in Lake Taupo funded via FRSTs Environmental Output Class. Broadly speaking these programmes focus on the effects of land use intensification and change on environmental issues such as eutrophication, loss of species, algal blooms and reduced water clarity.

It should be noted that Table 1 is far from complete, but it does provide some idea of what has been spent on Lake Water Quality research. The FRST Environmental Output allocation is simply half of the total funding allocated to the three projects, because the overall programmes have much wider relevance than just Lake Taupo.

Table 1. Research Programmes Relevant to Lake Taupo

Time Period	Source of Funds	Funds	In $2004
1970-1990	MWD, DSIR	$1.5 million ($1990)	1.98
1976-79	MWD (Hamilton)	$170,000/FTE	3.65
1982-87		$170,000/FTE	2.27
1995	NIWA / DSIR	$100K	0.117
1993-1997	EW	$50K/ann	0.296
2001-2003	EW	$72K/ann	0.290
2000-2001	Mighty River Power	$200K	0.208
?	Genesis	$60K	0.060
2001-2002	MfE, EW, Dairy Ind., Genesis, Ngati Tuwharetoa	$160K	0.167
2002	NIWA	$160K	0.167
2003-2008	**FRST Environmental Output**	**$2.5million**	**3.5**
1999-2003	EW and others, such as GNS on N movement through the soil	?	
		Total Funding	**11.7**

Outputs From Lake Taupo Research

In the early period there were no proposed outputs. There was an issue (Eutrophication of Freshwaters) and the research work in the 70s and 80s accumulated knowledge in a general sense to try and understand this process. The research identified above has clearly achieved this, the issues have been clearly defined as well as the causes.

While the issues of water quality were recognised and identified a long time ago (the results of the early research) nothing much (for a long time at least) was done to deal with the issues, except that more research was funded to understand the issues even better and fine tune some of the earlier findings.

The Government's outcome category is Water Quality. There is (in case of Lake Taupo) evidence that water quality has declined and continues to do so. Only in recent years have policies been proposed to tackle the main cause of the decline in water quality. It is notable that there has been such a substantial time lag between the knowledge that the research generated and formal recognition of the problem in a policy setting. Particularly give that in 1983 (and earlier) we could read in research outputs sentences like "Intensified use of land, whether it be with farming, forestry, or urban development, will inevitably lead to increased losses of nutrients to the waters draining into Lake Taupo. The contribution from increased agricultural activity seems likely to pose the greatest threat and it is here that future attention must be focused." (White et al. 1983)

Possible Future Benefits of Lake Taupo Research

The counter factual is that without any change (i.e. limiting the sources of nutrient supply to the lake), water quality in the lake will continue to decline. Even if policies were in place today, water quality decline will continue for a long time because there are still a lot of nutrients in the pathway land-to-lake that will finish up in the lake (N can travel very slowly through the soil – evidence from the UK suggests up to 50 years). As a consequence, even if we implemented strict policies today that would stop all nutrient supply to the lake, we may not see improvements in water quality for decades.

Net Benefits from Lake Taupo Research

To understand the benefits we need to know how research has enabled managers to improve the quality of the lake (or avoided further degradation). Unfortunately the relationship between management and outcomes are not that clear. The research findings have helped our understanding of the relationship between land use, nutrient flows and impacts on the Lake's ecosystem. However, there are still many unknowns, or as Parnell writes: "A key point to understand is that we do not know with certainty the biophysical consequences of various choices in alternatives to protect the lake. The models that are used to estimate the consequences of various policies are gross simplifications of what are very complex systems. There are no guarantees that the policies promoted to reduce input of nitrogen into the lake will have the estimated consequences (Nimmo-Bell,2002).

Lake Taupo has undeniable value both locally and nationally. A decrease in water quality will lead to a reduction of that value (if for the time being we only concentrate on economic value). Lake Taupo is key to the local economy, which is largely based on tourism and forestry. To estimate net benefits from halting the decline in water quality (the counter factual being a continued decline) we need to understand how water quality affects economic (and non economic) values. We are not going to lose Lake Taupo rather changes at the margin (in terms of levels of water quality) will change the economic benefits currently (and in the future) that will be lost. Therefore, measures taken to control water quality will stop that loss from occurring. These benefits of prevented economic losses (now and in the future) are a direct result of the research conducted (some over 30 years ago) to increase our understanding about the lake.

This year a paper was released that showed the findings of a survey of public opinion on the management of Lake Taupo (Huser, 2004). While the response rate of the survey was very small (1.05%) the number of respondents 1, 762 gave indication that there is widespread awareness of the deteriorating health of the Lake and that among the respondents there was a strong level of support for all the approaches proposed (by EW) for protecting the Lake. While there was strong support, there was also concern regarding the effect of the proposed actions, with a clear split along rural/urban lines depending on where the costs of the proposal were likely to fall. "One in three [of the respondents] are clearly in agreement that people living in Taupo District and the wider Region should pay more in their rates to protect the Lake, but among those who are less willing there is clearly a feeling that all New Zealanders should be contributing" (Huser, 2003. v).

In a report “The impact of Alternative Land Uses in Taupo Catchment” it was estimated that on current trend in land use change and growth rates in tourism, the annual value added of tourism could be worth $121 million ($1998 dollars) to the Taupo Catchment. In the same report a scenario was analysed in which dairying would expand in the catchment, water in the Lake would become polluted and that this would lead to a $50 million decrease in annual value added. No figures were given on how bad the water would be polluted or on how the $50 million decrease was calculated.

Another benefit from stopping declining water quality and eutrophication would be those obtained by power companies, as weeds and algae cost them significant clean up costs. Also, in a more general way the value to society of clean water is substantial, judging by the efforts of Fonterra in forcing (now voluntarily but soon compulsory) dairy farmers to clean up farm effluents so as to stop declining stream and lake water quality. With Taupo being such an important lake (in the eyes of New Zealanders and the world) a decrease in water quality (especially a very perceptible one – such as weeds, poor fishing, clarity) would detract from our clean and green image. The value of this is not only linked to tourism flows and incomes but also to the rest of the world’s perception of NZ and the potential for our clean and green products.

Beside purely economic considerations however, there will also be heritage, ecological and cultural values associated with water quality in Lake Taupo.

What has been the return on the investment made in research? As the above discussion shows, we don’t have the information to make a statement on that. What is important however is that without the research policies could not be implemented today to protect the water quality of Lake Taupo. The results also have contributed greatly to our understanding of the causes of the decline in water quality, which will play a role in the setting of policies and the discussion of property rights issues.

Having not being able to show the magnitude of the benefits that could arise from the research conducted, I would like to turn the question around, and ask: **“How large do the annual benefits (directly related to water quality in the Lake) have to be so that the present value of future benefits (which result from the policies to be implemented today) equals the current total cost of money invested in water quality research for Lake Taupo?”**

To conduct this experiment some assumptions will be necessary. The making of those assumptions demonstrates how difficult it is to really estimate the benefits of water quality control.

1. The cost of the research conducted (recall that the numbers are guesstimates and are still incomplete) was combined with a cost of capital (discount rate) of 6% and 7%, to give a present value today of the dollars devoted to Lake Taupo research over the years 1976-2004.
2. It has been assumed that there is a direct relationship between the level of benefits (economic and non-economic) and water quality, and that those benefits will change when water quality changes. When water quality changes the benefits with therefore change proportionately, e.g. if some index of water

quality declines 2% annually, then benefits are assumed to decline at the same rate.

3. A 50 year period is used for the analysis[1]. If no policies are put in place (the without situation), it is assumed that water quality declines and it will continue to do so over the next 50 years, and benefits to society decline accordingly. If policies are introduced however (the with situation), it is assumed (all very arbitrarily) that they won't have any effect for the next five years, but that after that they will slow down the decline in water quality, and then that after 25 years water quality starts to increase again.

The 'with minus the without' situations are compared to arrive at an annual benefit level that justifies the research expenditure. It is further assumed that the real value of the Lake (in light of increasing scarcity of freshwater lakes in NZ and world wide) increases at some percentage, which initially is set equal to 0%.

Given this model, we can now ask the question: "What does the annual dollar value of benefits have to be for the PV of the future benefits to equal to the total cost of research investments made into research for Water Quality in Lake Taupo?". The table below presents some of the results[2].

Table 2. Annual Net Benefits Required to Justify Lake Taupo Research Expenditure

Years		Change in Water Quality Without policies	Change in Water Quality With policies
2004-2053		-2%/year	
2004-2008		-2%/year	-2%
2008-2028		-2%/year	-1%
2009-2053		-2%/year	+1%
Opportunity cost of Research Funds (in $2004)			
@ 7%	$20.53 million		
@ 6%	$17.2 million		
$ Value of the Annual Year 2004 benefit, that makes the Research Costs = PV of future Benefits, if the real value of benefits change at:			
	7% discount rate	6 % discount rate	
%0	$15.26 million	$9.5 million	
%1	$11.33 million	$7.0 million	

[1] Benefits of course will go on much longer, but when one discounts, costs and benefits after 50 years won't have much importance.

[2] The experiment was set up as a spreadsheet, and the 'with' and 'without' scenarios were modelled.

Conclusion on Lake Taupo Research

A lot of research has done on water quality/clarity issues in Lake Taupo since the mid-70s. In terms of value today we are talking about a magnitude of $20 million. As a consequence, our understanding of the basic linkages between land use and water quality in the lake, and about lake processes has improved. However, there are still uncertainties about the effects of policies to stop the cause of water quality deterioration that are taken today, especially in terms of magnitude and timing.

While 20-25 years ago we clearly understood the consequences of land intensification on lake water quality, it appears that for quite some time, New Zealand also adopted a grow first clean up later attitude, and the research findings of 20-25 years ago are only now being acted upon. The reason for this delay may be found in inertia in government decision making (growth is important) and in society's values, which needed to change so that people would demand a greater urgency to act on environmental issues.

There is little or no research to link changes in water quality to a reduction in economic substitutes or complements (e.g. reduction in tourist earning, less recreation, reduced fishing, etc.). Still, a small change in economic benefits, from especially tourism, due to a decrease in water quality, could present a significant loss in economic benefits given the importance of economic activities in the Lake Taupo catchment. Having said that, it is important to remember that there are other economic benefits associated with halting water quality decline in the Lake, such as for example savings by power companies (removal of weeds) and cultural and heritage values.

An experiment to get some handle on the return to research investment for Lake Taupo water quality showed that annual benefits $15 million (and linked to water quality) would justify the research investment made (given the assumptions made about water quality decline and the discount rate). If this amount is judged not very large (compared to the real annual benefits today) than one can draw the conclusion that the research investment has been well spent to protect the current value of the Lake.

The implementation of policies that is currently taking place is possible because research has shown us the causes of the water quality problems and of the solutions. The benefits of the policies currently being considered may only occur many years in the future (perhaps decades). The accumulated knowledge from the research (1970 - today) has helped us to understand the problem and put in place measures to stop it from becoming worse.

Case 2: Biological Management of Possums

The biological management of possums (PBM) was suggested in the early 1990s as a potentially cost-effective means to control possums. The research programme to support this effort was initiated in 1992, following the advice of the National Science Strategy Committee for Possum and Bovine Tuberculosis Control (NSSC). The goal of the programme is to develop cost-effective methods of biological management that can be used in the field alone or to complement current control technologies. The reason for seeking alternative control methods was the high cost of ongoing possum and Tb control. The classical definition of biological control is the use of natural enemies to aid in controlling pest species. Research to date suggests that possums in New Zealand have no natural enemies that are sufficiently pathogenic to act as a classical biological control agent. Therefore, the definition of biological control has been expanded for possums to include the use of any biologically based reagents, including genetically modified organisms that interfere with some physiological process Eckery (2000).

Research Costs for Biological Management of Possums

It was estimated in 2001 that a total of $30 million had been spent on research into the biological management of possums (Davies, et.al. 2001). According to the NSSC, in 2001/02 a total of $4.6 million was spent on biocontrol research. FRST and the Ministry of Agriculture and Forestry (MAF) are the main providers of research funds in this area. Because the NSSC does not maintain a distinction between FRST funding output classes, it is not possible to determine from published sources precisely how much of the biocontrol funding is provided through the Environmental Output Class. A discussion with leading researchers in the area suggests that approximately $300,000 of the money that Landcare Research receives from the Environmental Output Class goes towards possum biocontrol research. It is assumed that at least half of the AgResaerch programme led by Dr McNatty on the Genetic and Hormonal Control of Reproduction is funded through the Enviornmental Output class. This suggests that somewhere between $700,000 and $1.15 million worth of research into possum biocontrol was funded from the Environmental Output Class in 2001/02. The latter sum represents approximately half of FRST's investment in possum biocontrol, and over 20% of the overall funding that went into biocontrol in that year. In 2003/04 the Government increased its commitment to supporting research aimed at possum biocontrol. As a consequence an additional $450,000 per year have been allocated to possum biocontrol research from the Environmental Output for the four years from 2003/04 through to 2006/07.

Research Outputs from Possum Biocontrol Programmes

The first phase of the biological management programme has been one of discovery. The goal of this phase has been the generation of basic scientific information on possum physiology, possum diseases, possum behaviour, the possum immune system, developing reagents to use in later phases of the PBM programme, and developing experimental methods to handle and breed possums in captivity. A wide range of scientific and general papers have been published from the first phase of this research, and there is some feeling in the scientific community that the outcome from this stage of the programme has been substantially achieved (Davies, et.al. 2001).

The second phase of the research has been targeting biological features such as organs, molecules or control processes of the possum that might potentially be manipulated for possum population control. Constant review of the progress being made in the second phase has led to a number of approaches being discontinued. It is apparent, for example, that there are no 'naturally occurring' pathogens that can be used for successful biological control. Fertility control methods targeting the viability of pouch young have also been discarded, mainly on animal welfare grounds.

Currently, there are two main methods of biological control under investigation. The first involves the use of genetically modified pathogenic organisms such as parasites and diseases with the objective of directly debilitating wild possums. The second involves physiological impairment – and is aimed almost exclusively at indirectly suppressing the possum population by reducing fertility. The majority of the research funding on possum biological control is focused on fertility control through a range of different mechanisms.

The biocontrol agents, whether they attack the possums directly or indirectly, need to be delivered to the possums. The third phase of the PBM research programme, conducted in parallel to the second, has been into the vectors or delivery systems that could potentially be used to present the biocontrol agent to the possums. There are two main delivery systems: Non-transmissible systems, and transmissible systems. With a non-transmissible system, every individual possum must ingest or come into contact with the biocontrol agent. Bait or aerosol delivery systems have been studied, as have the use of plants that have been genetically modified to produce the biocontrol agent in their leaves or fruits. Transmissible systems, by contrast, would involve a biocontrol organism (such as a species-specific parasite or virus) that would spread naturally from possum to possum.

The main advantage of a non-transmissible system is that it is easier to control, and could be withdrawn at any time. Pest control efforts could therefore be more effectively targeted and the risk to non-target species would be minimised. However, this system would require repeated exposure, and is unlikely to have any cost advantages over the use of conventional control techniques. It would, however, result in a reduction in the use of conventional poisons.

The final phase of the PBM research programme involves the development of biological control products that can be used in the field. It has been estimated that is will be at least another decade, probably longer before a biological control agent is available for use in the field.

Net Benefits from Possum Biocontrol Research

It will be at least a decade, probably longer, before a usable biocontrol product is available. Because of the timeframe involved, and the speed at which advances in molecular biology and genetic engineering can occur, an *ex ante* analysis of PBM involves a very high degree of uncertainty. The political environment can also have an important impact on whether and under what conditions this research (and the subsequent application of the research outputs) is allowed to continue.

Several caveats should be borne in mind when considering the potential net benefits of biocontrol. While mathematical models suggest that the field success of a biocontrol agent is theoretically possible, the modeling to support this conclusion is based on very optimistic assumptions about the amount of control achieved (how many females are sterile), and for how long (Barlow, 2000). Mathematical models also indicate that possum numbers respond faster to culling than they do to sterilization. This result implies that possums will do more damage to the conservation estate after a biocontrol operation than after a conventional control operation – further compromising the value of a biocontrol product. Some researchers also believe that there is a risk that immunocontraception will result in natural selection for possums that fail to mount a significant anti-fertility response to the vaccine - and remain fertile. This is essentially a biocontrol equivalent to toxin resistance Finally, field experiments with surgically sterilized possums suggest that immigration also has the potential to cancel out the effects of fertility control in small areas (Possum Research News, 2001).

Despite all of the uncertainty surrounding biological control, one issue is becoming increasingly clear: the cost savings associated with biological control will be much greater if the delivery system is self-disseminating. This cost savings must be weighed against the risk (real or perceived) of releasing a genetically modified organism into the environment, over which we have very little future control.

Scenario 1: A non-disseminating biocontrol agent is developed that meets all criteria in terms of efficacy and efficiency.

Under this scenario, the biocontrol agent would be delivered in the form of baits. Using current control technology, the cost of poisons is low relative to the costs of baits and delivery. This suggests that a non-disseminating delivery system would offer no cost advantage over conventional control techniques. It has even been suggested that the biocontrol product may need to be broadcast at more frequent intervals than toxins, so the costs of this approach may actually exceed the cost of current techniques (Davies, *et al* 2001).

The primary advantages of a non-disseminating system would therefore be a reduction in the amount of toxin used in the environment, and a decease in the risk to non-target species (because the biocontrol agent is more specific to possums). One estimate suggests that biocontrol will reduce the amount of toxins needed by 67% (Landcare Research Information Bulletin on Possum Biocontrol).

To fully evaluate the benefits of this scenario, we need an estimate of the value associated with fewer toxins in the environment. The continued wide-scale use of poisons imposes a number of costs: risk to non-target species of direct poisoning; secondary poisoning risk to non-target species; and the tarnishing of New Zealand's Clean-Green image. There is also some concern that negative public reaction to the aerial use of 1080 may eventually lead the government to de-register the poison, effectively banning its use.

It is known that there are secondary and non-target poisoning risks associated with most of the toxins used for possum control, and it is recognised that some of the poisons pose greater risk to non-target species than others (Eason, Warburton and Henderson, 2000). Among those individuals most at risk are pest control workers, livestock, dogs and indigenous birds and invertebrates. Although the toxicology of all of the major poisons is being actively researched, the literature contains no quantitative measure of the number of non-targets killed annually.

A promising way to place an economic value on the reduction in risk to non-target species would be to follow developments in the human health literature, where a reduction in mortal risk is expressed in dollar terms as the value of a statistical life. Essentially what is being valued is a reduction in the probability that a death will occur. This methodology is commonly applied to the evaluation of public policies that reduce mortal risk by improving environmental conditions. Estimates of value are typically obtained by surveying the relevant (human!) population. Alternatively, within the context of environmental risk to indigenous species, it may be possible to infer a value for risk reduction based on prior public expenditures aimed at conserving various native species. These values can be combined with market values for livestock and dogs at risk. Finally, statistical values for human lives at risk can be transferred from the health economics literature.

In terms of the protection of New Zealand's Clean-Green Image, it must be remembered that the use of biological control would involve trading-off the use of toxins for the use of GMOs. In order to value this benefit in economic terms, an estimate would be needed both of the value of the image, and the extent to which it would be protected by using biocontrol instead of (or in conjunction with) conventional control.

In summary, this scenario is unlikely to offer any cost advantages over conventional control. The primary advantage of biological control if the delivery system is non-disseminating is a reduction in the amount of toxin in the environment. An economic value can be placed on this benefit, but it would require a comprehensive understanding of the actual risks that toxins pose, and perhaps some primary data work to place a monetary value on a reduction in that risk.

Scenario 2: A self-disseminating biocontrol agent is developed
Under this scenario, the biocontrol organism would spread naturally from possum to possum – and not require the repeated delivery of baits. It therefore has the potential to result in significant cost savings over current control methods, as well as the benefits associated with a reduction in toxins outlined above. It may still need to be used in conjunction with conventional control, due to either possums not coming into contact with control agent, or because natural selection favours possums that fail to mount an anti-fertility response.

A rough estimate of the expected net benefits associated with a reduction in control costs can be obtained fairly readily. The current cost of possum control is $89m/yr. This annual expenditure in perpetuity has a value of $1.482 billion (at a 6% discount rate). Expressed in 2004 dollars, this amounts to $618 million. If a self-disseminating biological control agent could cut the cost of control by 50%, the annual cost of control would be $44.45 million/year, or in perpetuity – $741 million. In 2004 terms, the perpetuity has a value of $309 million. The difference ($309 million) represents the present value of the savings in control costs due to research into biological control. Note that this figure is very sensitive to the discount rate used for the analysis. If a 10% discount rate is assumed, the cost savings is much smaller ($106m).

How does this compare to the cost of research and development? It is expected that the research and development cost of a biocontrol agent will ultimately be about $100 million (Davies, et al 2001). This estimate is consistent with an estimate of $116 - $122 million (depending on the discount rate used), which represents the present value of all past investment, plus a further development time of 15 years at the current rate of expenditure. Under the assumption that there is a 100 percent chance that the research will lead to a self-disseminating biological control agent that can be used in the field, the benefit:cost ratio is favourable (2.6) at a 6% discount rate. At a 10% discount rate, however, the costs outweigh the expected benefits, and the benefit:cost ratio is only 0.87.

This result will be sensitive to the amount by which current costs are reduced. If the biocontrol agent reduced the cost of control by only 25%, the cost savings are half of those reported above. Annual costs will be reduced from $89 million to $66.75 million, or $1.1 billion in perpetuity assuming a 6% discount rate. This represents a cost savings of $370 million, which in 2004 dollars amounts to $155 million.

Because the development of a successful self-disseminating biological control agent is not guaranteed, probabilities of success should be attached to the outcomes. There is a chance that the biocontrol won't be successful, and the benefits won't be realized. If the chances are 50:50, for example, then the expected value of the benefits are cut in half. Results of a sensitivity analysis are presented in Table 3.

Table 3. Benefit : Cost Ratios For Possum Biocontrol Under Several Scenarios

	6% discount rate	10% discount rate
25% cost savings 25% probability of success	39 : 116	13.3 : 122
25 % cost saving, 50% probability of success	77 : 116	26.6 : 122
25% cost savings, 100% probability of success	155 : 116	53 : 122
50% cost savings, 25% probability of success	77 : 116	27 : 122
50% cost saving, 50% probability of success	155 : 116	53 : 122
50% cost saving, 100% probability of success	309 : 116	106 : 122

It should also be recognized that the advantages of a lower toxin load mentioned above (non-disseminating system) will also be realized under the successful development of a self-disseminating system, and should be added to the above estimates.

This analysis indicates that a benefit stream of approximately $20 million per year, received in perpetuity beginning in 2020 would justify the expected cost of the research on the biological management of possums. At a 6% discount rate, the research could be justified solely on the grounds of cost savings over conventional control if it achieved an 18% cost savings with certainty. Note that there is economic value associated with reducing the toxin load in the environment, but time and financial constraints precluded a calculation for these difficult to measure benefits.

Conclusions on Possum Biocontrol

A number of general conclusions can be drawn from the admittedly preliminary analysis presented in this case study. The economic/financial desirability of the outcome from research into the biological management of possums is much higher when the biological control agent can self-disseminate. It is also clear that the probability of success, and the degree of cost-savings conferred by a biological control agent are critical determinants of programme success from a benefit:cost perspective if the programme is to be justified on the basis of cost-savings alone. While it is recognized that a reduction in the environmental toxin load that should accompany the successful development of a biocontrol agent has value, there is currently insufficient information available to value this benefit in monetary terms.

It can be argued that the expectations for biological control research were initially optimistic. Researchers did not anticipate how long it would take to get a 'product' that could be successfully used in the field, and they didn't seem to anticipate a negative public reaction to the release of genetically modified organisms. The opposition (mainly from Australia) to a self-disseminating vector does not seem surprising in retrospect, but it did not appear to hamper the development of such a system. To be fair, however, the social/political environment that can be so critical to the overall acceptance of the research results for a programme like this is subject to rapid change. It can be argued, therefore, that public opinion should not be the sole determinant of the basic research agenda.

If the delivery system is not self-disseminating, then the main benefits of biocontrol are associated with a reduction in the use of toxins. This translates into a reduction in the risk of poisoning non-targets, and a lower level of overall environmental contamination. There may also be an advantage in terms of New Zealand's Clean-Green image, but this benefit is likely to be off-set by a wide-scale use of genetically modified organisms.

The risk to non-targets of the biocontrol agent has not been widely discussed in the literature The current consensus seems to be that only possum-specific mechanisms will be targeted – essentially eliminating the risk to non-targets in New Zealand. It could be argued, however, that the risk of a biological control agent to non-target species in New Zealand is not fully understood. It is also true that a biological control agent that is specific to marsupials will not eliminate the non-target risk to native Australian marsupials if the biocontrol agent should be transferred across the Tasman.

The framework developed above illustrates that basic environmental research is difficult – but not impossible – to evaluate ex ante. It should also be borne in mind that benefit cost analysis is not the only methodology available for the evaluation of public expenditure. In fact, there may be other ways (aside from expected value/CBA) to evaluate basic research, which has a more explicit recognition of risk. One possibility is multi-criteria decision analysis.

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