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Quantitative decision tools for conservation programme planning: practice, theory and potential

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Summary

Conservation programme planning involves allocating a limited budget amongst different potential conservation projects. The selection of projects for funding is subject to a high degree of uncertainty and a number of competing objectives such as ecological protection, recreation and community relations. The purposes of this paper are to summarize the quantitative methods currently used in deciding which conservation projects to fund and to present a general methodology based on decision analysis that can be used for making conservation programme planning decisions. The methodology directly links the proposed contributions of projects to the objectives of the conservation agency, and it includes an explicit consideration of uncertainty and a conversion of ordinal scores into utilities. The methodology is a rational way of making decisions in conservation situations that are characterized by high degrees of uncertainty and subjective information. An application of decision analysis with staff from the New Zealand Department of Conservation is described. Some of the difficulties with using this methodology in practice are discussed in both the New Zealand and broader contexts. The conclusions are that conservation programme planning is currently based on managerial experience and relatively simple scoring procedures, but that a more rational approach based on decision analysis is possible, and additional research would reduce the amount of effort required to use decision analysis for conservation programme planning.

Keywords: conservation, programme planning, conservation management, decision analysis, conservation budgeting, project selection

Introduction

Conservation management encompasses more than the management of species and the selection of protected areas; many of the government agencies responsible for biological conservation management are also responsible for a host of related activities such as providing recreational and educational opportunities and managing cultural and historical assets. For example, the US 1916 National Parks Service Organic Act (US National Parks Service 1995, p. 1) established that the mission for the US National Parks Service (US NPS) is to 'conserve the scenery and natural and historic objects and the wildlife therein by such means as will leave them unimpaired for the enjoyment of future generations.'

As another example of the variety of activities included in conservation, the New Zealand Conservation Act (New Zealand Department of Conservation 1998, p. 59) defines conservation as 'the preservation and protection of natural and historic resources for the purpose of maintaining their intrinsic values, providing for their appreciation and recreational enjoyment by the public, and safeguarding the options of future generations.'

In fulfilling their legislative mandates, conservation agencies must decide on which projects to fund, given a limited budget and a diverse legislative mandate. The increasing stress that human society is placing on the natural world, and the consequent loss of habitat and species (Wilson 1989), mean that judiciousness is required in using conservation resources. One of the crucial stages in the process of allocating scarce conservation resources is the process of selecting a set of projects. We term the process of choosing a set of projects to undertake as 'conservation programme planning', and it is the focus of this paper.

The problem of selecting a set of projects when constrained by resources is one that has a rich history of analysis. Civil and environmental engineering, in particular transportation planning, often relies on methods for allocating funds between alternative projects (Kulkarni *et al.* 1993; Ravirala & Grivas 1995; Teng & Tzeng 1996). Similarly, many financial management techniques have been developed for choosing between alternative capital investment options (Beenhakker 1975). The problem of resource allocation when faced with many alternatives is a problem within the broader field of Decision Analysis, which deals with formalizing the value judgements inherent in any decision in an effort to improve the quality of the decisions made. It allows subjective information and uncertainty to be explicitly included in the decision process. The main contributions of decision analysis are that it (1) leads to well-documented, reproducible decisions, (2) encourages an explicit statement of values and beliefs on the part of the decision-maker, (3) focuses attention on the objectives of the decision situation, (4) encourages an explicit examination of the trade-offs between conflicting objectives, and (5) facilitates communication amongst different parties.

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Table 1 Summary of conservation planning procedures: current practice.

Conservation agency	*Summary of process used*
NZ DoC: conservancy level	Negotiation and interpretation of guidance documents. Some project scoring.
NZ DoC: regional level	Project scoring with cut-off scores.
US NPS: conservation planning	Project scoring with weighted additive aggregation model.
US NPS: staffing level planning	Gap analysis based on current and required staffing level.
ANCA: selecting protected areas	Scoring of areas.
Hong Kong: selecting projects	Ranking of projects by criteria.
IUCN	Criteria scoring, conversion of scores to values, and an additive aggregation model.

For example, in analysing a decision, it is expected that the decision-maker will document why the projects were assessed as they were. In discussing decisions that have been analysed through decision analysis, disagreements over 'facts' (e.g. the output of population models) can be separated from disagreements over values (e.g. the relative importance of captive and wild populations of an endangered species). In some cases, the mere act of explicitly considering and writing down what it is the decision-maker hopes to achieve can bring greater clarity to the decision process. Perhaps the biggest advantage of using formal decision analysis is not that it leads to a clear choice of action (which it often does), but that the process of analysing a decision often leads to greater insight into and understanding of the decision situation.

This is especially true in a decision situation that is as highly politicized as environmental conservation can be. Recent books on environmental management (Clark 1997; O'Leary *et al.* 1999) highlight how the competition between bureaucratic interests and the lack of leadership in government can lead to inefficient bureaucratic choices.

In this paper, we describe the processes currently used to make conservation programme planning decisions in selected countries, we describe how decision analysis could be used as part of the conservation programme planning process, we introduce an application of decision analysis in New Zealand, and we discuss the opportunities and limitations of decision analysis in future conservation programme planning practice.

Current use of quantitative methods in conservation programme planning

We conducted a review of the current use of quantitative methods in making conservation programme planning decisions. We successfully contacted 31 individuals from 22 different governmental and non-governmental organizations involved in biological conservation, natural resource management, the provision of recreation in natural areas, and strategic planning and decision support for these areas. A list of those contacted is available from the authors. Of the 22 organizations contacted, only five reported that they used some sort of quantitative tool related to conservation programme planning. The rest reported that they relied on non-quantitative methods such as managerial experience and the political process. The responses of the five organizations that reported the use of quantitative methods are now summarized (Table 1).

New Zealand Department of Conservation

The New Zealand (NZ) Department of Conservation (DoC) has a hierarchical structure with a Head Office and three Regional Offices (New Zealand Department of Conservation 1998). Each of the regional offices oversees a number of Conservancy Offices. Each Conservancy, in turn, oversees a number of Area Offices.

Scoring procedures for project selection have been developed at both the Conservancy and Regional levels for a number of programmes, such as animal pest control (possum, goat and deer control), weed control, structural maintenance, and hut and trail maintenance. For example, in selecting which weed control projects to fund, all of the proposed projects are scored on a number of factors, such as the ecological importance of the site the weeds are growing on, the potential for the weed to spread to nearby ecologically sensitive areas, and the potential for the weed to disperse widely throughout New Zealand. The scores that a project receives for each of the factors are added together to give an overall score for the project. A cut-off score is set and all projects with scores above the cut-off are funded while those projects below the cut-off are not funded. The scoring procedures for the possum, deer and goat control programmes are similar to the weed programme scoring procedure.

US National Parks Service

Conservation budget allocation in the US National Parks Service (NPS) is divided into two areas based on the distinction between base operating funds and project funds. In the area of project funding, formal sets of guidelines have been developed for (1) proposing natural resource projects, and (2) evaluating the proposed projects (US National Parks Service 1998*a*, *b*, respectively). These guidelines are for programmes and projects dealing with natural resource preservation, research, water resources, geologic resources, inventory and monitoring, and visitor education. The call for projects provides guidance as to what types of projects are acceptable, the length of time projects may cover, and minimum and maximum allowable budgets. The call for projects also limits the number of projects that each region can propose based on expected funding levels. A set of criteria is then used to rank all

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of the projects except those in the areas of inventory, monitoring and education. The criteria used are:

- significance of the resource to the park,
- severity of resource threat, problem, or need(s),
- problem definition and information base,
- feasibility,
- problem resolution,
- transferability, and
- cost effectiveness.

Each project to be ranked is given a score on a 1–5 ordinal scale based on the definitions and explanations given in the instructions. Then these individual scores are aggregated into an overall project score by using weighting factors.

The US NPS has also developed a quantitative process, the Natural Resource Management Assessment Program (NR-MAP), to aid in setting staffing levels. The general steps in NR-MAP are: (1) assess the natural resources of each park; (2) determine the required staffing levels for each park based on the resource assessments; and (3) compare the current staffing levels with the required levels (US National Parks Service 1995). In NR-MAP, the resources of each park are divided into 15 categories, and surrogate indicators (i.e. indexes representing each category) are assessed.

Australian Nature Conservation Agency

The Australian Nature Conservation Agency (ANCA) has a quantitative decision support tool in place to assist with the selection of new protected areas. This tool is based on a biogeographic regionalization of Australia and is intended to be used in setting priorities for establishing new protected areas. The three criteria used in assessing the priority of a land area are: (1) the level of reservation status within that area; (2) how comprehensively the current reserve network samples the known environmental variability within that area; and (3) the constraints and limitations on establishing new reserves in that area (Australian Nature Conservation Agency 1995). The scores are added together and cut-off scores are developed to separate the high, medium and low priority areas.

Hong Kong

A ranking procedure that takes into account the relative importance, priority, urgency, and budget required is used in Hong Kong to select conservation projects for funding. No further information was available.

World Conservation Union

The World Conservation Union (IUCN) has developed several evaluation tools for fields related to conservation. While these tools are not directly used in decision-making, evaluation is a crucial step in the decision-making process. One area in which the IUCN has made major advances in developing quantitative assessment tools is in measuring progress towards sustainable development. With the *Barometer of Sustainability* (World Conservation Union 1997*a*) and *Participatory and Reflective Analytical Mapping for Sustainability* (World Conservation Union 1997*b*), the IUCN has developed a method of explicitly examining the values of organizations and governments and evaluating their progress towards sustainability. The evaluation is based on the values of the organization in combination with a collection of objective and subjective criteria. In the *Barometer of Sustainability*, the different criteria levels are first converted to a value scale: then the different criteria are combined through either a weighted or an unweighted additive model to give two measures of sustainability, one for human well-being and one for ecosystem well-being.

Decision analysis background

We now outline the basic features of decision analysis that are most relevant to quantitative conservation programme planning. Components of decision analysis have been introduced into the conservation biology and environmental management literature (O'Banion 1980; Bakus *et al.* 1982; Thibodeau 1983; Maguire 1986, 1991; Smith & Theberge 1987; Ralls & Starfield 1995). We will describe multi-component decision analysis (MCDA), and focus on the development of objectives and the assessment of utilities because these areas have received relatively little treatment in the conservation biology and environmental management literature. Readers interested in a more comprehensive treatment of decision analysis or in a thorough explanation of the underlying theory should consult amongst others Keeney and Raiffa (1976), Holloway (1979), von Winterfeldt and Edwards (1986) and Keeney (1992).

The procedure described here can be summarized as consisting of four separate components (Fig. 1). The objective model consists of framing the decision and developing the objective hierarchy. The uncertainty model involves assessing the probabilities of the different attribute levels for each project. The utility model is based on developing a utility function for each attribute and combining these utility functions into overall project utilities using an aggregation model.

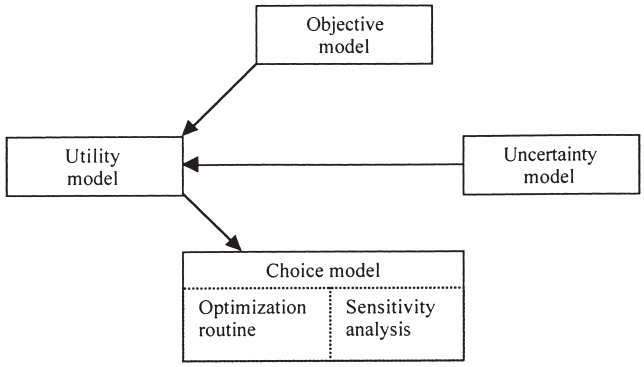


Figure 1 Components of the proposed conservation programme planning procedure.

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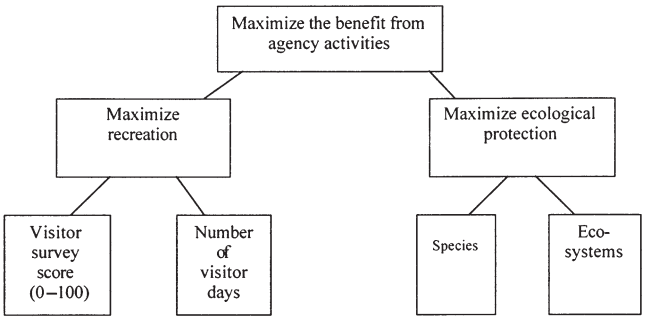


Figure 2 Example of a structured set of objectives and attributes for conservation programme planning.

The optimization routine and the sensitivity analysis are the two components of the choice model (Fig. 1).

Framing the decision and determining the decision-maker's objectives

The first step in analysing a decision consists of identifying precisely what decision is being considered, what the relevant level of detail is, and who the decision-maker is. In the example developed in the following sections, we will assume that the relevant decision is choosing a set of projects to fund in a given year. We will further assume that the decision is a preliminary one so that great detail is not needed and that there is a single decision-maker, the manager, who is responsible for the funding decisions made in the department.

After the decision is framed, the proper objectives (i.e. what the decision-maker hopes to achieve) need to be determined. The first step is to identify a comprehensive list of objectives (Keeney 1992). The objectives are then structured into a hierarchy, and a list of attributes (i.e. the criteria that will be used to measure the achievement of the objectives) is developed (Keeney 1992). These attributes should be both comprehensive and measurable (Keeney & Raiffa 1976). The development of attributes has been discussed in an environmental management setting (O'Banion 1980). It should be noted that the attributes do not need to be objective, directly measurable entities. Subjective attributes, also called constructed attributes, can be, and often are, used instead (Keeney 1992).

Table 2 Constructed attribute for species protection.

Attribute level	*Explanation of attribute level*
5	The project causes an increase in the population of an endangered species.
4	The project halts the population decline of an endangered species.
3	The project slows the rate of population decline of an endangered species.
2	The project has no effect on the population of an endangered species.
1	The project causes an increase in the rate of population decline of an endangered species.

While the set of objectives and attributes shown in Figure 2 represents a highly simplified version of a real conservation programme planning situation, it does serve to illustrate the main points. First, the objective listed at the top of the hierarchy represents the reason for being interested in the decision. The lower-level objectives ('Maximize ecological protection' and 'Maximize recreation') further describe the highest-level objective. The attributes below the lower-level objectives measure the achievement of those objectives. For the purposes of our example, we will assume that these attributes are comprehensive. For the two attributes that do not have a natural measurement scale (i.e. 'Species' and 'Ecosystems'), a constructed attribute would need to be developed. Table 2 gives an example of a constructed attribute for 'Species' in the example; a similar attribute can be created for the 'Ecosystems' attribute.

It is important that the objective hierarchy be developed in a way that ensures additive independence if an additive value model is to be used (Keeney 1992). Additive independence means that the utility of different levels for a particular attribute can be determined without knowing the levels of the other attributes (Keeney & Raiffa 1976; O'Banion 1980). For example, consider a situation in which an endangered species depends on another species for survival, such as the black-footed ferret and its prey, the prairie dog (Maguire *et al.* 1988). If two attributes in this situation were (1) population level of ferrets and (2) population level of prairie dogs, then the attributes would not satisfy additive independence. The utility of the population level of ferrets would depend on the population level of prairie dogs.

Establishing the utility of the different projects

Each of the three steps in the utility assessment procedure is discussed briefly below.

(1) Developing a utility function for each attribute

A utility function converts an attribute score into a utility; a utility function would therefore need to be developed for each attribute if decision analysis were to be used. Utility functions are needed if the preferences of the decision-maker are to be accurately captured (O'Banion 1980). Attribute scores often cannot be used directly because they are not scaled suitably and do not accurately capture the preferences of the decision-maker. If used directly, the raw score needs to have a range that is similar between attributes. If the attribute scale for ecosystem protection varies from 0 to 20, while the scale for species protection varies from 1 to 5, adding these numbers to assess the total ecological value of the project would imply a greater weighting for ecosystem protection than for species protection. Most analysts prefer to have the weights considered separately and explicitly from the scaling issue.

Another concern with using raw scores directly is that equal incremental increases in scores might not have equal incremental increases in value. As a result, analysts prefer to convert the scores to something, namely utilities, that more truly reflects the value to the decision-maker. An example of possible utility values for the attribute levels in Table 2 is

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Table 3 Utilities and probabilities for the species protection project in the example.

Attribute level	*Utility of attribute level*	*Probability of attribute level*
5	1.0	0.20
4	0.8	0.55
3	0.4	0.25
2	0.1	0.00
1	0.0	0.00

given in Table 3, where the decision-maker can be seen to benefit greatly from an increase from a score of 3 (project slows the rate of loss of an endangered species) to a score of 4 (project halts the loss of population), but less from an incremental benefit going from a score of 4 to a score of 5 (project causes an increase in population). In some situations, the scores might accurately reflect the relative utility of various projects; still, the use of utilities, although adding a complicated step in the process, allows for greater flexibility and accuracy in the analysis method.

There are different procedures for developing a utility function for each attribute. Von Winterfeldt and Edwards (1986) outline a direct assessment procedure in which the utilities of a few attribute levels are determined and a curve is sketched in. Their procedure has the appeal of being much easier to use than more formal methods, but consistency checks should be included.

As an example of utility assessment, the variable probability method will be demonstrated. Suppose that there are three items, X, Y and Z and that the order of the decision-maker's stated preferences for these three items is $X>Y>Z$; X is then the most preferred, and Z is the least preferred. The variable probability method can be used to find the utility of item Y. First a hypothetical situation is set up in which the decision-maker can choose between receiving Y for certain or a lottery in which there is a probability, p, of getting X and a probability of $(1\text{-}p)$ of getting Z. Then p is varied until the decision-maker is indifferent between receiving Y for certain or the lottery; that is, the p is found at which the decision-maker cannot decide between Y and the lottery. This value of p is then the utility of item Y. To understand why, we need the following two ideas from utility theory (Keeney & Raiffa 1976):

(i) The utility of a lottery is the expected utility of the outcomes. In other words:

$$u(\text{lottery}) = p*u(X) + (1\text{-}p)*u(Z) \quad (1)$$

(ii) The utility of the most preferred item can be scaled to 1 and the utility of the least preferred item can be scaled to zero. In other words:

$$u(X) = 1 \text{ and } u(Z) = 0 \quad (2)$$

If the decision-maker is indifferent between receiving the lottery and receiving Y, then $u(\text{lottery}) = p$. In practice X, Y and Z would be replaced by the items being assessed. In the case of conservation programme planning, these items would be the different score levels. The procedure can easily be extended to handle more than three items by increasing the number of different lotteries considered. There are other methods by which utilities may be assessed (Keeney & Raiffa 1976; von Winterfeldt & Edwards 1986; Keeney 1992).

(2) Assess the uncertainty of the scores

In most decision-making, including that of conservation programme planning, the outcomes of projects, and thus the scores that should be assigned to projects, cannot be known with certainty before the completion of projects. For example, consider a project dealing with the protection of an endangered species. Using the constructed attribute given in Table 2, it is thought that the project will probably halt the decline of the species population and should thus be given a score of 4. However, due to the uncertainty inherent in endangered species management, the project could lead to an increase in the population of the species (a score of 5), or it could slow the decline of the population of the species, but not halt that decline (a score of 3). After considering external information sources (e.g. population models, expert opinion, and the outcomes of similar projects), the person scoring the project specifies a probability for each outcome that best reflects their beliefs. Procedures can be used to avoid the biasing and other difficulties that often accompany probability assessment (Holloway 1979; Keeney 1992). In our example, we will assume that the decision-maker assigns probabilities of 0.25, 0.55 and 0.20 (the probabilities must sum to one) to attribute levels of 3, 4 and 5 respectively. Table 3 shows the probabilities of the different attribute levels and the utility of these attribute levels.

The expected utility for each attribute of the project is calculated by multiplying each utility level by the probability of its occurrence. For the species protection attribute of the example project, this calculation would be:

$$u_i(x_i) = \sum_{k=1}^{5} p_k * u_k(x_k) = (0.2)(1.0) + (0.55)(0.8) + (0.25)(0.4) = 0.74 \quad (3)$$

where $u_i(x_i)$ is the expected utility of a project with respect to attribute i, p_k is the probability of the k^{th} level for the i^{th} attribute, x_k is the k^{th} level of attribute i, and $u_k(x_k)$ is the utility of level x_k.

(3) Determine the weighting factors and combine the expected utilities for the attributes into an overall utility for each project.

After the expected utilities have been calculated for each attribute, they can be combined into an overall utility for the project by using an additive aggregation function (Keeney 1992):

$$u(x_1,\ldots,x_N) = \sum_{i=1}^{N} k_i * u_i(x_i) \quad (4)$$

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Table 4 Single attribute and overall attribute weighting factors.

Attribute	*Attribute weighting factor*	*Overall weighting factor*
Visitor survey score	0.75	0.248
Number of visitor days	0.25	0.082
Species protection	0.33	0.221
Ecosystem protection	0.67	0.449

where x_i is the level of the i^{th} attribute, $u_i(x_i)$ is the expected utility of the i^{th} attribute and k_i is the weighting constant for the i^{th} attribute. Formally, the weighting constants represent the trade-offs between the utilities of the different levels of the different attributes, but in practice, the weighting constants are often taken to represent the relative importance of the different attributes and are usually normalized to sum to one.

The weighting constants can be determined by using a series of trade-offs between different attribute levels (O'Banion 1980). This method works well for situations with small numbers of attributes, but it can be prohibitively difficult for large numbers of attributes. Another procedure exists in which the weighting constants are found by assigning points to each objective or attribute in proportion to its relative importance within that level of the hierarchy (Von Winterfeldt & Edwards 1986). This procedure is much easier to use but, when using it, the decision-maker can have more difficulties deciding on the proper weights because of not working directly with the attribute levels.

We now continue with our example of the conservation programme planning process by assuming that the decision-maker determines that a unit increase in utility in the ecological protection objective is twice as important as a unit increase in utility in the recreation objective (Fig. 2). This implies weights of 0.67 and 0.33 for the second-tier objectives. The decision-maker also determines that (1) a unit increase in utility in the visitor survey score attribute is three times as important as a unit increase in utility in the number of visitor days attribute within the recreation objective, and (2) a unit increase in utility in the ecosystem protection attribute is twice as important as a unit increase in utility in the species protection attribute within the ecological protection objective. Table 4 summarizes the weighting factors for each of the attributes.

The overall weight for each of the attributes is found by multiplying its within-objective weight by the weight on the objectives it describes. For example, since a three to one level of importance between visitor survey score and visitor days implies 0.75 and 0.25 weightings for the attributes, the overall weighting for visitor survey score is given by:

$$\text{Overall Visitor Survey Weight} = (0.33)(0.75) = 0.248 \quad (5)$$

Similarly, the overall weights for number of visitor days, species protection, and ecosystems protection would be 0.082, 0.221, and 0.449 respectively. Note that the sum of the weights found by this method is 1.0, as is the convention.

Table 5 gives examples of possible conservation projects, where it is assumed that the attribute scores have been converted to expected single-attribute utilities using the methods given above. The expected single-attribute utilities for the projects can be converted into overall project utilities by using equation (2) with the weighting factors given in Table 4. For example, for project 1, the overall utility would be computed as:

$$\text{Utility(project 1)} = 0.248(0.8) + 0.082(0.7) + 0.221(0.5) + 0.449(1.0) = 0.815 \quad (6)$$

The overall utilities of the remaining projects are computed in a similar manner and are shown in Table 6.

Analysing the decision and conducting sensitivity analysis

Once the project utility values have been determined, an optimization routine is used to find the 'best' set of projects to fund. In the case of conservation programme planning, the overall utility of the funded projects will be the sum of the utilities of the funded projects. Because of this linearity, an integer linear programming model can be used (Greenberg 1971; Zoints 1974). For single-year conservation programme planning, the model is given by:

$$\text{Maximize} \quad Z = \sum_{j=1}^{N} u_j(p_j)^* y_j \quad (7)$$

$$\text{Subject To:} \quad y_j \text{ is 0 or 1} \quad (8)$$

$$\sum_{j=1}^{N} C_j^* y_j \leq C_T \quad (9)$$

In equations (7)–(9), $u_j(p_j)$ is the utility of the j^{th} project, N is the number of possible projects (i.e. the number of proposed

Table 5 Examples of proposed conservation projects, their costs and their utility for each attribute.

Example project number	*Example project description*	*Cost (1000s of dollars)*	*Visitor survey score*	*Number of visitor days*	*Species*	*Ecosystem*
1	Develop a new marine wildlife sanctuary	120	0.80	0.70	0.50	1.00
2	Hiking trail maintenance	90	0.85	0.90	0.20	0.15
3	Close park to vehicle traffic	25	0.40	0.20	0.80	0.90
4	Restore a small wetland	100	0.45	0.20	0.20	1.0
5	Begin a rat eradication programme on an off-shore island to protect endangered bird species	80	0.05	0.15	0.74	0.80

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Table 6 Overall utilities for the five example projects.

Project number	*Overall project utility*
1	0.82
2	0.40
3	0.70
4	0.62
5	0.55

projects), C_j is the cost of project j, C_T is the maximum budget available, and y_j is the decision variable that is zero if a project is not funded and one if it is. Equation (7) shows that the goal of the optimization routine is to find the selection of projects that maximizes the total utility of the selected projects. Equation (8) restricts y_j to be either 0 if the j^{th} project is not funded, or 1 if the j^{th} project is funded. Equation (9) restricts the total cost of the funded projects to less than the maximum budget available. The model given by equations (7)–(9) can be solved for small- to medium-sized problems by using a spreadsheet with an optimization tool such as Solver in Microsoft Excel©. For large problems, more efficient optimization tools are needed.

If the example projects shown in Table 5 are used with the overall utilities shown in Table 6 in the above model in conjunction with a maximum budget of $140 000, then the optimization model selects projects 3 and 4 to be funded. The total cost of funding these two projects is only $125 000, but funding projects 3 and 4 gives the maximum utility for the given budget limitation.

After the initial optimization has given the 'best' set of projects to fund, a sensitivity analysis can be conducted to examine the effects that changes in the model parameters would have on the suggested decision. For example, the weights assigned to the recreation objective could be changed from the value of 0.33. Because the weights at any level in the objective hierarchy must sum to one, the weight assigned to the ecological protection objective is known once a weight for the recreation objective is chosen.

Table 7 gives an example of the results of varying the weight on the recreation objective from zero to one. Project 3 is funded for all possible weights on recreation, however, as the weight assigned to recreation increases, project 4 is funded instead of project 5 (Table 7). As the weight on recreation is increased further, project 2 is funded instead of project 4. The sensitivity analysis is important because it can reveal the range of weights over which certain funding decisions should be made. In our example, if the weight on recreation is 0.12 or less, then projects 3 and 5 should be funded. If the weight on recreation is between 0.12 and 0.55, projects 3 and 4 should be funded, and if the weight on recreation is 0.55 or above, projects 2 and 3 should be funded (Table 7). In a real decision situation, similar sensitivity analyses would be conducted for other model inputs (i.e. the utility function for each attribute, outcome probabilities, and budget limitations in addition to the weighting constants), and graphical displays of the results would be used. These sensitivity analyses are valuable in showing what effects possible changes in inputs would have on the decision. In addition, more detailed information can be gathered for those variables that are shown to have a large impact on the decision if they are changed. In this case, if the decision-maker is not sure if the weight associated with recreation is too high at 0.33, that person could consult others and conduct a survey of the relevant public.

Table 7 Sensitivity analysis for the weight assigned to the recreation objective.

Weight on recreation	*Projects funded*
0	3, 5
0.1	3, 5
0.12	3, 5
0.13	3, 4
0.25	3, 4
0.5	3, 4
0.54	3, 4
0.55	2, 3
0.67	2, 3
1	2, 3

Discussion

We have described the current practice of quantitative conservation programme planning and indicated how decision analysis can be used in the process. We now intend to join these two analyses by exploring the potential expansion of the use of these techniques.

Analysis of existing methods for programme planning

It is apparent that the use of quantitative procedures for choosing conservation projects is uncommon. Before discussing why this is so, it is worthwhile examining the existing quantitative methods in more detail.

First, the existing approaches usually do not convert scores into values (Table 1). Although the use of single-attribute scores is satisfactory when compared against a cut-off level, it is often not satisfactory when scores are added or multiplied to give overall project value. Smith and Theberge (1987) reviewed past approaches to evaluating natural areas and made this same point, reinforcing its relevance to conservation management. While it is not directly applicable to conservation programme planning, the *Barometer of Sustainability* (World Conservation Union 1997*a*) provides an example of scores being converted into values before being added together into overall 'scores'.

The second drawback to the relatively simple scoring procedures commonly used (Table 1) is that the procedures do not explicitly consider the uncertainty inherent in conservation management. For example, in considering projects dealing with endangered species protection, a range of outcomes is possible because the outcome of the project occurs in the future and is the result of many factors besides that of funding. Thus, any scoring procedure that assigns a single

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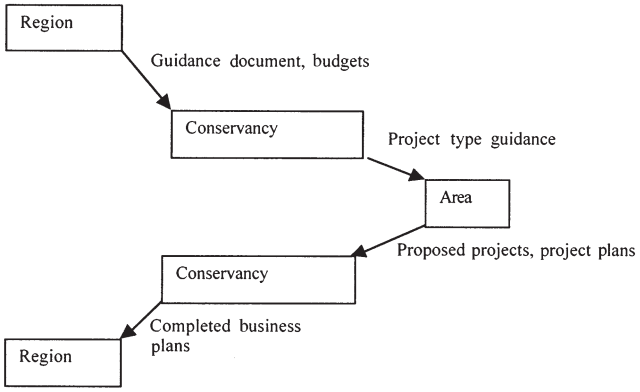


Figure 3 Overview of the current NZ DoC programme planning structure.

score to a project before implementing that project ignores the uncertainty in the outcome of that project.

The last major drawback to many current scoring procedures is that they are often not directly linked with the strategic goals and objectives of the organization or agency. For example, in many scoring procedures, the objectives of the organization funding the conservation work are not explicitly written down and organized as part of the process of developing the scoring system. While some scoring systems, such as the IUCN procedures discussed earlier, are likely to reflect the objectives of the organization in which they were developed, a closer link between the objectives and the project evaluation procedure can only serve to improve the achievement of those objectives.

Development of a MCDA-based procedure in practice

To explore further the use of MCDA in conservation programme planning, we worked intensively with the NZ DoC, which uses a project-based budgeting process to determine its programme for each year (Fig. 3). First the three Regional offices jointly compose a guidance document based on the DoC Strategic Business Plan and other national-level documents. Each of the 13 Conservancies reviews the guidance document and discusses with the Area offices the types of projects to propose that year (Fig. 3). The Area offices then propose projects and do the necessary paperwork. This is followed by the Conservancy offices making decisions on which projects will be funded for the coming year and combining these into a statement of the Conservancy's work which is called a business plan (Fig. 3). These Conservancy business plans are combined at the Regional level to form a Regional business plan. The decisions regarding project funding made at the Conservancy level are based mainly on managerial experience with some input from the relatively simple scoring procedures discussed previously.

We worked with DoC staff on:

(1) Structuring a preliminary set of national objectives;
(2) Developing scoring procedures that can be used to measure the contribution of individual projects to the DoC's achievement of its objectives, and then scoring sample projects;
(3) Assessing the utilities of the different score levels, and applying these to sample projects;
(4) Assessing the weighting constants needed to compare the different objectives, and applying these to sample projects; and
(5) Developing the optimization and sensitivity analysis portions of the resulting analysis.

We found that the MCDA methodology described in this paper could be used in practical conservation programme planning situations. Some general observations based on the work with DoC are:

(1) The methodology could be used in a multi-level organization as long as the objectives used at any one level were the national objectives of the agency as a whole;
(2) The DoC managers could assess the utility and scaling constants, as long as the terms and procedures were fully explained and they were given time to adjust to thinking in terms of utilities and probabilities through the use of examples;
(3) The DoC decision-makers were willing to quantify and use their preferences and value judgements as long as they understood how these would be used; and
(4) To avoid confusion and resistance to the implementation of the procedure, the scoring procedures must be developed at a level suitable for those who will be using them, and the ways in which the scores will be used must be made clear to those conducting the scorings.

The conclusion is that it is possible to implement a procedure based on the MCDA method in a practical situation as long as care is taken in how this is done. In addition, members of the DoC management reported that working through the procedure based on decision analysis helped clarify what the agency's objectives and values should be and helped them view their project-selection decisions in an objective-focused way.

Obstacles to the use of decision analysis for programme planning and possible treatments

Because it seems that the MCDA theory has many benefits for conservation planners, and yet it is little used by them, we must ask why there is such a gulf between theory and practice. Based on our experiences with DoC and our own analysis, we will analyse a number of possible difficulties with using MCDA in practice and ways of overcoming those difficulties.

One potential obstacle is that the model given here is limited to single-year programme planning, however incorporating multi-year planning would require only minor changes to the model (Keeney & Raiffa 1976; Keeney 1992). For example, the utility assessments can include an explicit consideration of the timing of the costs and benefits of the projects, or a form of discounting can be used.

A second potential drawback is that the model developed here is also limited to situations in which there is either a

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single person responsible for the decision, or a group that behaves as a single decision-maker. In some cases it may not be possible to identify the single person who is ultimately responsible for the decisions made in the department concerned. Methods do exist for extending decision analysis to group decision-making. For example, there are methods for aggregating the preferences and values of multiple decision-makers (Beroggi 1999), and a 'social utility function' that represents the preferences and values of a large group can, in some cases, be developed (de Neufvile 1990). Beroggi (1999, Chap. IX) provides a good introduction to many of the issues involved in group decision-making. Additional research on the extension of the model developed here into group decision-making situations should broaden its use in practice.

Another potential drawback is that the hierarchical structure of many organizations may preclude a general approach to project selection (Sinuany-Stern & Mehrez 1987). In such cases, there may be different units within the organization competing for the same resources. These conflicts can make it very difficult to develop a suitable general approach to project selections (Sinuany-Stern & Mehrez 1987). One way that may be helpful in overcoming these conflicts is to ensure that the objectives and scoring procedures developed for the situation and used by the lower-level offices within the agency are the national objectives of the agency, as was done in the work with DoC. In practice, this approach would require that a system be set up to ensure that the national objectives were being interpreted as intended by the lower-level offices.

A common objection to the use of quantitative approaches to project planning, including decision analysis, is the extra time needed for scoring projects against criteria and finding the optimum set of projects under various situations. In some cases, quantitative techniques can become burdensome because there are too many attributes or the method of evaluation is too complex. The analyst can limit the number of projects to only those that have a significant chance of funding, and can aggregate the attributes until they are at a manageable level; however, the desire to simplify the problem through combining attributes must be balanced against the need to have a comprehensive and understandable set of attributes. The use of spreadsheet add-ons for optimization makes evaluation much quicker and more accessible to today's managers than to those of 20 years ago. Computer-based methods can improve the development and communication of sensitivity analyses quickly and easily (e.g. Guikema 1998). The development of methods and tools that make the decision analysis and optimization processes easier and quicker is an important area for further research.

In many cases, the results of quantitative approaches to programme planning can be difficult to interpret; the statistics and mathematics involved can be difficult for managers without quantitative training to understand, and it can be difficult for managers to think of projects in terms of utilities. A clear explanation of what is meant by 'utility' and 'probability,' and of what the results mean, is a crucial step in the process of using any quantitative method for programme planning.

When no quantitative method of project evaluation is used, a process presumably exists where local managers make informal proposals, receive informal feedback from regional managers on the likelihood of funding for a project, modify their original proposal to optimize their chances of success, and formally submit the proposal. In fact, the NZ DoC currently uses a system similar to this. The use of a quantitative process as outlined above might be seen to have the disadvantage of removing the feedback process, making staff more removed from management. On the other hand, a quantitative process also provides quantitative and transparent results showing which projects were funded and why. This information could be fed back to local staff as a clear way for them to interpret why their projects were or were not funded. In addition, using a quantitative method of project selection does not preclude informal feedback.

Some would argue that the subjective knowledge, beliefs and preferences of decision-makers have no place in the selection of conservation projects, and that projects should be selected solely on the basis of objective, scientific criteria. However, because of the extra time and cost needed to develop objective criteria (where this is possible), managers are likely to develop subjective measures first for critical evaluations. As a result, subjective attributes as described here are likely to find widespread use in programme planning for the foreseeable future. In addition, past applications of decision analysis in conservation biology have shown that subjective knowledge and value judgements can be successfully used in improving conservation management decisions (Thibodeau 1983; Maguire 1986; Maguire & Servheen 1992).

Another potential difficulty is that the project scorers could assign higher scores to their projects than the projects merit in an effort to obtain additional funding from the higher levels of the organization. To avoid this problem, common scoring procedures could be used throughout the organization and those scoring the projects would be expected to justify their scores and uncertainty assessments. This precaution was not included in the example given here because the purpose of the example is to illustrate how the proposed process would be used. In practice, the system put in place to ensure that the national objectives were being interpreted consistently throughout the organization would also need to include an auditing of the scores resulting from the process. Similarly, the utility function and weights used would be those developed by the decision-maker ultimately responsible for the funding decisions in the department concerned (or the responsible group if this were the case), and the same utility function and weights would be used throughout the department to ensure that the same preference and value structure was used throughout the agency.

Conclusions

Conservation management involves more than the management of single species and the selection of protected areas. While these are important aspects of conservation manage-

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ment, most conservation agencies have a variety of responsibilities including the protection of a number of species and ecosystems, the provision of recreational and educational opportunities, and the management of cultural and historical sites. In managing these varied activities within their given budgets, conservation agencies often cannot fund all of the proposed programmes.

Current methods for deciding which projects to fund rely mainly on negotiation, managerial experience and relatively simple scoring procedures. Our review of the current use of quantitative methods for conservation programme planning reveals that relatively few of the agencies contacted use quantitative methods. In addition, the quantitative methods that are in use usually (1) do not explicitly consider the uncertainty inherent in conservation programme planning, (2) do not convert scores to utilities, and (3) are not linked to the strategic objectives of the conservation agency.

The use of MCDA is one option for reducing 'bureaucratic pluralism' (O'Leary *et al.* 1999). It provides a way of focusing the discussion between involved parties on the overall goals rather than on the often-politicized means of achieving them. It provides a reproducible method that shows why certain projects should or should not be funded. The efforts to protect the black-footed ferret (Clark 1997) show the tendency of organizations to use the uncertainty of outcomes to advance their bureaucratic interests. MCDA should be seen as a way to help make uncertainty explicit and so more transparent and more amenable to discussion and agreement. Clearly, MCDA is not a solution to all the ills of bureaucratic or political conflict in environmental management. Having a quantitative tool to advise on a recommended course or action helps, but one must always appreciate the political arena of public-sector decision-making.

A generalized approach to the quantitative analysis of project selection has been presented. Taken as a whole, it represents an extension of the present scoring models to include an assessment of the objectives of the agency involved and to incorporate an explicit consideration of uncertainty in project outcome and a utility conversion to capture better the preferences of the decision-maker. The authors' work with the NZ DoC suggests that using a procedure based on decision analysis is possible in real programme planning situations and may offer substantial benefits over other methods.

Additional research is required on reducing the time needed for scoring projects, developing utility functions, and finding the optimal set of projects to fund under different parameter scenarios. Reducing the time needed for these activities would improve the practicality of using decision analysis for conservation programme planning. Additional research is also needed to develop methods for displaying the results of the optimization and sensitivity analyses in a way that is clear and useable for decision-makers.

As with any quantitative decision tool, decision analysis should not be viewed as producing the only 'right' decision. Rather, decision analysis is a tool that can help bring clarity to conservation programme planning decisions through a careful and thoughtful analysis of the situation. If used properly, decision analysis can be a powerful tool for conservation programme planning.

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References

Australian Nature Conservation Agency (1995) *An Interim Biogeographic Regionalisation for Australia: a Framework for Setting Priorities in the National Reserve System Cooperative Program*, ed. R. Thackway & I.D. Cresswell. Canberra: ANCA: 88 pp.

Bakus, G.J., Stillwell, W.G., Latter, S.M. & Wallerstein, M.C. (1982) Decision making: with applications for environmental management. *Environmental Management* **6**: 493–504.

Beenhakker, H.L. (1975) *Capital Investment Planning for Management and Engineering*. Rotterdam: Rotterdam University Press: 210 pp.

Beroggi, G.E.G. (1999) *Decision Modeling in Policy Management, an Introduction to the Analytic Concepts*. Boston: Kluwer Academic: 349 pp.

Clark, T.W. (1997) *Averting Extinction: Reconstructing Endangered Species Recovery*. New Haven: Yale University Press: 270 pp.

de Neufvile, R. (1990) *Applied Systems Analysis*. New York: McGraw-Hill: 470 pp.

Greenberg, H. (1971) *Integer Programming*. New York: Academic Press: 196 pp.

Guikema, S.D. (1998) Sensitivity analysis for the objective function parameters of large-scale Knapsack problems with application to project selection in the Department of Conservation. In: *The Proceedings of the 5th Annual New Zealand Engineering and Technology Postgraduate Conference*, ed. B. Teekman, P. Milliken & N. Body, pp. 275–80. Palmerston North, New Zealand: Massey University.

Holloway, C.A. (1979) *Decision Making under Uncertainty: Models and Choices*. New Jersey: Prentice-Hall: 522 pp.

Keeney, R.L. (1992) *Value-Focuses Thinking: a Path to Creative Decisionmaking*. Cambridge, USA: Harvard University Press: 416 pp.

Keeney, R.L & Raiffa, H. (1976) *Decision Analysis with Multiple Objectives: Preferences and Value Trade-offs*. New York: John Wiley and Sons: 569 pp.

Kulkarni, R.B., Burns, R.L., Wright, J., Apper, B., Baily, T.O. & Noaek, S.T. (1993) Decision analysis of alternative highway alignments. *Journal of Transportation Engineering* **119**: 317–32.

Maguire, L.A. (1986) Using decision analysis to manage endangered

https://doi.org/10.1017/S0376892999000260 Published online by Cambridge University Press

species populations. *Journal of Environmental Management* **22**: 345–60.

Maguire, L.A. (1991) Risk analysis for conservation biologists. *Conservation Biology* **5**: 123–5.

Maguire, L.A. & Servheen, C. (1992) Integrating biological and social concerns in endangered species management: augmentation of grizzly bear populations. *Conservation Biology* **6**: 426–34.

Maguire, L.A., Clark, T.W., Crete, R., Cada, F., Groves, C., Shaffer, M.L. & Seal, U.S. (1988) Black-footed ferret recovery in Montana: a decision analysis. *Wildlife Society Bulletin* **16**: 111–20.

New Zealand Department of Conservation (1998) *Restoring the Dawn Chorus*. Department of Conservation Strategic Business Plan 1998–2002. New Zealand Department of Conservation, Wellington, New Zealand: 64 pp.

O'Banion, K. (1980) Use of value functions in environmental decisions. *Environmental Management* **4**: 3–6.

O'Leary, R., Durant, R.F., Fiorino, D.J. & Weiland, P.S. (1999) *Managing for the Environment: Understanding the Legal, Organizational, and Policy Challenges*. San Francisco: Jossey-Bass Publishers: 436 pp.

Ralls, K. & Starfield, A.M. (1995) Choosing a management strategy: two structured decision-making methods for evaluating the predictions of stochastic simulation models. *Conservation Biology* **9**: 175–81.

Ravirala, V. & Grivas, D.A. (1995) Goal-programming methodology for integrating pavement and bridge programs. *Journal of Transportation Engineering* **121**: 345–51.

Sinuany-Stern, Z. & Mehrez, A. (1987) Discrete multiattribute utility approach to project selection. *Journal of the Operational Research Society* **12**: 1133–9.

Smith, P.G.R. & Theberge, J.B. (1987) Evaluating natural areas using multiple criteria: theory and practice. *Environmental Management* **11**: 447–60.

Teng, J. & Tzeng, G. (1996) A multiobjective programming approach for selecting non-independent transportation investment alternatives. *Transportation Research Part B* **30B**: 291–307.

Thibodeau, F.R. (1983) Endangered species: deciding which species to save. *Environmental Management* **7**: 101–7.

US National Parks Service (1995) The natural resource management challenge, the NR-MAP report. Prepared for National Resources Strategic Plan Team II by Bob Krumenaker and Abby Miller. US National Parks Service: 7 pp.

US National Parks Service (1998*a*) Natural resources unified project call. Planning document, US National Parks Service: 3 pp.

US National Parks Service (1998*b*) Instructions and criteria for natural resources unified project call. Planning document, US National Parks Service: 22 pp.

von Winterfeldt, D. & Edwards, W. (1986) *Decision Analysis and Behavioural Research*. Cambridge, UK: Cambridge University Press: 604 pp.

Wilson, E.O. (1989) Threats to biodiversity. *Scientific American* **261**: 108–12.

World Conservation Union (1997*a*) *Barometer of Sustainability*. Prepared by Robert Prescot-Allen. Cambridge, UK: IUCN Publication Service Unit: 40 pp.

World Conservation Union (1997*b*) *Participatory and Reflective Analytical Mapping for Sustainability*. Prepared by Alejandro Imbach, Eric Dudley, Natalia Ortiz & Hernando Sanchez. Cambridge, UK: IUCN Publication Service Unit: 41 pp.

Zoints, S. (1974) *Linear and Integer Programming*. New Jersey: Prentice-Hall: 514 pp.

https://doi.org/10.1017/S0376892999000260 Published online by Cambridge University Press