ECONOMIC ISSUES AND THE PROTECTION OF ENDANGERED SPECIES

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Introduction

This paper attempts to blend economic theory with environmental facts and social circumstances. The basic theme is the application of the standard cost-benefit or efficiency criteria of economics and the decision analysis technique to the problem of managing the Eastern Barred Bandicoot as an endangered species. The objective is to use the Eastern Barred Bandicoot as a case study, elaborate on the tools used in economics within endangered species programs, and show how they can link with modelling of biologists.1

Endangered species programs may not produce the intended results, or may be undertaken too late, because the human factors contributing to the extinction process can be difficult to address. The social costs of human activity may be greater than the private benefits but not recognised because of externalities. Species and habitat can be seen as a public good. Property rights may also be an issue with habitat, e.g. along road reserves, being subject to several management authorities each with rights to undertake certain activities.

The social costs of protecting species, or one population, may seem exceedingly high especially on the urban fringe or near a mining site, when the direct economic benefits of development are well-known, though often greatly over-stated, and the non-market values are under-stated. However, extinction of a species is quite simply irreversible. Once lost it is not possible to find substitutes for all the services and benefits it provides, in both human and ecosystem terms. If future generations value the species more than the present generation, which seems likely as the bandicoots become scarcer, benefits of present-day development will be over-valued and future preservation benefits undervalued. Further, the significance to the ecosystem of the niche occupied by the species, and of cumulative losses of other species that may follow, may not be apparent. Because not all decisions include all the human and ecosystem benefits of preserving the bandicoot, the general conclusion is that the species has been consistently undervalued and as a result, its habitat exploited.

1The views expressed in this paper are those of the authors not the Department of Conservation and Environment or other involved in recovery effort.
In terms of the economics of threatened species protection, the urgent need is for biologists to act on their knowledge that the extinction process is largely human-driven. They need to ensure that this is addressed as thoroughly as are the biological and technical aspects of protection and recovery plans. This message is all the more powerful for originating from amongst biologists. In offering a new paradigm for endangered species protection, Clark et al. (1991) argue that for success recovery programs must focus on three dimensions apart from the biological. These are organisational, power/authority, and socio-economic. Failure of recovery programs can be often attributed to biologists consistently down-playing these dimensions. The consequences are likely to be extinction and/or failure of a poorly constructed preventative program which may cost millions in later years. An expensive captive breeding program may continue unnecessarily for years if the causes of species decline, and hence problems associated with re-introductions, are not properly addressed.

Economists and other social scientists have a crucial role to play here, provided that their work is directed to finding the keys to managing the human threats and to clarifying the management choices available.

The four dimensions of endangered species protection

Biological/technical factors. Characteristics of the species and its habitat usually receive the most attention in management plans. Even here, information available can be limited and not easily obtainable. Management success depends on understanding factors such as life history characteristics, habitat requirements, scarcity (autoecology), demographics, genetics, dispersal (population ecology), predator/prey relations, competition, biotic and abiotic interactions (community ecology) (Reading et al 1991). Uncertainty over these factors can paralyse action or lead in the wrong direction. Some progress has been made in incorporating uncertainty into modelling techniques such as population viability analysis which in turn can be integrated within a decision analysis framework (Maguire 1986). A critical issue given the biological uncertainty is organisational - constantly reviewing progress against objectives, and preserving sufficient flexibility to change strategy if necessary.

Authority/power. The success of an endangered species program may depend upon: ensuring that agencies with land management responsibilities undertake agreed actions and obtain the commitment of all relevant staff to them, reducing fear of landholders that allowing temporary access will lead to permanent change in property rights, winning the support of landholders or community groups for the program, involving local communities without their agendas taking over the program. Rivalries between different bureaucratic centres for control of parts of the program must also be addressed.

Organisational. Clark et al. (1989) state the problem succinctly: 'The inability of organisations to solve dilemmas, to examine their own structures and management, and to change themselves for more effective, efficient, and equitable performance is seen as the major obstacle to improved recovery programs.'
Social and economic. The role of public support in the success of recovery programs is emphasised. Potential support, or opposition, depends on values and attitudes towards this species, endangered species in general and the relevant authorities implementing the program are crucial. The costs of species conservation are usually emphasised above their value because the latter is difficult to quantify. The principle of the safe minimum standard of avoiding extinction unless the social costs are too high is cited (Reading et al 1991).

This approach to the four dimensions is valuable because it gives a proper context for economic evaluation. Economic evaluation becomes an integral part of the program, not an add-on required by another authority. The approach helps focus on the right economic questions to address, how the evaluation fits into the whole program. The evaluation in turn can assist in determining whether a program is worthy of further financial support, which direction it should take, and priorities within the program.

Policy and legislation give, a mandate for the protection of species on the verge of extinction like the Eastern Barred Bandicoot. The economic problem is to optimise resource allocation in order to achieve the conservation objective, not to decide whether or not the processes leading to extinction should or shouldn't continue. A safe minimum standard rule (Bishop 1978, Chisholm 1988) is particularly appropriate in dealing with the uncertain events surrounding endangered species and facing irreversible loss. A safe minimum standard of protection should be maintained unless the social costs of doing so are judged to be too high.

Population viability analysis

If extinction is seen as a process rather than as an end-point, then having available tools to predict the outcome of different events and management alternatives is very important. Population viability analysis is one such tool.

Historically wildlife managers have relied on calculations of average birth and death rates to forecast the future of populations. They may have also made possibly educated guesses as to the impact of random environmental, demographic and genetic events. However, such stochastic events critically determine the future of small isolated populations which may have little capacity to recover from a sudden, but normal, drop in numbers. Population viability analysis, developed over the last 10 years, models both the 'deterministic and stochastic forces determining the fate of a population' (Lacy & Clark, 1989). It derives the probability of survival over a given period under different scenarios. Population viability analysis can be used to identify cumulative impacts, the minimum viable population size, the threats which need to be addressed and the efficacy of alternative management options. Data required are probabilities of different random events, and estimates of mean and variances of population size, fecundity, mortality and other population parameters.

Modelling using population viability analysis in 1989 predicted a 25% annual decline in numbers of Eastern Barred Bandicoot in the wild, and extinction by 1996 (Lacy & Clark 1989). These results alerted the program managers to the urgency of its situation and to the important management issues. However, despite its obvious importance, PVA has not been used since then in the program. It was beyond the scope of this paper to undertake a further population viability analysis, though the need for it is clear.
Decision analysis offers an explicit framework for dealing with uncertainty about the political, scientific and financial events affecting the management program. In recovery planning, an explicit decision framework is necessary because saving endangered species is often a crisis situation where neither time nor money is sufficient (Maguire 1986). This technique is particularly useful for recovery planning where decisions are made without adequate information and where each decision can present a conflict of one sort or another. Incorporating probability estimates generated by population viability analysis, decision analysis was used in 1989 to develop appropriate management strategies (Lacy and Clark 1989). However, as then acknowledged, there were a number of significant omissions from the analysis, such as using sensitivity analysis to determine which values appear to be the most critical, and including the economic costs of the respective management interventions. Clark and Seebeck then pointed to the need to ‘repeat the process with more attention being paid to management actions as they change those factors affecting the probability of population persistence’. This paper contains the first use of decision analysis in the program since 1989.

Elicitation of subjective probabilities is the preferred technique owing to the ‘crisis’ facing the Eastern Barred Bandicoot. Studies on subjective probabilities and their use in decision making have been conducted by researchers in many fields. The principal reason for using subjective probabilities is that it has been a fundamental element of theories of decision making under uncertainty, and a working knowledge of how people make probability judgements is essential for the application of such theories (Norris & Kraper 1990).

The cost-benefit framework

Cost-benefit analysis can be used concurrently with decision analysis to provide a rational framework for choosing between worthwhile outlets for public expenditure. Though the practical application of benefit-cost analysis is subject to a number of serious limitations, that should be made explicit, it is nevertheless, most useful in providing a systematic comparison of all the associated benefits and costs of all alternative courses of action.

In the absence of relevant data, this paper will also attempt to apportion all the economic costs and benefits of the various management strategies or scenarios. Unfortunately, the basic problem of efficient utilisation of resources does not disappear simply because there is a need for the preservation of an endangered species. Conservation involves opportunity costs. With the current budget as it is, any decision to proceed with any one project means other possible undertakings are foreclosed. Each possible management strategy must be assessed to determine the extent to which it generates benefits in excess of its costs to society. However, the cost-benefit analysis must address resource allocation within the endangered species program, not whether the program goes ahead. It cannot be treated an optimising one where maximum social benefits might result from extinction.
The most fundamental problem with applied benefit-cost analysis is the analytical treatment of the benefits and costs. In brief, the decision maker cannot consider only aggregate benefits and costs, but must examine the difficult issue of who receives the benefits and who bears the costs of any of the proposals. Because the gainers and losers from any management action in general will not be identical, the decision-maker must decide the magnitude of the net gains and losses among various groups and individuals, and then somehow balance the desireable distributional effects amongst all the parties who are likely to be affected by the action. For example, the construction of double fencing and planting provides obvious benefits for bandicoot habitat improvement but, at the same time, landowners may benefit from improved shelter benefits. On that account, how then are the total costs allocated equitably amongst all the parties concerned?

The Eastern Barred Bandicoot Recovery Program

This paper examines the case of the Eastern Barred Bandicoot. Once widespread across Victorian grasslands and Tasmanian woodlands, by the 1950s its Victorian range had contracted markedly. Since then it has become confined to three small (<200ha.) sites on the outskirts of Hamilton in western Victoria. The Tasmanian population is doing somewhat better. Biologists believe that the differences between the two populations are significant. Survey and monitoring of the Victorian population began in the 1950s, active management did not begin until the 1980s.

Causes of the decline include: the loss of native grassland and associated invertebrate food sources, predation by foxes and cats, and use of pesticides. Factors associated with the continuing decline once the population near Hamilton fell below 1000 include predation, road kills, pesticides and disease. The very high reproductive rate for the Eastern Barred Bandicoot, the highest of any Australian mammal, mean that its prospects are sound if habitat can be made secure from these threats.

Once it began, the management program concentrated on habitat enhancement (double fencing and hard shelters for security), promotion of domestic cat control to residents of Hamilton, fox and feral cat control, measures to reduce road kills, and improved population monitoring.

The seriousness of the decline, and the inability to control all threats, led to a captive breeding program starting in 1988. Fencing part of the Hamilton Community Parklands occurred in 1989 to provide for a semi-captive population. Establishment of the Community Parklands population has been a success, with upwards of 50 animals now present. A semi-captive population, now between 40 and 80 animals, has also been established at Gellibrand Hill. Captive populations are now maintained at Gellibrand Hill, Healesville Sanctuary and Melbourne Zoo. The captive breeding program has not yet produced the results expected.

A turning point in Eastern Barred Bandicoot recovery efforts was reached at the end of 1991. The monitoring data revealed a crisis. 1991 monitoring showed that the earlier 25% estimate of decline was conservative. It is estimated that no more than between 20 and 50 animals remain in the wild. The likelihood of Eastern Barred Bandicoot becoming extinct in the wild within a very short time is overwhelming.
At the end of 1991, the structure of the program was urgently over-hauled: a new planning process initiated and community involvement increased through a Friends of Eastern Barred Bandicoot group. It is useful to treat the program that is now emerging as a new one. Key immediate objectives of the program, in order of priority, are to now:

a) capture the additional animals necessary to maximise genetic variability in the captive population.

b) produce as many animals in the captive breeding program as can be absorbed back into semi-captive populations and successfully re-established in the wild.

c) protect and expand the semi-captive populations

d) identify and prepare suitable re-introduction sites in suitable habitat across western Victoria

e) support community efforts to address the threats to the wild sub-population in the Chatsworth Rd/Lochberr Estate area of Hamilton. These threats must be addressed if the Eastern Barred Bandicoot is to be successfully re-introduced in the Hamilton environs. The success of such measures will also determine the chances of survival of the remaining wild animals until re-stocking.

Methodology

Decision analysis is now applied to captive breeding and re-introductions. Management of the semi-wild populations and of the remaining wild population is not addressed here.

The probabilities (numbers of young bandicoots bred, extinction probabilities etc.) were discussed at a short meeting of Eastern Barred Bandicoot program managers, and later modified by the authors after further consideration.

The decision analysis in each case is followed by a consideration of wider social costs and benefits.

The procedure can be summarised as follows:

1) Identify current and possible future threats.
2) Define alternative management strategies that are available.
3) Provide an estimate of the probabilities that each of the threats will occur.
4) Estimate the probabilities each of the respective management controls that will be unconditionally effective.
5) Provide an estimate of the probability of extinction (E(pE)) in the light of the different number of events and strategies.
6) Analyse the sensitivities of the various estimates to their changes in values.
7) Determine the types of spillovers and estimate their costs or benefits wherever possible.

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2 The authors have been involved with the program only since December 1991.
Captive breeding

The objectives of captive breeding are to ensure the survival of the captive population until wild populations are secure, and to produce the maximum number of many young bandicoots that can be absorbed by the re-introduction program.

An interim plan for captive breeding involves 18 breeding pairs with a total of 82 pens spread across four locations. Breeding pairs are kept in the one pen, with offspring being housed in individual pens under intensive management for 4 months after achieving a weight of 300g. The young are then 'hardened' in transition pens for up to 4 months. For each 1.8 pairs, an additional founder is also housed individually to replace any non-viable animals.

The ultimate aim is for a captive breeding program with 175 Eastern Barred Bandicoots in captivity; funding is being sought for this proposal. This would require a total of 200 pens in the same four locations.

Other alternatives should also be considered systematically. One is to reduce the number of locations to three or less in order to save $50,000 or more each year but accepting an increased risk of catastrophe such as disease wiping out the populations.

Another alternative is to alter the management approach in order to reduce likely outlays, with each reduction having a corresponding adverse effect on probability of extinction. One option may be to house two female bandicoots in the one pen, and keep fewer males.

Decision analysis and Captive breeding

The above alternatives have been incorporated into figures 1a and 1b. In the figures, a square indicates a decision that has to be made, a circle indicates a random event. The probability of extinction is \( pE \); it varies for each management option and the probability of the random event which is shown as \( P \). \( E(pE) \) gives the expected probability of extinction those values that are underlined in figures 1a and 1b are the ones that have been changed.

The first decision choice addressed here is whether to have three or four captive breeding locations. The risk of catastrophic events such as disease increases with fewer locations. For each location, random probabilities are assigned to the number of young bandicoots produced falling within certain ranges. If properly managed, the 43 pairs of bandicoots in 200 pens could produce three or more young in each of three litters a year. A 0.8 probability, \( p \), is given to more than 387 young being reared to 300g weight. The \( p \) for the number of young produced falling in the range of 193-386 young is only 0.1, and for less than 192 also only 0.1. The associated probability of extinction, \( pE \), if more than 387 young are produced is 0.2; for the other two ranges it is 0.7 and 0.85.
Figure 1a - CAPTIVE BREEDING OPTIONS

<table>
<thead>
<tr>
<th>Number of young bred</th>
<th>p</th>
<th>pE</th>
<th>E(pE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;387</td>
<td>0.8</td>
<td>0.2</td>
<td>0.315</td>
</tr>
<tr>
<td>&lt;192</td>
<td>0.1</td>
<td>0.7</td>
<td>0.45</td>
</tr>
<tr>
<td>&gt;387</td>
<td>0.6</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>&lt;192</td>
<td>0.2</td>
<td>0.7</td>
<td>0.45</td>
</tr>
<tr>
<td>&gt;162</td>
<td>0.8</td>
<td>0.7</td>
<td>0.74</td>
</tr>
<tr>
<td>&lt;80</td>
<td>0.1</td>
<td>0.85</td>
<td>0.78</td>
</tr>
<tr>
<td>&gt;162</td>
<td>0.6</td>
<td>0.7</td>
<td>0.78</td>
</tr>
<tr>
<td>&lt;80</td>
<td>0.2</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>&gt;270</td>
<td>0.6</td>
<td>0.5</td>
<td></td>
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<tr>
<td>&lt;135</td>
<td>0.1</td>
<td>0.8</td>
<td>0.65</td>
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<tr>
<td>&gt;270</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>&lt;135</td>
<td>0.15</td>
<td>0.8</td>
<td>0.68</td>
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<tr>
<td>&lt;135</td>
<td>0.35</td>
<td>0.9</td>
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Figure 1b - CAPTIVE BREEDING WITH CHANGES TO PROBABILITIES

<table>
<thead>
<tr>
<th>Number of young bred</th>
<th>p</th>
<th>pE</th>
<th>E(pE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;387</td>
<td>0.8</td>
<td>0.4</td>
<td>0.47</td>
</tr>
<tr>
<td>193-387</td>
<td>0.1</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>&lt;192</td>
<td>0.1</td>
<td>0.85</td>
<td></td>
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<tr>
<td>&gt;387</td>
<td>0.6</td>
<td>0.4</td>
<td></td>
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<tr>
<td>193-387</td>
<td>0.2</td>
<td>0.7</td>
<td>0.54</td>
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<tr>
<td>&lt;192</td>
<td>0.2</td>
<td>0.8</td>
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<tr>
<td>&gt;162</td>
<td>0.7</td>
<td>0.7</td>
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<tr>
<td>81-161</td>
<td>0.15</td>
<td>0.85</td>
<td>0.76</td>
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<tr>
<td>&lt;80</td>
<td>0.15</td>
<td>0.95</td>
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<tr>
<td>&gt;162</td>
<td>0.6</td>
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<tr>
<td>81-161</td>
<td>0.2</td>
<td>0.85</td>
<td>0.78</td>
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<tr>
<td>&lt;80</td>
<td>0.2</td>
<td>0.95</td>
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<tr>
<td>&gt;270</td>
<td>0.6</td>
<td>0.5</td>
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<tr>
<td>135-269</td>
<td>0.1</td>
<td>0.8</td>
<td>0.65</td>
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<tr>
<td>&lt;135</td>
<td>0.3</td>
<td>0.9</td>
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<tr>
<td>&gt;270</td>
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<tr>
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<td>0.15</td>
<td>0.8</td>
<td>0.68</td>
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<td>&lt;135</td>
<td>0.35</td>
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The expected probability of extinction within 25 years, $E(pE)$, is derived by multiplying the random event probability by the probability of extinction ($p$ and $pE$), and adding the products. In the case of four locations, the $E(pE)$ of 0.315 is derived in the following manner:

$$E(pE) = (0.8)(0.2) + (0.1)(0.7) + (0.1)(0.85) = 0.315.$$  

The above results means that the probability of extinction of the bandicoot during the next 25 years given four locations yielding 387 or more young, is about 31.5%.

By contrast, the $E(pE)$ for three or less locations is 0.45. This result is consistent since we can expect a fewer number of bandicoots to have much less chance of lasting 25 years or so.

The sensitivity of these results can be tested by changing $p$ or $pE$. If the $pE$ changes from 0.2 (figure 1a) to 0.4 (figure 1b) when more than 387 young are produced, then $E(pE)$ becomes 0.47 for four locations and 0.54 for three locations. Under this probability scenario, $E(pE)$ is now less sensitive to number of locations, and it is less likely that managers will proceed with the fourth. Including the fourth location in the program in figure 1b reduces $E(pE)$ by 0.07 by comparison to figure 1a where the additional location reduced $E(pE)$ by 0.135. Once the manager's preference function for $S$ and reduction in $E(pE)$ is determined, the point at which they are indifferent to an additional site can be determined.

The second decision addressed is the overall size of the captive breeding program, expressed as number of pens. The plan at present calls for 200 pens with 47 breeding pairs while the interim measure is for 84 pens with 18 breeding pairs. Figure 1a shows that $E(pE)$ falls from 0.74 to 0.315 if the larger program is implemented over four locations. The average expected probability of extinction is very sensitive to the event of achieving an excellent result, that is producing more than 387 young bandicoots, in four locations with 200 pens. This is a highly significant result for the overall management program. Reducing the number of pens from 200 to 84 pens results in at least a 40% increase in the probability of extinction (given the probabilities assigned here).

With 84 pens, the overall probability of extinction is insensitive to the probability of achieving excellent, good or bad results. This is shown by changing the subjective probabilities for each of these outcomes for the four location option. If the respective probabilities are changed from 0.8, 0.1 and 0.1 respectively to 0.7, 0.15 and 0.15, the associated $E(pE)$ only changes from 0.74 to 0.76. The small difference indicates that changes to probabilities leads to only marginal changes in the expected probability of extinction.

Housing two or more females in one pen, and keeping fewer males, is another possible decision alternative. Figure 1a shows the effect of using 84 pens in this way. The two options which both have 84 pens spread over four locations are compared here. By increasing the number of females from 18 to 30, and reducing males from 18 to 5, it is possible to increase numbers of young bandicoots from over 162 to over 270. However, the uncertainties associated with breaking the usual pair bonding of males and females are estimated here to decrease the probability of an excellent result from 0.8 to 0.6; the risks increase the probability of outright failure increase from 0.1 to 0.3. If successful, the strategy will have a lower $pE$ than the pair bonding approach (0.5 compared to 0.7). The results show that $E(pE)$ falls from 0.74 to 0.68.
Costs and benefits of captive breeding

Costs of captive breeding

Capital cost including pens, vehicles and veterinary equipment total $1,075 per pen. Cost of land is not included. If it was known that the pens were to be later used for captive breeding of other species, the capital costs attributed to the Eastern Barred Bandicoot program could be reduced. Recurrent costs including keeper's salaries, feed, vehicle running costs, veterinary services etc. total $1,496 annually per space. For 200 pens, net present value (NPV), using a 4% discount rate over a project life of five years, is $1,600,000. For 84 pens, NPV is $672,000.

Spillovers

There are some spillover effects associated with the captive breeding program. Whether or not the future of the Eastern Barred Bandicoot is secured in Victoria depends on the captive breeding program; hence the social values associated with Eastern Barred Bandicoot are dependent on its success.

The number of young bandicoots produced will also determine the choice of re-introduction site. The spillover effects associated with each site are addressed in the next section.

Positive Spillovers

The total value that the individual places on the EBB is a combination of non-consumptive and indirect-use values. The indirect-use value, is, where many people never have any direct contact with the species in its natural habitat, but do derive satisfaction from indirect contact with it. Among other activities for the EBB, there is the educational quality of people reading about the EBB and what is involved with protecting it as an endangered species. Another form of indirect-use value arises from the captive breeding research, i.e. having a primary interest in the physical attributes and biological functioning of the species. This type of value is expressed as Scientistic (Kellert 1980). Empirical studies on the non consumptive uses as well as the option and existence values of wildlife, indicate that these values may be significant.

The contribution of the Bandicoot program to environmental education in Victoria can be expected to continue. Bandicoot conservation makes a unique contribution to environmental education because it links together several land use themes - endangered species conservation, habitat restoration, predator control, urban-rural interface - and illustrates their impact on wildlife species. The program has led directly to the formation of the Vox Bandicoot theatre group which is very popular in schools. Hamilton Institute of Rural hearing also uses EBB in its educational programs.

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3Cost estimates are preliminary.
By increasing statewide awareness of the fact that the EBB is listed as an endangered species, and that there is a captive breeding program for it, it is quite feasible to expect some people to place higher values on its preservation and existence.

Although no surveys have been done, Victorians would probably value a captive population based on Victorian Bandicoots only more highly than one interbred with introduced Tasmanian animals. In order to maintain a population in Victoria, whatever its composition, a program roughly similar in cost to the present one would be necessary. To fund the entire program (NPV -$1,616,000), adult Victorians would have to be prepared to make an average one-off payment of less than $1. A contingent valuation study could possibly assist management planning by testing these different values.

The use values for the EBB will be difficult to arrive at since individuals do not actively interact with the species. For example, bird watching or hunting are examples of activities that may be used for the purposes of generating some type of value. The EBB does not generate any such use at this moment which can be expressed in this light.

**Negative Spillovers**
There do not appear to be very many negative spillovers to be raised other than the opportunity cost of funds associated with the captive breeding program. This is the most important issue of all, because environmental policies must take their place in the context of other demands on scarce resources, such as the current Victorian budget. The essential point made by community activists at present, is that the amount of resources (particularly funds) is perceived by the general community as significantly too high in the light of the well known consensus that the economy is in a recession and that any funds used for the captive breeding program is at the enormous expense to the rest of society. However, ascertaining at what point the community would be indifferent between the population security of the bandicoot, which the captive breeding program is an integral part of, and the 'economic viability' (presumably jobs) the community demands is open for considerable debate and discussion. However, with the perception that the captive breeding program is absorbing substantial opportunity costs, the publics involvement and support, in all aspects of the species will begin to diminish.

**Re-introductions**
If the captive breeding follows the interim plan, there will be a minimum of 160 young Bandicoots available for release to the wild or to the semi-captive populations. In order to clarify options about the possible release sites in the wild, the assumption is made that the animals, or an equivalent number from the semi-captive populations, will be released to the wild. However, should fewer than 40 young be 'hardened' for release, it is unlikely that re-introduction to the wild would proceed.
Realistically, at most two sites are to be chosen as release sites for 1992 or 1993 given that survival chances are greater for a larger number of animals released together, than small numbers. Also the fewer sites there are, the smaller the costs of monitoring of their fate. The likely options for re-introduction sites over the next 12 months are:

- Chatsworth Rd/Lochberr Estate only
- Cobra Killuc State Wildlife Reserve only
- Cobra Killuc and Chatsworth Rd/Lochberr Estate

There are costs associated with delaying the choice of site. Once site(s) are chosen, predator control, dealing with other threats, and liaison with landholders can begin. There is also a pressing need to test the re-introduction process so that the size of the captive breeding program can be determined. The captive breeding program must be able to endure the loss of animals while re-introduction techniques are being developed and perfected. Should another site with extremely favourable characteristics become known within the next few months, and the costs of delay are not significant in preparing it for re-introduction, the decision could be reviewed.

Cobra Killuc Nature Reserve near Mortlake in Western Victoria is a large area of public land within the former range of the Eastern Barred Bandicoot which retains the original vegetation. Foxes would be the main threat to re-introduced bandicoots. An effective control program will require the co-operation of neighbours on an annual basis.

Chatsworth Rd/Lochberr Estate is on the eastern fringes of Hamilton. At Hamilton to date, it has not been possible to control the threats to Eastern Barred Bandicoot. There is virtually no chance of the wild population surviving, and a small chance that if the threats to Eastern Barred Bandicoot are addressed that some animals will still remain if re-stocking is possible within 12-24 months.

Several factors make success in addressing the threats to Eastern Barred Bandicoot at Hamilton more feasible than in previous years. Firstly, the effort can concentrate on the Chatsworth Rd/Lochberr Estate area. Most animals are located here, and key community activists live here or are involved in protection efforts here. Secondly, the Companion Animal Act will be soon passed by State Parliament and will give a boost to efforts to introduce responsible pet ownership in Hamilton. Thirdly, the Friends of Eastern Barred Bandicoot has recently been established and should act as a focal point for the recovery effort.

One difficulty is that Eastern Barred Bandicoot numbers are at perilously low levels, and without re-stocking from captive sources, cannot be expected to recover. A second difficulty is that the answers to dealing with the complex of threats are not clear. Major factors involving human activity are difficult issues to resolve; these include predation by domestic cats and dogs, destruction of habitat, pesticides and road kills. Other threats such as disease, predation by feral and native animals (foxes, birds of prey and snakes), are not directly related to human activity.
Funding at Hamilton by DCE has been at a high level for several years, particularly for habitat development. However, fewer DCE resources will now be available because priorities in the program have necessarily shifted to captive breeding. Because of its unlikely survival, the wild population at Hamilton can no longer be seen as central to the recovery effort. Consequently, any resources from DCE will be directed towards community efforts which, while possibly assisting the remaining wild animals, address the problems which must be overcome if re-introductions are to occur at Hamilton. Decisions are needed on the type of support to give, whether directly to a community group or in support of particular actions.

*Decision analysis and re-introductions*

Figure 2 shows the probability of extinction for the Chatsworth Rd/Lochberr Estate area, the Cobra Killuc area and the combined areas with more, and less, than 80 bandicoots released. For this case, there are two possible events - that is, over 50% of the released bandicoots either do or do not survive after 12 months. The estimated result, \( E(pE) \), for 80 or more bandicoots released at Chatsworth Rd/Lochberr Estate is 0.49. If fewer animals are available to release, \( E(pE) \) increases to 0.65.

Release of animals only at Cobra-Killuc decreases \( E(pE) \), in comparison to Chatsworth Rd/Lochberr Estate area, by 0.11 if more than 80 animals are released and by 0.05 for less than 80 animals. Given the probabilities assigned here, re-introduction at Cobra-Killuc is the preferred option if probability of extinction is the only factor taken into account.

Release of animals at both sites produces the worst result in terms of extinction likelihood because smaller numbers of animals released are more subject to predators and other threats. This is shown in figure 2 with \( E(pE) \) increasing to 0.55 for more than 80 animals released and to 0.74 if less than 80 are released.
Figure 2 - PROBABILITIES OF SURVIVAL UNDER DIFFERENT RELEASE OPTIONS

<table>
<thead>
<tr>
<th>Number Released</th>
<th>Success</th>
<th>Failure</th>
<th>p</th>
<th>pE</th>
<th>E(pE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 80</td>
<td></td>
<td></td>
<td>0.7</td>
<td>0.4</td>
<td>0.49</td>
</tr>
<tr>
<td>&lt; 80</td>
<td></td>
<td></td>
<td>0.3</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Chatsworth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lockberr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 80</td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.6</td>
<td>0.65</td>
</tr>
<tr>
<td>&lt; 80</td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Cobra Killuc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 80</td>
<td></td>
<td></td>
<td>0.8</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>&lt; 80</td>
<td></td>
<td></td>
<td>0.2</td>
<td>0.7</td>
<td>0.46</td>
</tr>
<tr>
<td>&gt; 40</td>
<td></td>
<td></td>
<td>0.6</td>
<td>0.6</td>
<td>0.64</td>
</tr>
<tr>
<td>&lt; 40</td>
<td></td>
<td></td>
<td>0.4</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 40</td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.40</td>
<td>0.55</td>
</tr>
<tr>
<td>&lt; 40</td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td></td>
<td></td>
<td>0.3</td>
<td>0.6</td>
<td>0.74</td>
</tr>
<tr>
<td>Both</td>
<td></td>
<td></td>
<td>0.8</td>
<td>0.7</td>
<td></td>
</tr>
</tbody>
</table>
Changing P(pE) from 0.4 and 0.7 respectively to 0.3 and 0.65 for the 80 or more bandicoots released at the Cobra Killuc site show. The resultant E(pE) charges from 0.46 to 0.37 thus, the survival of the bandicoots after 12 months is dependant upon its chance of reaping the benefits of effective management actions on the mortality factors.

Changing the probabilities from 0.7 and 0.3 to 0.3 and 0.7 respectively for the Chatsworth/Lockberr area results in the E(pE) changing from 0.49 to 0.61. This significant difference emphasises the importance of subjective probabilities, as any discrepancies involved with its judgement is highlighted by the magnitude of changes in the E(p/E). In this instance, the result is not surprising because there are a whole host of complex management actions (i.e. pet and road controls) each with their varying degrees of importance in terms of the sustained growth of the bandicoot in the area. In essence, the large difference of opinion means that there would be a correspondingly large change in the probability of extinction that there is a relatively strong correlation between the events of achieving either success or failure and the overall expected probability of extinction.

Figure 2 shows that when the E(pE) changes from 0.7 to 0.6 the resultant E(pE) changes from 0.72 to 0.64. Once again, this value tells us that it is very sensitive to the E(p/E) value chosen for the hardening off of the bandicoots. The original value of 0.72 provides a standard against which the event compares for its relative efficacy.

Figure 2 also shows those type and number of factors that have contributed significantly to the Eastern Barred Bandicoots decline in the Chatsworth Rd/Lochberr Estate area. Before re-introduction is to be attempted into this area, these factors must be controlled so as to sustain growth of the Eastern Barred Bandicoot population in the area.

There are several alternatives associated with the process of releasing captive animals to the wild. First, they can be 'cold-released' into the alien environment or 'hardened-off' for several months in small enclosures in the open. The costs of 'hardening-off' are significant, possibly upwards of $80,000 per year, mainly for staff, veterinary care and vehicles, with three lots of 54 bandicoots (if 162 in total produced) passing through. The young animals could also be transferred to the semi-wild populations rather than directly to the wild; this option is not considered here.

Figure 3 addresses the decision on whether or not to harden off. There is a 0.8 chance that over 50% of the 'hardened-off' animals will survive. By contrast, there is a 0.3 chance of 'cold-released' animals surviving. The probability of extinction, pE, is 0.6 if 'hardened-off' bandicoots are released, and 0.7 for 'cold-released' animals. The outlay of $80,000 for 'hardening off' produces a reduction in E(p(E) of 0.11 from 0.75 to 0.64. An alternative way to 'hardening-off' for achieving the same reduction in probability of extinction is to 'cold-release' a greater number of captive-breed animals. the choice of approach then depends on the relative costs of the two methods.
**FIGURE 3. HARDENING OFF AND COLD RELEASE**

<table>
<thead>
<tr>
<th></th>
<th>$p$</th>
<th>$pE$</th>
<th>$E(pE)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success</td>
<td>0.8</td>
<td>0.7</td>
<td>0.72</td>
</tr>
<tr>
<td>Failure</td>
<td>0.2</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Don't</td>
<td>0.5</td>
<td>0.7</td>
<td>0.75</td>
</tr>
<tr>
<td>Harden</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>0.5</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Failure</td>
<td>0.5</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

**Costs and benefits of re-introductions**

Apart from the financial cost, the spillover effects are very different at each site. The Cobra Killuc site offers the lower probability of extinction, and hence better chance of preserving the social values associated with Eastern Barred Bandicoot. Nearby landowners may also benefit from measures associated with its re-introduction, particularly fox control. They may or may not welcome an association with the program.

The Chatsworth Rd/Lochberr Estate option allows Hamilton residents a greater association and involvement with the program than available if only the Hamilton Community Parklands semi-wild population is present. Preliminary results from a recent social survey suggest that, while some residents do not derive value from the Hamilton populations, the great majority do. The extent to which these values are particularly associated with the wild population is not clear. However, a large number of residents have been involved in activities to protect the wild population, and many are used to Eastern Barred Bandicoot being present on their properties.

**Direct Costs**

There are substantial costs associated with release at both sites. Funds are needed for salaries, vehicles (and their maintenance) for transporting and eventual releasing of the bandicoots; equipment and supplies for monitoring the released animals; predator control and so on. These costs are likely to be approximately $30,000 per year if one of the two sites is chosen. If both sites are chosen, costs will increase to approximately $45,000 per year.
Additional expenses will be needed in the Chatsworth/Lockberr Estate area, in addition to the input of voluntary labour from community members. The main costs will relate to companion animal control. Depending on what options are chosen, and a decision analysis will help determine the most effective one, the costs could fall within a wide range. A responsible pet ownership campaign could cost $10,000; household visits to achieve the same purpose in the Chatsworth Rd/Lochberr Estate area would be possibly $2,000. Reduction of numbers of dumped cats would require a cat pound, with capital costs of $30,000. An effective subsidy for neutering cats would cost over $3,000 per year.

Whichever site is adopted, the effort to understand and deal with other threats to the Eastern Barred Bandicoot will also require substantial funding.

The spillover effects are much greater at Hamilton than Cobra-Killuc because it is a semi-urban environment. The major spillovers are outlined below. Quantification of some of them is possible; whether or not this would warrant the costs and data collection is something to determine case by case.

Positive Spillovers
The implementation of an effective predator control program will benefit all native fauna prone to predation and encourage species to return to areas that have been protected. The implementation of the companion animals locals laws Act by the Hamilton City Council will be an example to other municipalities of how the Companion Animals Act (1990) can be implemented successfully. It will afford control over a population of companion animals that have been a serious threat to the survival of both urban and semi-urban wildlife.

If survival of the Eastern Barred Bandicoot in the wild of Hamilton can be assured, associated benefits from tourism will somewhat higher than if only the semi-captive population remains at Hamilton. Many businesses now benefit from publicity about the unique situation of the Eastern Barred Bandicoot. It is impossible to quantify this but the value of an emblem or unique characteristic for Hamilton is being exploited by at least five businesses, including a motel, plant nurseries and some retail outlets already. It is used by the Hamilton Rural Learning Centre as a major theme for the environmental education program.

Major benefits do not relate to Eastern Barred Bandicoot but to a) reduced nuisance value from cats to most residents, and b) cat owners who have reduced costs associated with veterinary visits.

Many landholders, mainly with small allotments on the fringes of Hamilton, now derive considerable prestige from having Bandicoots on their property. These benefits will continue if the species survives in the wild. The future release of captive-bred animals into restored habitat will bring these benefits to other landholders.

Having the Eastern Barred Bandicoot in semi-urban areas assists in blurring the edge between the natural and the urban environment for many residents; the importance of this factor to many residents is illustrated by the high demand in towns and cities for large urban fringe blocks with remnant bush.
Negative Spillovers

Negative spillovers could include the indirect costs borne by cat owners in constraining cats. Compensation in the form of incentives could be necessary.

Some alienation has already occurred with some Hamilton residents not appreciating the importance of conservation and feeling that the Eastern Barred Bandicoot is being unduly favoured when community services are inadequately funded.

There may be an opportunity cost associated with the program if establishing the preferred bandicoot habitat produces fewer benefits than alternative revegetation approaches. Preferred species recommended for Bandicoot habitat have a height of only 1-2 metres, however integration of low prickly shrubs with normal tree shelterbelts is possible and recommended for effective wind protection.

Bandicoot feeding can interfere with manicured lawns or turf on bowling greens, golf trees and greens or ovals. However, although the damage is negligible, the action itself has appeared to generate a substantial degree of annoyance amongst member of both the bowling clubs and the croquet club.

Conclusions

The paper has shown that for captive breeding, the average expected probability of extinction is very sensitive to the event of achieving an excellent result; that is, producing more than 387 young bandicoots in four locations with 200 pens. It is therefore of critical interest to consider whether or not to outlay the high costs of captive breeding. To fund the captive breeding program, over a five year period, it would cost approximately $1,600,000 (NPV). Choosing between the financial costs and the lower E(pE) is difficult, but can be assisted by determining the point at which managers are indifferent between marginal changes in cost and E(pE).

One way to help ascertain the 'indifference point' is to use sensitivity analysis and compare E(pE)'s when the underlying probabilities are changed. For example, when the pE was changed from 0.2 to 0.4 for the 200 pen option, E(pE) increased from 0.315 to 0.47. Managers are likely to judge that this possible outcome is still worth the cost of the whole program. But as the E(pE) increases, the point of indifference is approached. Beyond that point, the program will be rejected. Clearly if the E(pE) had increased to 0.9, then the decision makers would not even consider outlaying the costs of the 200 pen option as the cost does not justify the likelihood of having such a large probability of extinction.

The comparison between the 200 pen option and the 84 pen option has clearly shown the limitations of the interim strategy.

Increasing the number of pens to 200 means the E(pE) falls substantially from 0.74 to 0.315 although the associated costs increase by $950,000 (NPV). Conversely, saving approximately $950,000 (NPV) means that around 0.40 reduction in the probability of extinction is foregone.
As discussed earlier, the possible strategy of housing two or more females in one pen reduces both the cost of the program and the probability of extinction. Further evaluation of this strategy is warranted, particularly in exploring the number of pens (i.e. the size of the program) needed to produce an equivalent number of young bandicoots to 200 pens occupied by 43 breeding pairs. There may also be other options such as reducing the intensity of care which achieve significant cost savings for acceptable reductions in \( E(pE) \).

Difficult choices also have to be made about re-introductions. This paper has only partially explored the issues. It is clear that Cobra Killuc is the best site for re-introductions in terms of both direct cost and reduction in probability of extinction. In assessing whether to proceed with re-introduction at Hamilton, decision-makers need to determine if the higher direct costs and the reduction in \( E(pE) \) are outweighed by the spillovers being on balance positive and also sufficiently large. They also need to be confident that the required management actions needed to secure the viability of the species will have more than a negligible impact upon the overall probability of extinction.

The paper has tested the sensitivity of results to changing probabilities. This is important. Firstly, the managers of the program have yet to agree on their estimates of these probabilities. Secondly, it can assist in rapidly evaluating variants on the options so far proposed for inclusion in the final plan.

The usefulness for endangered species recovery programs of incorporating population viability analysis and decision analysis into a cost-benefit framework paper has been illustrated. This combination of tools can be a powerful means of ensuring that programs do not simply become a drain on the public purse and that program managers are forced to rigorously justify their claims to further funds. The objective is to achieve the conservation goal in a cost-effective way and with most benefit to society.

Acknowledgements

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References


