Economics and the Biological Control of Weeds

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The economic evaluation of scientific research has received little attention in New Zealand until recent years. However, the increased emphasis on 'accountability' in science has led to some appreciation of the value of the results of such analysis in the allocation of scarce research resources. The economic analysis of basic research effort is the subject of considerable contention but the contribution of cost-benefit analysis in the evaluation of applied research projects in both "ex-post" and "ex-ante" situations has been recognised by many scientists. Cost-benefit analysis of biological control projects exemplifies the full range of problems encountered in the economic evaluation of research. The outcomes of biological control are extremely uncertain, frequently very long-term and are not always able to be valued using market mechanisms. In this paper, the means of evaluating biological control projects and the means of overcoming the inherent problems will be discussed, using as examples several recent studies carried out by the AERU at Lincoln University. These include a non-market valuation of the benefits of research into the biological control of *Clematis vitalba* and valuations of the biological control of *Hieracium*, sweet brier and rose-grain aphid. The latter 3 studies employed a market approach of valuing resource losses and gains associated with successful biological control. They also explicitly included uncertainty in the analysis framework. Finally, some implications for biological control scientists which have emerged from these studies will be discussed. In particular, for high-quality economic analysis to be possible, more information on the probabilities of success of biological control projects is needed. Secondly, public education on the subject is essential if society is to be willing to pay for such research.

Introduction

The economic evaluation of research–almost unheard of a decade ago–is becoming a necessity, albeit an unpalatable one, for scientists in New Zealand. The introduction of the "user-pays" policy for Government services, including the provision of science, has meant that scientists are frequently faced with the task of justifying their research programs in terms of nationally stated objectives and economic outcomes.

There is no doubt that the implementation and administration of the new systems have caused tremendous, and perhaps unnecessary, dislocation of scientific effort in this country. However, the concept of the allocation of New Zealand's resources to where they are most likely to result in increased economic welfare for New Zealand society is fundamental. It is difficult to see why scientific resources should be entirely exempted from this allocative principle. Certainly there are aspects of scientific research, for example basic research and "blue skies research," where economics can contribute little to resource allocation decisions. However, particularly for applied research, cost-benefit analysis can provide much useful information for those involved in such decision making. It can also provide a framework for the scientist to look objectively at his proposed research in a wider context than that of scientific merit.

Briefly, cost-benefit analysis involves the derivation of a stream of all the annual costs and benefits associated with a particular investment. A technique known as *discounting* is used to reduce those costs and benefits, which accrue over time, to a value today. The basic premise on which discounting works is that people value a dollar today more highly than they value a promise that they will receive that same dollar in 5

yrs time. Hence a project which results in annual benefits of one million dollars from next year will be more highly valued than a project costing exactly the same but with a 5-yr lag period before the realisation of the same annual benefits.

Cost-benefit analysis allows the comparison of projects which have different costs, annual returns, time horizons and probabilities of success, in terms of the most easily understood common unit–the dollar.

For example, decision-makers may be expected to make decisions about the appropriate allocation of funds to the hypothetical research projects A, B and C which are summarised in Table 1. By calculating the net present values, or values now, of each project, cost-benefit analysis provides a means of ranking those projects, despite their differing requirements for funding, probabilities of success and expected benefits if success is achieved.

Table 1. Hypothetical research projects for funding decision.

Parameter	Project		
	A	B	C
Annual cost of problem addressed ($000)	5,000	5,000	5,000
Research Investment			
Year 1 ($000)	200	100	50
Year 2 ($000)	200	–	50
Year 3 ($000)	–	–	50
Probability of success (%)	50-60	30-50	20-30
% Reduction in cost of problem if successful	40-50	50-60	70-80
Period over which cost reduction occurs	yrs 3-10	yrs 2-6	yrs 4-7

This economic ranking should not, of course, be the sole criterion for determining the allocation of funds amongst those projects. Issues of equity, the environment, scientific merit, international obligation, etc., may all be used to weight the overall ranking.

The purpose of this paper is to discuss several issues which are of particular relevance to biological control projects and those who conduct them. These include the identification of costs and benefits, the inclusion of uncertainty in project evaluation, dealing with non-market benefits and public attitudes to biological control.

Identifying the Potential Costs and Benefits of Biological Control Research

Crawley (1989*b*) observes that from a scientific perspective "there can be no absolute measurement of the success of a weed control project." An economist would argue that in many cases economics can assist in providing this answer. From an economic perspective a successful outcome of biological control research may be defined as the introduction of a biological control agent which has sufficient impact on the target species to generate a net economic

benefit. This benefit must be net not only of the costs of research, but also of costs associated with any adverse effects on other species which may be caused by the biological control agent. It is important to note that "economic benefit" in this context does not imply "market benefit." Biological control projects are likely to generate impacts for which market values are not available but which are, never-the-less, highly valued by society.

Scientists, whose work involves the establishment of scientific fact, frequently question the validity of *ex-ante* evaluation of research projects because so much of this type of analysis involves the estimation of future, and therefore unknown, impacts of research. In cost-benefit analysis "expert opinion" is regarded as a perfectly valid method of obtaining information on matters for which no objective data are available. In my experience, when scientists are assisted to systematically identify the expected effects of a research project, they are frequently surprised to discover that they are able to offer confident "expert opinion."

In assessing the economic impact of biological control projects–whether *ex-ante* or *ex-post*–it is essential to identify and quantify all of the effects

of introducing the agent. Where those effects are expected to lessen over time, for example where the target species develops resistance to the biological control agent or where new weeds take over its habitat, estimates of the changes in effect should be made. Possible effects include:

A. *Market Effects*

• Changes in the quantity of production
• Changes in the quality of production
• Changes in the resources needed for production
• Changes in market prices if very large increases in production are achieved i.e. elasticity effects
• Changes in benefits generated by the weed itself
• The level of resources required to implement research

B. *Non-market Effects*

• Effects on native flora and fauna
• Effects on aesthetic values
• Effects on the physical environment

To determine the relative importance of the market effects it is necessary to estimate the area presently affected by the weed, its expected rate of spread and the extent and type of damage caused. Various measures are available for determining the extent of spread and damage including ground surveys, aerial photography, statistical techniques based on the relationship between crop losses and weed density etc. Frequently, however, these techniques are extremely costly and within the constraints of the project budget it may be necessary to rely heavily on expert opinions from a range of sources.

Crop loss data, both qualitative and quantitative, and information on the resources required for production may be acquired from scientific trials on those crops, producer surveys, or in the form of expert opinion from consultants and producers. It may be possible to modify existing crop production models to incorporate the effects of the weed.

Price effects due to increased crop production are unlikely to warrant specific investigation in the context of the cost-benefit analysis of biological control. However, incorporation of existing

information may be justified if large-scale production increases are anticipated.

The non-market effects of the implementation of biological control projects may, for many projects, exceed the market effects. An *ex-ante* economic analysis of the biological control of *Clematis vitalba* in New Zealand is described later in this paper, as an example of non-market evaluation. A number of techniques exist for eliciting society's valuation of such things as the environment, which are not valued in the market-place. In essence, they involve the estimation of the amount society is prepared to pay for a chance of achieving biological control of a particular weed, either by indirect means or by asking individuals within society directly.

Uncertainty in the Evaluation of Biological Control Projects

Uncertainty is a critical factor in all research evaluation but in the *ex-ante* evaluation of biological control projects there is a particularly high element of uncertainty. Initially there is the uncertainty as to whether a potential control agent will be identified. Sandrey (1985) observed that once a possible agent has been identified there is still uncertainty as to:

• establishment and dispersal of the agent;
• population responses of the agent in the absence of its natural enemies;
• impact of native predators and parasites on the agent;
• response of plant competitors to the weakened target plant; and
• impact of local climate on the agent.

There is also uncertainty as to whether the target species will develop resistance to the control agent (Tisdell *et al.* 1984).

Harris (1980) noted that, at that time, only 10% of biological control agents introduced to Canada had produced economic benefits, although 60% of those agents had become established. In a worldwide analysis of all attempts at biological control of weeds with invertebrates and fungi prior to 1980, Julien *et al.* (1984) found that 39% of all projects were successful and 28% of all target weeds were controlled to some extent. In this study 71% of agents were successfully established. Significant differences in effectiveness, although not in

establishment, were found between world regions although these may be due, at least in part, to differences in the definition of "successful control."

Because of the high levels of uncertainty associated with biological control projects, economic evaluations which simply assess the costs and benefits of a successful outcome clearly lead to considerable distortion. In 2 *ex-ante* economic evaluations of projects aimed at the biological control of sweet brier and *Hieracium spp*, Grundy (1989) made an innovative attempt to incorporate the uncertainty associated with the introduction and establishment of biological control agents, using a decision theory approach. Grundy defined 3 scenarios:

1.) A low impact scenario where successful establishment is achieved but biological control has only a minor impact on the weed and, therefore, on production;

2.) A medium impact scenario in which the biological control agent controls the spread of the weed and reduces the vigour of some plants; and

3.) A high impact scenario where biological control is successful to the extent that the weed is no longer a major impediment to production.

The exact definition of the scenarios differed between the weeds. The economic value of the benefits arising under each scenario, including increases in production and reduction in costs of conventional control methods, were estimated for each year until a stable situation was attained.

In conjunction with scientists involved with the projects probabilities were assigned to each of these scenarios and to the likelihood that there will be no measurable economic benefit arising from the project. There may of course be non-measurable benefits in terms of scientific experience gained.

In addition, probabilities were assigned to the likelihood of the full impact of biological control being achieved in 0, 5 and 10 yrs. Thus 12 separate scenarios were defined according to the level of success and lag-time until that level is achieved and an intermediate probability was assigned to each. The probabilities estimated for sweet brier are shown in Table 2.

Streams of costs and benefits were derived for each scenario and weighted by the estimated probability of occurrence to calculate the expected streams of costs and benefits. The

normal investment criteria of net present value, internal rate of return, etc., were then estimated.

Further refinement of this approach would involve the estimation of separate probabilities for successful introduction, level of weed control achieved, development of resistance and other parameters.

This approach was certainly a step in the rational evaluation of projects of this kind although the basis on which the probabilities were defined was necessarily coarse. It provides a framework which allows the assessment of projects which have a number of potential outcomes and permits the assessments to be easily updated as more information becomes available. It also facilitates the comparison of projects deemed to have significantly different chances of success.

A major difficulty in conducting and refining the economic evaluation of biological control projects is that very few data are available on the success of biological control programs. In the absence of those data scientists are noticeably reluctant to commit themselves to probabilities which they might find difficult to defend if challenged by their peers.

A number of scientists working in the field of biological control have, in recent years, expressed the view that analysis of past successes and failures does not provide an accurate means of estimating which biological control projects will be successful in future anyway (Crawley 1989, Lawton 1989). However, even in these discussions there is confirmation of a fact which is perfectly evident when working with scientists in the economic evaluation of their research. There are intuitive checklists relating to the characteristics of the plant, the control agent, the environment and the research itself which scientists use in the process of deciding which project to undertake. Simberloff (1989) noted that "There is every reason to think that careful consideration of the biotic and physical habitat into which a species is to be introduced, plus an insightful study of its natural history will yield sounder predictions that the sorts of general models that have been attempted to date." Lawton (1989) acknowledges that there are "general, rather crude, guidelines that all modern practitioners follow...".

Harris (1989) argued that scientists must collectively continue to assemble and analyse

data to refine those rules which have been provided by analysis of past biological control projects and, presumably to add to them. In terms of improving the quality of economic evaluation possible, it is equally important that scientists accept the need to assign the best

possible probabilities to the outcomes of research in the light of their collective experience. This is a much more useful approach than declining to do so because there is insufficient information available to accurately define the probability distribution.

Table 2. Probabilities of successful biological control of sweet briar.

Level of Impact ($ Per Annum)	Lead Time Period (yrs) From Release to Full Impact			Total Probability
	0	5	10	
Nil ($0)	0.025	0.175	0.3	0.50
Low ($100,000)	0.0125	0.0875	0.15	0.25
Medium ($350,000)	0.01	0.07	0.12	0.20
High ($2.5 Million)	0.0025	0.0175	0.03	0.05
Total Probability	0.050	0.35	0.60	1.00

Perhaps the most important contribution to the refining of evaluation of research generally will be the changing attitudes of scientists themselves. The economic analyst cannot formulate expert opinions on the importance of each of the elements of uncertainty in a new project. Such estimates can be made only by those integrally involved in the development and monitoring of projects. Economists can, however, help develop those checklists from the purely intuitive and individual to a more formal framework for use in project evaluation.

Economic Evaluation of Research with Non-market Outcomes

Where the targets of biological control projects are weeds which invade productive land, the benefits of research can be estimated in terms of the market value of production loss. However, where the target weed is one which is destroying a resource such as indigenous forest, market valuation of the loss is not available, although many members of society clearly value it highly.

The value which individuals place on a non-priced resource may have several components including:

- *Use value:* The value placed on the current use of a resource.
- *Option value:* The value of retaining the option of future use of an irreplaceable, unique resource even if there is no intention of taking up that option (Weisbrod 1964)

- *Preservation value:* The value of knowing that a resource exists (existence value) and the value of preserving it for future generations (bequest value) (Kerr 1985)

The value of a particular research project may include any or all of these values. In the case of a weed degrading indigenous forest, all 3 values are at risk.

Greer and Sheppard (1990) concluded that a method known as contingent valuation (*CV*) is most suitable for valuing projects whose object is the prevention of such degradation.

This method estimates the value that an individual places on the undegraded resource by directly eliciting the individual's willingness to pay (*WTP*) to prevent the resource degradation. The value calculated by this method reflects the sum of the individual's use, option and preservation values.

In the case of a widespread resource such as native bush, it is probable that the most satisfactory method of approaching individuals will be by means of postal survey. A nationwide personal interview approach is extremely costly. In a mail survey, two approaches are possible. Open-ended questions may be asked to ascertain the individual's *WTP*, or the respondent may be asked to accept or reject a single offer. This accept/reject method is known as dichotomous choice.

The dichotomous choice approach is much easier for respondents to understand and react to. For an individual, attempting to place a value

on a resource, not previously thought of in monetary terms, is a daunting prospect. Being asked to accept or reject a single offer provides the respondent with a reference point.

Once data have been obtained by asking a large number of individuals to accept or reject bids which vary within a specified range, models of qualitative choice such as logit or probit models are used to infer the individual's *WTP* from the pattern of acceptances and rejections obtained in the survey.

Two sources of bias may affect estimates of *WTP* obtained using contingent valuation techniques. As the monetary valuation of resources will be an unfamiliar exercise for most respondents, their stated *WTP* may be inaccurate if they do not take the time to consider the implications of their decision. Secondly, if they believe that understating their *WTP* will result in their incurring a lesser cost if the project is implemented, they may be tempted to do so.

However, Kerr (1985), in reviewing a number of studies which have attempted to verify estimates obtained by *CV* techniques, concludes that provided care is taken in the use of the technique, contingent valuation can provide meaningful estimates of how proposed changes in non-market goods are valued.

The evaluation of research into the biological control of *C. vitalba* (Greer and Sheppard 1990) was the first economic evaluation of the biological control of weeds in New Zealand to use the non-market contingent valuation approach.

In this study a random sample, stratified on the basis of geographical location, of 3,000 adult New Zealanders was sent questionnaires. Respondents were first asked to accept or reject a token $1 bid to determine whether they were prepared to "play the game." They were then asked to accept or reject 2 levels of a one-off taxation payment. These "bids" were randomly selected amounts between $2 and $100–the upper limit having been established during the pretest of the questionnaire.

The questionnaire also provided sufficient information about the problem to enable respondents to make a rational decision on their *WTP*. As postal surveys should not include lengthy preambles which discourage respondents, it was decided that photographs depicting similar areas of bush with and without

C. vitalba would be an appropriate method of demonstrating the damage caused by the weed. Surprisingly, despite the amount of scientific research and control effort into this weed, a matching set of photographs could not be obtained from any of those involved. The 2 photographs used were eventually obtained from separate sources.

It was also necessary to inform respondents that the payments being suggested were to fund research which does not have a certain successful outcome. In the absence of any probability information, the phrase "relatively small" was used with the reluctant concurrence of the scientists concerned. Exactly what this phrase conveyed to respondents is not known, and it is likely that many under-rated the project's chances of success.

Over 90% of respondents to the survey were prepared to make at least a token payment of $1 to fund the research. The main reasons cited by those who would not do so were extreme economic hardship and reluctance to have biological control agents introduced to New Zealand.

The logit model fitted to the data obtained is shown in Fig. 1 and has the mathematical form:

$$L_i = 1.191 - 0.03141 \; Dollars_i \quad N = 2,332$$
$$(12.99) \qquad (-18.13)$$

where $L_i = \log_a(P_i / [1-P_i])$ and P_i = the probability that any randomly chosen individual will be willing to pay $DOLLARS_i$

Integration of this function with respect to the variable *DOLLARS* gives the benefit accruing to the average respondent if the research program is implemented–in this case, $46.37 with an approximate 95% confidence interval of $40.65-$53.03.

The response rate, 46.1%, to this survey, although high for a survey of this type, may give rise to doubts as to whether this result represents the *WTP* of the population as a whole. Two other possibilities exist. Firstly that non-respondents are not interested at all and would pay nothing for this type of research. Alternatively non-respondents could actually resist the introduction of biological control agents, and would therefore require compensation to maintain their existing levels of welfare if the research project were to be

implemented. The latter possibility is, however, unlikely since those individuals would be highly motivated to return their questionnaires stating their views. A large proportion of those who were strongly in favour of the project wrote substantial notes on the subject.
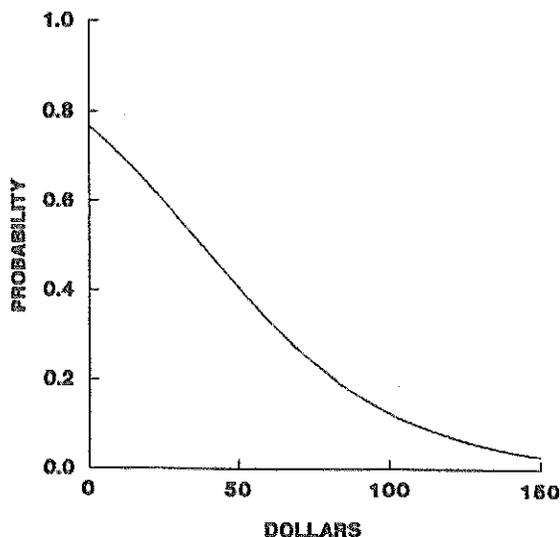

Figure 1. Willingness to pay for research into biological control of *Clematis vitalba*.

Consequently it was estimated that the true willingness to pay of New Zealand society for this research lies between the upper bound defined by the sample *WTP* and the lower bound estimated by adjusting the estimated *WTP* to reflect the assumption that the sample non-respondents, and therefore a similar proportion of the population, would be unwilling to pay anything. Thus it was estimated that New Zealand society as a whole would be willing to pay between $44-111 million for a "relatively small" chance of controlling *C. vitalba* by biological means.

Non-market valuation of research projects, while relying less heavily on input from the scientists involved, does require the provision of information about the problem and the research to individuals asked to make valuation decisions. Scientists considering new research projects should be able to provide that information in support of those projects.

Public Attitudes to Biological Control

Only a small proportion of respondents to the *C. vitalba* survey (1%) were unwilling to pay for this type of research because of their reluctance to have new species introduced to the country. Many more, however, expressed a desire for reassurance that the biological control agents would not have any undesirable effects. This concern has been echoed by respondents to 2 subsequent surveys conducted in New Zealand.

Sheppard and Urquhart (1990) conducted a survey into public attitudes to the biological control of pests in New Zealand. They found that 50.8% of respondents believed that biological control was not a good method of pest control. The main reasons given for this belief were that the agent itself becomes a problem and that the consequences of such introductions are not known.

In a survey concerned primarily with public attitudes to genetic engineering, Couchman and Fink-Jenson also found that 56% of respondents were concerned about biological pest control. Sixty-four percent of these were worried or seriously worried about it. Despite this, 85% of those surveyed believed that biological control is a worthwhile area of research for New Zealand.

It is apparent that, although there have been no instances in New Zealand when introduced biological control agents have damaged species other than the intended target (Syrett, P., personal communication, 1990), there needs to be more effort put into the education of the public if research of this type is to receive unqualified support.

Conclusions

Economic analysis can be of value to biological scientists in several ways.

Science funding in New Zealand has moved into the competitive market in which each research project will be accepted or rejected according to a number of criteria, including its expected economic return. Sound economic analysis, based on the best possible information, will assist decision makers to make better decisions on the allocation of science funding.

Analytical techniques are available for dealing with many of the aspects of research which the scientific fraternity too frequently regards as being beyond the scope of such analysis. While it is true that economic analysis based on estimates and expert opinion is far from perfect, it is certainly more convincing to those outside the research arena than research resource allocation on the basis of intuition.

Cost-benefit analysis of biological control research not only permits more rational allocation of funds amongst such projects but also provides scientists themselves with a framework for looking objectively at all the probable ramifications of their research. It is a tool which should be used as in the early stages of decisions as to which projects should be put forward for funding.

Research into public attitudes to biological control provides information which will assist the researcher to approach the selection and design of research projects in a socially sensitive manner. It can provide insight into which weed problems the public regards as most serious and pinpoint areas of public concern about research which should be addressed by the scientists involved. Research is not an activity to be conducted behind closed doors. Rather it is activity carried out for the ultimate benefit of society and within the context of society's objectives.

Armed with this information, scientists may well discover opportunities to enlist considerable public support for their research, thus adding greater strength to their arguments for funding. For example, studies have shown both that there is considerable public concern about the incidence of chemicals in the environment (Greer and Sheppard 1990) and that there is considerable interest in biological control (Couchman and Fink-Jensen 1990), tempered with concerns about its safety. The onus rests with the scientist to demonstrate that biological control is a safe solution and that it is a good investment.

Finally, if the scientist is not prepared to be involved in the provision and refinement of expert opinion as the basis of economic analysis, then the economist will have to find that information elsewhere, to the undoubted detriment of the quality of the economic analysis of the research.

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