

Optimal Allocation of Resources among Threatened Species: a Project Prioritization Protocol

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Abstract: *Conservation funds are grossly inadequate to address the plight of threatened species. Government and conservation organizations faced with the task of conserving threatened species desperately need simple strategies for allocating limited resources. The academic literature dedicated to systematic priority setting usually recommends ranking species on several criteria, including level of endangerment and metrics of species value such as evolutionary distinctiveness, ecological importance, and social significance. These approaches ignore 2 crucial factors: the cost of management and the likelihood that the management will succeed. These oversights will result in misallocation of scarce conservation resources and possibly unnecessary losses. We devised a project prioritization protocol (PPP) to optimize resource allocation among New Zealand's threatened-species projects, where costs, benefits (including species values), and the likelihood of management success were considered simultaneously. We compared the number of species managed and the expected benefits gained with 5 prioritization criteria: PPP with weightings based on species value; PPP with species weighted equally; management costs; species value; and threat status. We found that the rational use of cost and success information substantially increased the number of species managed, and prioritizing management projects according to species value or threat status in isolation was inefficient and resulted in fewer species managed. In addition, we found a clear trade-off between funding management of a greater number of the most cost-efficient and least risky projects and funding fewer projects to manage the species of higher value. Specifically, 11 of 32 species projects could be funded if projects were weighted by species value compared with 16 projects if projects were not weighted. This highlights the value of a transparent decision-making process, which enables a careful consideration of trade-offs. The use of PPP can substantially improve conservation outcomes for threatened species by increasing efficiency and ensuring transparency of management decisions.*

Keywords: conservation planning, conservation priorities, cost-benefit analysis, probability of success, species management, species values, threat status

Asignación Óptima de Recursos entre Especies Amenazadas: un Protocolo de Priorización de Proyectos

Resumen: *Los fondos para la conservación son insuficientes para atender la difícil situación de las especies amenazadas. Las organizaciones gubernamentales y de conservación encargadas de la tarea de conservar especies amenazadas desesperadamente requieren de estrategias simples para la asignación de recursos limitados. La literatura académica dedicada a la definición sistemática de prioridades generalmente recomienda clasificar a las especies considerando varios criterios, incluyendo el nivel de peligro y medidas del valor de las especies como la unicidad evolutiva, la importancia ecológica y el significado social. Estos métodos ignoran dos factores cruciales: el costo del manejo y la probabilidad de que el manejo sea exitoso. Estas omisiones resultarán en la asignación errónea de recursos de conservación escasos y, posiblemente, en pérdidas innecesarias. Diseñamos un protocolo de priorización de proyectos (PPP) para optimizar la asignación de recursos entre los proyectos sobre especies amenazadas de Nueva Zelanda, en el que se consideraron simultáneamente los costos, los beneficios (incluyendo valor de las especies) y la probabilidad de éxito del manejo. Comparamos*

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el número de especies manejadas y los beneficios esperados obtenidos con cinco criterios de priorización: PPP con ponderaciones basadas en el valor de las especies; PPP con ponderaciones equitativas de especies; costos de manejo; valor de las especies y estatus de amenaza. Encontramos que el uso racional de la información de costo y éxito incrementó sustancialmente el número de especies manejadas, y la priorización de proyectos de manejo de acuerdo con el valor de las especies o el estatus de amenaza fue insuficiente y resultó en menos especies manejadas. Adicionalmente, encontramos una clara desventaja entre el financiamiento de la mayoría de los proyectos más rentables y menos riesgosos y el financiamiento de menos proyectos para manejar las especies de mayor valor. Específicamente, 11 de 32 proyectos pudieran ser financiados si los proyectos fueran ponderados por el valor de las especies en comparación de 16 proyectos si no hubiera ponderación. Esto resalta el valor de un proceso transparente de toma de decisiones, que permite una consideración cuidadosa de los pros y contras. El uso de PPP puede mejorar sustancialmente los resultados de la conservación de especies amenazadas al incrementar la eficiencia y asegurar la transparencia de las decisiones de manejo.

Palabras Clave: análisis de costo-beneficio, estatus de amenaza, manejo de especies, planificación de la conservación, prioridades de conservación, probabilidad de éxito, valores de las especies

Introduction

The resources available for conserving the world's biodiversity are grossly inadequate for the task. The existing expenditure is just a fraction of the predicted total cost of maintaining global biodiversity (James et al. 2001; Balmford et al. 2003). Currently, only a small proportion of species recognized as threatened with extinction are managed for recovery (Baillie et al. 2004). In the years 1989–1991, 54% of U.S. funding was devoted to conservation of just 1.8% of all U.S. threatened species (Metrick & Weitzman 1996). Similarly, in 2006 only 22% of New Zealand's threatened species were managed, and many of these were inadequately managed to ensure persistence (Joseph et al. 2008). Given this shortfall in available resources, it is essential that the capital available for management of threatened species be spent wisely.

Formal methods for setting threatened-species priorities are often conducted by identifying species that are highly threatened or valuable and ranking them according to one or both criteria. The management of species near the top of the rank-ordered list is then funded (Miller et al. 2006). A number of frameworks exist for ranking species based on criteria such as the level of endangerment (Master 1991; Carter et al. 2000), evolutionary distinctiveness (Faith 1994; Vane-Wright et al. 1994; N. J. Isaac, S. T. Turvey, B. Collen, C. Waterman, and J. E. Baillie. 2007. Mammals on the EDGE: conservation priorities based on threat and phylogeny. Public Library of Science ONE 2:e296.), a combination of these and sociopolitical significance (Rodríguez et al. 2004), ecological importance, and potential for recovery (Marsh et al. 2007). Understanding how to value species and the urgency required for management is essential for making good decisions. Nevertheless, any method that considers only these criteria and ignores financial and technical con-

straints will result in fewer species being managed and potentially unnecessary extinctions (IUCN 2001; Possingham et al. 2002; Mace et al. 2006; Miller et al. 2006).

A species of low threat status or value may be cheap to secure, whereas management of a highly threatened or valuable species may be costly and have little potential to reduce extinction risk. By failing to consider the cost of management, the technical capacity to manage, and the potential for species recovery, standard approaches to priority setting make the implicit assumption that the conservation budget is large enough to fund all projects. This incorrect assumption results in misallocation of scarce conservation resources and potentially more extinctions. Simultaneously considering species value and financial and technical constraints ensures that cost-efficient management is given priority and will maximize conservation outcomes.

The Noah's Ark framework (Metrick & Weitzman 1998; Weitzman 1998) provides a cost-efficient solution to the problem of threatened-species resource allocation. The framework considers the benefits (i.e., increase in the probability of a species persisting under a recovery project), costs of the recovery project, species contribution to diversity (i.e., distinctiveness), and value of the species (i.e., utility of a species). On the basis of mathematical theory (i.e., knapsack theory, Kellerer et al. 2004), with a slightly flexible total budget of a reasonable size, the Noah's Ark framework presents an optimal or near-optimal solution (i.e., a greedy solution, Martello & Toth 1990; Weitzman 1998; Hartmann & Steel 2006).

Although the Noah's Ark framework provides an appropriate methodology for considering costs and benefits of conservation, it fails to consider a factor that is crucial for making sound decisions to maximize conservation outcomes: the probability that the management will succeed. A management action that is likely to succeed should be given a higher priority than an action that is

likely to fail. Managers often have a good understanding of their confidence in management projects, but these judgments have never been included in a formal decision-making process. Thus, we developed the Noah's Ark framework to include the likelihood that management will succeed.

In addition, we extended the Noah's Ark concept and applied it to a genuine management problem. Only theoretical examples are described in the literature (Weitzman 1993). We developed the theoretical framework into an operational Project Prioritization Protocol (PPP) that requires setting conservation objectives (Nicholson & Possingham 2006) and targets (see Sanderson 2006), clarification of realistic working definitions of benefits, costs and values, and careful consideration of the effects of data limitations. We applied the PPP to the problem of minimizing the number of extinctions of species over 50 years with a fixed budget. We used the framework in a case study of the allocation of conservation resources for managing the threatened species of New Zealand, including a representative range of terrestrial and freshwater taxonomic groups.

Our aim was to investigate efficiency of the PPP in choosing the optimal set of management actions to maximize the overall benefit to a region's threatened species under financial constraints. We compared 5 priority-setting methods: PPP with weightings based on species value, PPP with species weighted equally, management costs, species value, and threat status. We examined their efficiency with 4 metrics of success: number of species managed; expected benefit gained by managing the set of species; summed value of the set of species managed; and summed expected value gained by managing the set of species. In summary we assessed the gains in efficiency in spending afforded by properly incorporating information about species values and the management costs, benefits, and likelihood of management success.

Methods

Case Study: Management of the Threatened Species of New Zealand

New Zealand is experiencing a massive biodiversity crisis. Over the last 100 years, there have been 33 documented extinctions, including 16 birds, 9 terrestrial invertebrates, and 6 vascular plants (King 1984; Hitchmough et al. 2005). Of the more than 90,000 indigenous species, about 2,000 are listed as threatened and another 3,000 are data deficient under New Zealand's threatened-species classification system (Hitchmough et al. 2005). The Department of Conservation has a total budget of approximately NZ\$32 million/year (Department of Conservation 2006) specifically to improve the status of threatened species.

Project Prioritization Protocol

The PPP consisted of 9 steps: (1) define objectives, (2) list biodiversity assets (in this case, threatened species), (3) weight assets, (4) list management projects, (5) calculate the costs of each project, (6) predict the benefit to species generated by each project, (7) estimate likelihood of success, (8) state constraints, and (9) combine information on costs, values, benefits and likelihood of success to rank projects according to benefits per unit dollar and choose set of projects.

STEP 1: DEFINE OBJECTIVES

To optimally allocate resources among management projects, it is essential to clearly state the objectives (Possingham et al. 2001; Sanderson 2006). The general goal set by New Zealand's Department of Conservation Threatened Species Program is to improve security of the greatest possible number of unique species. The term *security* refers to initial security from extinction in the wild. Security is achieved when available evidence indicates there is a viable population (i.e., one or more spatially discrete populations) that is stable and will be able to recover in the future once key agents of decline have been removed or mitigated. The uniqueness of a species is measured as its taxonomic distinctiveness (see step 3).

STEP 2: LIST BIODIVERSITY ASSETS

Biodiversity assets are the components of biodiversity that one wishes to secure from extinction. In our case study, biodiversity assets were species that have $\leq 95\%$ probability of being secure in 50 years if they are not managed. We assumed that species that are not likely to be secure in 50 years are those that are currently listed in one of the following threat categories of New Zealand's threatened species classification system (Hitchmough et al. 2005): nationally critical (NC), nationally endangered (NE), nationally vulnerable (NV), serious decline (SD), gradual decline (GD), sparse (S), and range restricted (RR).

To illustrate our protocol, we used 32 species listed on New Zealand's list of threatened species that represented a broad range of threat categories (15 NC, 10 NE, 1 NV, 2 SD, 2 GD, 1 S, and 1 RR), taxonomic groups (4 frogs, 1 bat, 7 birds, 3 freshwater fish, 3 reptiles, 4 terrestrial invertebrates, and 10 vascular plants), measures of taxonomic distinctiveness (number of close relatives, see step 3), and potential management actions (e.g., captive breeding and translocation, fencing, predator control). The common and scientific names of the case-study species are in Table 1.

STEP 3: WEIGHT ASSETS

Social, political, or biological values may be incorporated into PPP by weighting species (see step 9). Species may

Table 1. A list of the project parameters (benefit, *B*; cost, *C*; and probability of success, *S*) and species parameters (taxonomic distinctiveness, *T*; and threat status) that were used to calculate weighted and unweighted project efficiency.

<i>Common name</i>	<i>Scientific name</i>	Weighted efficiency * 1e12	Unweighted efficiency * 1e9	<i>Benefit</i>	<i>Taxonomic distinctiveness</i>	<i>Cost</i> (\$)	<i>Probability of success</i>	<i>Threat status</i>
Dactylanthus	<i>Dactylanthus taylorii</i>	218502	927	0.70	0.236	755,103	1.00	4 serious decline
Maud Island frog	<i>Leiopelma pakeka</i>	47849	550	0.70	0.087	1,273,311	1.00	2 nationally endangered
Shrubby tororaro	<i>Muehlenbeckia astonii</i>	43206	473	0.40	0.091	760,615	0.90	3 nationally vulnerable
Hamilton's frog	<i>Leiopelma hamiltoni</i>	39012	448	0.60	0.087	1,338,631	1.00	1 nationally critical
North Island brown kiwi	<i>Apteryx mantelli</i>	26854	120	0.95	0.224	7,910,292	1.00	4 serious decline
Climbing everlasting daisy	<i>Helicrysum dimorphum</i>	22112	942	0.35	0.023	371,438	1.00	2 nationally endangered
Hochstetter's frog	<i>Leiopelma hochstetteri</i>	22099	254	0.10	0.087	354,472	0.90	6 sparse
New Zealand shore plover	<i>Plimornis novaeseelandiae</i>	15296	355	0.40	0.043	855,261	0.76	1 nationally critical
	<i>Pittosporum patulum</i>	12902	294	0.95	0.044	3,229,002	1.00	2 nationally endangered
	<i>Oreomyza sp.</i>	12746	869	0.70	0.015	724,823	0.90	2 nationally endangered
	<i>Pachycladon exilis</i>	12573	515	0.95	0.024	884,866	0.48	1 nationally critical
Archev's frog	<i>Leiopelma archeyi</i>	11168	128	0.70	0.087	4,909,753	0.90	1 nationally critical
Canterbury mudfish	<i>Neochanna burrowsius</i>	8425	173	0.95	0.049	891,340	0.16	2 nationally endangered
	<i>Carmichaelia hollwayi</i>	3721	637	0.70	0.006	751,950	0.68	1 nationally critical
	<i>Poa spania</i>	3570	743	0.70	0.005	847,626	0.90	1 nationally critical
Chatham Island oystercatcher	<i>Haematopus chathamensis</i>	2768	223	0.95	0.012	1,798,486	0.42	1 nationally critical
Kaki	<i>Himantopus novaeseelandiae</i>	1962	102	0.95	0.019	8,851,848	0.95	1 nationally critical
	<i>Cardamine cf. bilobata</i>	1647	216	0.95	0.008	874,373	0.20	1 nationally critical
Black robin	<i>Petroica traversa</i>	1311	107	0.40	0.012	1,534,592	0.41	1 nationally critical
Pygmy button daisy	<i>Leptinella nana</i>	704	86	0.60	0.008	297,571	0.04	2 nationally endangered
Cook Strait giant weta	<i>Deinacrida rugosa</i>	592	509	0.40	0.001	785,586	1.00	7 range restricted
Big-nose galaxias	<i>Galaxias macronansus</i>	525	28	0.95	0.019	2,047,005	0.06	5 gradual decline
Long-tailed bat	<i>Chalinolobus tuberculata</i>	332	31	0.95	0.011	6,210,151	0.21	2 nationally endangered
Carabid beetle	<i>Zecillenus tillyardi</i>	325	117	0.70	0.003	1,242,714	0.21	1 nationally critical
Lowland long jaw galaxid	<i>Galaxias cobitidis</i>	283	15	0.95	0.019	1,757,261	0.03	1 nationally critical
Orange-fronted parakeet	<i>Cyanoramphus malberbi</i>	266	6	0.95	0.041	14,453,678	0.10	1 nationally critical
Mohua	<i>Moboua ochrocephala</i>	188	26	0.40	0.007	5,762,489	0.38	2 nationally endangered
Grand skink	<i>Oligosoma grande</i>	159	58	0.95	0.003	7,754,153	0.48	1 nationally critical
Otago Skink	<i>Oligosoma ottagense</i>	159	58	0.95	0.003	7,754,153	0.48	1 nationally critical
Short horned grasshopper	<i>Sigaus minutus</i>	49	33	0.90	0.001	3,795,354	0.14	5 gradual decline
Chevron skink	<i>Oligosoma bomalonotum</i>	35	13	0.70	0.003	7,888,632	0.14	2 nationally endangered
Robust grasshopper	<i>Brachapsis robustus</i>	19	8	0.90	0.002	5,636,964	0.05	2 nationally endangered
Minimum		19	6	0.10	0.0012	297,571	0.03	7 range restricted
Maximum		218502	942	0.95	0.2357	14,453,678	1.00	1 nationally critical
Mean or median (denoted by *)		2365*	150*	0.73	0.0167*	3,259,484	0.56	2 nationally endangered*
Coefficient of variation				0.33		1.06	0.67	
Fold difference		11661	146	10	203	49	36	7

be weighted on the basis of factors such as cultural significance, economic importance, evolutionary significance, ecological function, and endemism, or species may be treated equally (i.e., no weights). If more than one type of value is used to weight species, the values can be combined by summing their weighted scores. The Noah's Ark framework combines 2 species values: distinctiveness and species utility. We considered only distinctiveness and assumed the utility of species was the same for all species (i.e., equal to zero).

The weighting factor, W_i , quantified the taxonomic distinctiveness of species i , where distinctiveness was inversely related to the number of relatives of species i . For example, a species that has many close relatives (e.g., robust grasshopper) was given a small weight, whereas a species that has few close relatives (e.g., North Island Brown Kiwi) received a large weight. We expressed taxonomic distinctiveness as the inverse of the product of the number of branches at the genus, family, and order nodes (i.e., a modified version of the method of Daniels et al. [1991]). We believe taxonomic distinctiveness is well characterized for our purposes by this method because it delivers a metric that is continuous and encapsulates diversity at the species, genus, and family levels. This method is rapid and inexpensive and can be applied to a simple, widely available, and partially resolved taxonomic system, such as Linnaean taxonomy.

By weighting species by their taxonomic distinctiveness, we sacrificed species richness for taxonomic diversity (Solow et al. 1993). We maintained the order of species while reducing the magnitude of the weighting so that less emphasis was placed on taxonomic diversity and more on species richness by taking the x th root of measure of distinctiveness (Solow et al. 1993). The choice of x depended on the relative value of taxonomic diversity and species richness; we used $x = 2$ because it provided a balance between conserving the greatest number of unique species and simply the greatest quantity of species. Therefore, we measured the taxonomic distinctiveness for species, W_i , as the x th root of the inverse of the product of the number of branches, b , at the genus, family, and order nodes, n :

$$W_i = \sqrt[x]{\frac{1}{\prod_n b}}, \quad (1)$$

where $x = 2$. We used the on-line version of the Annual Checklist (<http://www.catalogueoflife.org/annual-checklist/2007/>) of the Catalogue of Life (Bisby et al. 2007) to estimate the number of branches at each node. The Catalogue of Life is incomplete and some of the species or genera are not listed. When a species or genus of interest was absent from the list, we added this taxon to the total number of branches.

STEP 4: LIST MANAGEMENT PROJECTS

We asked experts to choose an appropriate project for each species. A project was the minimum set of all necessary actions for obtaining a reasonable ($\geq 95\%$) probability of securing the species over 50 years. Projects had 4 compulsory components (outcome monitoring, services and support, project management, and infrastructure) and at least one optional intervention (e.g., captive breeding, translocation, pest animal control, weed control, legal actions, and education). Experts clearly described a precise location, intensity, and duration of management for each action. Because there was a one-to-one match of projects and species, we used the index i for both.

STEP 5: ESTIMATE COST

The cost of each project, C_i , was estimated each year and converted to current dollar values. Costs included all future outlays, whereas past outlays (e.g., the cost of building captive-breeding facilities that are now available for use) were not considered. We calculated the net present value of the cost to fund each project over 50 years as

$$C_i = \sum_t^{50} \frac{c_{i,t}}{(1+r)^t}, \quad (2)$$

where c is the cost of project i in year t and r is a discount rate derived from the present value of future spending (i.e., discount factor). For example, if it cost \$10,000/year to control stoats now, \$395,881 in today's dollars ($r = 0.01$) would be needed for stoat control over 50 years. Effectively, our choice of the discounting rate (e.g., $r > 0$) resulted in the cost of actions in the future being cheaper in today's dollars. In the case in which an action benefited more than one species, the cost of the action among the species projects could be shared; thus, actions that benefited multiple species were favored.

STEP 6: ESTIMATE BENEFITS

The impact of project i on the species probability of being secure was recorded as the biodiversity benefit, B_i . Security probabilities are related to extinction probabilities and may be calculated from stochastic population models (Burgman et al. 2001; Drechsler & Burgman 2004) or estimated directly with expert knowledge (Cullen et al. 2001, 2005). Because knowledge available for many of the species is not sufficient to estimate parameters for population viability models, we used experts to estimate security probabilities directly. The biodiversity benefit of project i , B_i , is the difference between the probability of the species being secure in 50 years with (P_i) and without (P_0) management:

$$B_i = P_i - P_0. \quad (3)$$

STEP 7: ESTIMATE LIKELIHOOD OF SUCCESS

We asked experts to state the probability that each project, i , could be implemented successfully, M_i , and the probability that, if implemented successfully, it would be reasonably ($\geq 95\%$) successful in securing the species, N_i . Only actions that would have a direct impact on the probability of security (e.g., translocation) were assessed, whereas essential actions that would not have direct effects (i.e., compulsory actions such as infrastructure and service support) were assumed to have 100% probability of succeeding. Total probability of success of each project, S_i , was $S_i = M_i N_i$.

To aid in estimation of the probabilities of implementation success, we asked experts to provide probabilities on a series of possible limitations to the success of the projects. Factors that may contribute to failure of the project included operational (e.g., isolation, difficulty moving around terrain, capacity, unpredictable, prohibitive weather), legal (e.g., resource-management acts, building codes, health and safety, animal ethics), and political and social (e.g., public attitude, conflicting land use, iwi views, access permission) constraints. Experts estimated the probability of successfully implementing each action of project i , and we combined the probabilities to calculate the total probability of successful implementation of the full project, M_i :

$$M_i = \prod_{j=1}^J K_{ij}, \quad (4)$$

where K_{ij} is the probability that action j of project i works.

Experts directly estimated the probability of technical success, N_j , of each action in the project through demonstrated evidence and confidence in project choice. Experts based their estimates on knowledge of the proportion of successes and failures of past implementation and said whether their opinions were based on information relevant to the same or other species, habitats, threats, and scales. We combined the probability of technical success for each action to calculate the total probability of technical success for the i th project, N_i as follows:

$$N_i = \prod_{j=1}^J L_{ij}, \quad (5)$$

where L_{ij} is the probability that action j of project i succeeds.

STEP 8: STATE CONSTRAINTS

The primary constraint on the resource-allocation problem was the total budget available for management of threatened species. We focused on 32 species, and the total budget was proportional to the budget available for

all 2000 threatened species. The total budget available for the management of 2000 threatened species in the 2005–2006 financial year (i.e., \$32,000,000) was equivalent to an annual budget of \$512,000. Allocation of this amount among 32 species projects resulted in a budget of \$20,269,096 for the 50-year period (with $r = 0.01$ discounting).

STEP 9: CHOOSE SET OF PROJECTS

The Noah's Ark framework ranks species or species projects on the basis of ranking criterion, R , which is a cost-efficiency metric:

$$R_i = \frac{W_i \times \Delta p_i}{C_i}, \quad (6)$$

where Δp is analogous to our biodiversity benefits, B , and is defined as the change in survivability of a species i and W is the sum of distinctiveness and species utility.

We modified the cost-efficiency measure to include the likelihood of success of a project and called the modified metric the project efficiency, E , of project i . The E_i was calculated as:

$$E_i = \frac{W_i \times B_i \times S_i}{C_i}, \quad (7)$$

where W_i is the species weights, B_i is the biodiversity benefits, S_i is probability of success, and C_i is the cost of project i .

COMPARISON OF PRIORITY SETTING METHODS

We used 4 metrics to measure efficiency: number of species managed; expected benefit gained by managing the set of species (i.e., sum of the product of the benefit and the probability of success); uniqueness of the set of species managed (i.e., summed uniqueness values); and expected uniqueness gained by managing the set of species (i.e., the sum of the product of the benefit, the probability of success, and the taxonomic distinctiveness). We compared the efficiency of prioritizing management projects by their project efficiency with species weighted by taxonomic distinctiveness with 4 other criteria: project efficiency when species are weighted equally, cost, taxonomic distinctiveness, and threat status.

Project efficiency with species weighted by taxonomic distinctiveness was calculated with the methodology described earlier (hereafter referred to as weighted project efficiency). We ranked species projects in order of decreasing weighted project efficiency values: small values were ranked lower than high values. The project efficiency when species were weighted equally was calculated in the same manner; however, species weights were considered equal to each other and equal to one (hereafter referred to as unweighted project efficiency).

We ranked species projects in decreasing order of the unweighted project efficiency value. The procedure for calculating project costs is outlined earlier. We ranked projects in increasing order of price. Taxonomic distinctiveness was calculated with the methods described earlier. Projects were ranked on the basis of the taxonomic distinctiveness of each species: species with few close relatives were ranked higher than those with many close relatives. To rank projects by species threat status, we used the threat categories and species status of New Zealand's Classification Species List (Hitchmough et al. 2005). In this system species are listed in 1 of 8 categories of threat. We assumed an order of decreasing extinction risk from NC, NE, NV, SD, GD, S, and RR to not threatened. We ranked projects in order of decreasing extinction risk of the species. To distinguish among species within threat categories, we ranked projects by their cost: inexpensive projects were given a higher ranking. We selected cost of management because it is an intuitive and important consideration and information required to rank management projects by cost is readily available (compared with probability of success or benefits).

Results

The management project parameters (costs, benefit, and probability of success) and species parameters (taxonomic distinctiveness and threat status) spanned a wide range and generated informative project efficiency values for species management projects (Table 1).

Order of Species Projects

The order of species projects varied considerably for each of the 5 priority-setting methods (Table 2). For the projected available budget of \$20,269,096, a different set of projects was selected by each of the priority-setting methods. The first 4 methods (both project efficiency, cost and distinctiveness methods) selected comparatively similar sets of projects, whereas the threat-status ranking criterion's set of projects was noticeably different. For threat-status ranking, 3 projects were selected in common with both of the project efficiency and cost methods, whereas these 3 methods shared 9 of a possible 11 projects in common.

Table 2. Species projects ranked with the weighted project efficiency (columns 1 & 2) and priority ranks obtained with the 4 other priority-setting methods: unweighted project efficiency, cost, taxonomic distinctiveness, and threat status.

Species	Weighted efficiency rank	Unweighted efficiency rank	Cost rank	Distinctiveness rank	Threat status rank
<i>Dactylanthus</i>	1*	2*	6*	1	27
Maud Island frog	2*	6*	15*	4	20
Shrubby tororaro	3*	9*	7*	3	26
Hamilton's frog	4*	10*	16*	5	7*
North Island Brown Kiwi	5*	18	30	2	28
Climbing everlasting daisy	6*	1*	3*	13	17
Hochstetter's frog	7*	13*	2*	6	31
New Zealand Shore Plover	8*	11*	10*	10	3*
<i>Pittosporum patulum</i>	9*	12*	21	9	21
<i>Oreomyrrhis</i> sp. nov (= <i>O. aff rigida</i>)	10*	3*	4*	17	18
<i>Pachycladon exilis</i>	11*	7*	12*	12	5*
Archeys frog	12	17	23	7*	11*
Canterbury mudfish	13	16*	13*	8*	19
<i>Carmichaelia bollowayi</i>	14	5*	5*	24	1*
<i>Poa spania</i>	15	4*	9*	25	2*
Chatham Island Oystercatcher	16	14*	19*	18	10*
Kaki	17	21	31	14	14
<i>Cardamine</i> cf. <i>bilobata</i>	18	15*	11*	22	4*
Black Robin	19	20	17*	19	8*
Pygmy button daisy	20	22	1*	21	16
Cook Strait giant weta	21	8*	8*	32	32
Big-nose galaxias	22	27	20*	15	29
<i>Long-tailed bat</i>	23	26	26	20	24
<i>Carabid beetle</i>	24	19	14*	26	6*
Lowland long jaw galaxid	25	29	18*	16	9*
Orange-fronted Parakeet	26	32	32	11	15
Mohua	27	28	25	23	23
Grand skink	28	23	27	27	12
Otago skink	29	24	28	28	13
Short-horned grasshopper	30	25	22	31	30
Chevron skink	31	30	29	29	25
Robust grasshopper	32	31	24	30	22

*Species selected with a fixed budget of \$20,269,096.

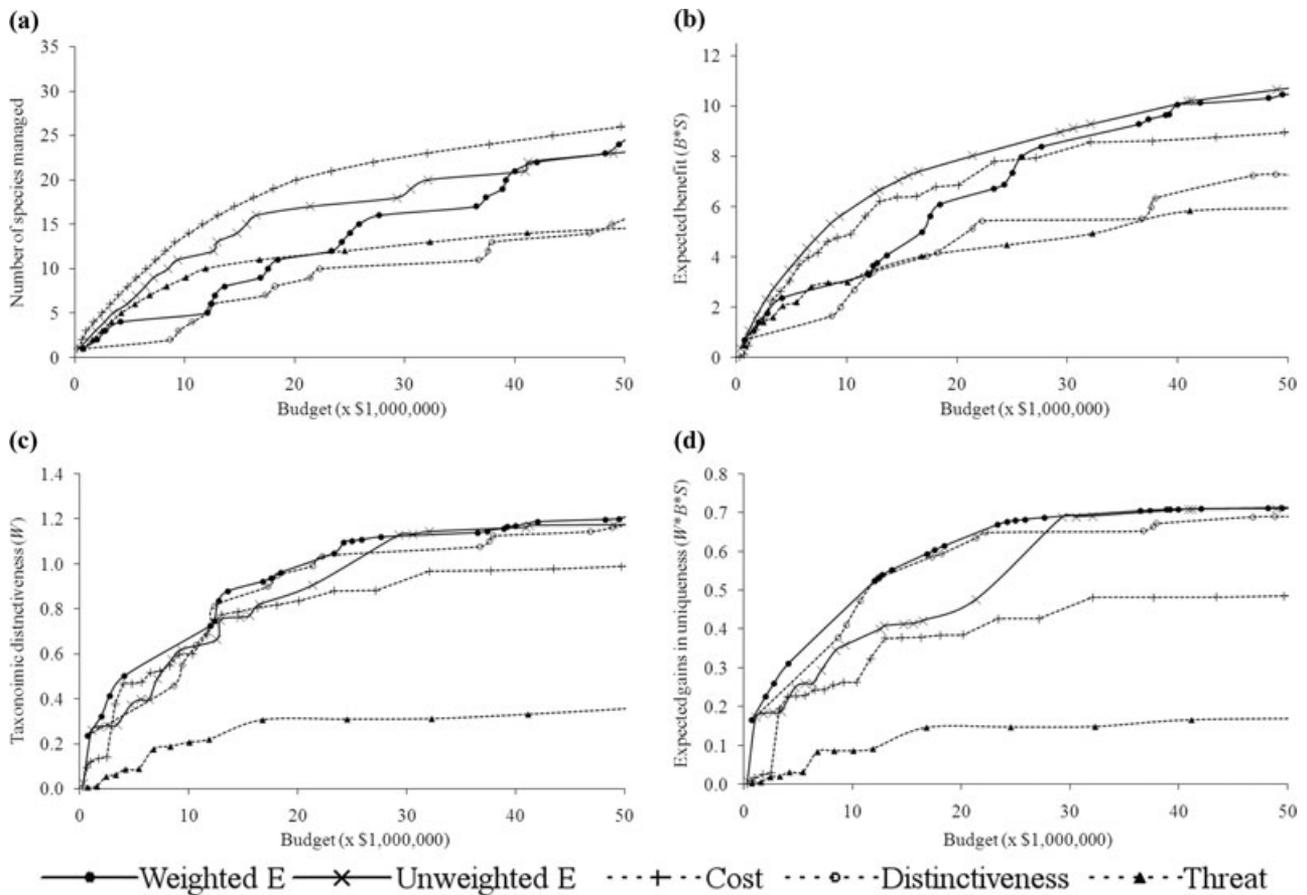


Figure 1. Returns on spending budgets up to \$50 million over 50 years for each of the 5 priority-setting methods: project efficiency with species weighted by taxonomic distinctiveness (weighted E); project efficiency when species are weighted equally (unweighted E); cost; taxonomic distinctiveness (distinctiveness); and threat status (threat). Returns are measured as (a) number of species managed, (b) expected benefit gained by managing the set of species (i.e., summed product of benefit and probability of success), (c) uniqueness of the set of species managed (i.e., summed taxonomic distinctiveness), and (d) expected uniqueness gained by managing the set of species (i.e., product of the benefit, probability of success, and taxonomic distinctiveness).

Number of Species Funded

The number of species projects that may be funded with a range of budgets (Fig. 1a) and the projected budget (Table 3) differed for each of the 5 priority-setting methods. The rank order produced by prioritizing projects

on the basis of cost always resulted in the most projects being funded for any given budget. Ranking projects with the unweighted project efficiency criterion was the second-most efficient method. Ranking species by taxonomic distinctiveness always resulted in the fewest species managed.

Table 3. The returns on the spending of \$20,269,096 over 50 years for each of the 5 priority-setting methods.*

Efficiency metrics	Weighted efficiency	Unweighted efficiency	Cost	Taxonomic distinctiveness	Threat status
Number of species managed	11	16	20	8	11
Expected benefit gained (B^*S)	6.09	7.39	6.86	4.18	4.02
Uniqueness of species managed (W)	0.96	0.82	0.83	0.95	0.31
Expected uniqueness gained (W^*B^*S)	0.61	0.42	0.38	0.59	0.15

*Returns are measured as number of species managed; expected benefit gained by managing the set of species (i.e., the summed product of benefit, B and probability of success, S); uniqueness of the set of species managed (i.e., summed taxonomic distinctiveness, W); and expected uniqueness gained by managing the set of species (i.e., the summed product of the benefit, B; probability of success, S; and taxonomic distinctiveness, W).

Expected Benefit Gained

The expected benefit gained by funding projects with the projected budget (Table 3) and across the range of budgets (Fig. 1b) differed among the 5 methods. The rank order generated by prioritizing projects on the basis of the unweighted project efficiency metric was always the most efficient because it generated the highest expected benefit for a given budget. Prioritizing projects on the basis of threat status or taxonomic distinctiveness produced the lowest expected benefit.

Uniqueness of Species Managed

Interestingly, ranking projects by taxonomic distinctiveness did not produce a rank order of species with the highest uniqueness for the majority of budgets (Fig. 1c), including the projected available budget (Table 3). For some budgets, 3 of the priority selection methods (cost, weighted and unweighted project efficiency criteria) generated a rank order that selected a set of species with a higher summed uniqueness value than ranking by taxonomic distinctiveness. Generally, ranking species projects by the weighted project efficiency produced a rank order with the highest summed uniqueness. Conversely, ranking species by threat status consistently selected a set of species with the lowest summed uniqueness.

Expected Uniqueness Gained

Across the range of budgets, the expected gains in uniqueness was maximized if projects were ranked by the weighted project efficiency (Table 3 & Fig. 1d). Ranking projects on the basis of taxonomic distinctiveness generated the second-highest expected gains in uniqueness. For larger budgets, the unweighted project efficiency criterion was equally as efficient as the weighted index; however, for smaller budgets, this method generated lower expected gains in uniqueness. Ranking projects by the species threat status performed poorly across all budgets because this ranking method produced very low expected gains in uniqueness.

Discussion

The PPP provided a means for prioritizing management to maximize conservation outcomes for threatened species when budgets were limited. Efficiency in spending was improved by considering project costs, benefits, and likelihood of success. The unweighted project efficiency criterion resulted in the maximum benefits gained for all budgets. The expected gains in value (i.e., uniqueness) from projects were maximized by simultaneously considering values, benefits, costs, and the probability of management success.

Inadequate Priority-Setting Methods: Threat Status and Values

Methods for prioritizing projects that focus exclusively on threat status resulted in management of fewer species and procurement of less benefit to threatened species in general. The projected available budget for threatened species management was enough to fund only 11 species projects when ranked by threat status, compared with the 16 projects that would be funded if species were ranked with the unweighted project efficiency ranking criterion. In addition, ranking species by threat status ignored species distinctiveness and hence selected projects for a set of species that were not highly valued.

Likewise, to prioritize projects efficiently, it is not sufficient to consider a species value, such as taxonomic distinctiveness, in isolation. Ranking species by their taxonomic distinctiveness resulted in appreciably fewer projects (8 projects) being funded with the available budget when compared with either of the project efficiency ranking methods (weighted project efficiency = 11 projects and unweighted project efficiency = 16 projects). In addition, the expected benefit gained was substantially lower than the unweighted project efficiency method (taxonomic distinctiveness = 4.18, unweighted project efficiency = 7.39). Significantly, for the majority of budgets, ranking projects by taxonomic distinctiveness did not maximize the summed taxonomic distinctiveness for the set of priority projects; in many cases, ranking projects by their cost or unweighted and weighted project efficiency scores performed better. Nevertheless, the expected uniqueness gained when ranking species on taxonomic distinctiveness was only slightly lower than the optimal choice of ranking with weighted project efficiency for all budgets. Prioritizing projects by species distinctiveness produced gains in uniqueness by giving high priority to a few species with high taxonomic distinctiveness rather than, as with the weighted project efficiency method, a greater number of species that are less taxonomically distinct.

Values and Objectives

A trade-off exists between funding the management of a greater number of the most cost-efficient and least risky projects and funding fewer projects to manage the species of higher value (i.e., uniqueness). The unweighted project-efficiency method resulted in the management of 5 additional species because it ignored species distinctiveness (i.e., unweighted project efficiency = 16 species compared with weighted project efficiency = 11 species). Five of 32 species is 15.6% of the case-study species; this is a considerable proportion, equivalent to 312 of the 2000 species listed as threatened in New Zealand.

Specifically, the unweighted project-efficiency method ranked the species such that 6 additional species,

including 3 plants (*Carmichaelia hollowayi*, *Cardamine* cf. *bilobata*, and *Poa spania*), a bird (Chatham Island Oystercatcher), a fish (Cantebury mudfish), and an invertebrate (Cook Strait giant weta) could be funded at the expense of the highly taxonomically distinct North Island brown kiwi. The additional 6 species were not individually taxonomically distinct (median = 0.007), but they were all relatively cheap to manage (mean = \$991,560, CV = 0.40) and had high benefits (mean = 0.78, CV = 0.28) or a high potential for management success (mean = 0.56, CV = 0.63).

To maximize the expected value (in this case, taxonomic distinctiveness) of a set of species, it is essential to weight management benefits by the species value. Nevertheless, to what degree should efficiency (e.g., number of species managed or total expected benefit) be sacrificed for the preferential allocation of resources to highly valued species? The North Island Brown Kiwi has high taxonomic distinctiveness ($W = 0.224$); hence, it is highly valued by the weighted project efficiency criterion. Nevertheless, is funding this species worth sacrificing 6 other species, even if each is individually relatively taxonomically indistinct? Managers need to think clearly about their intention for weighting species by their uniqueness or any other value and the ramifications of the form of metric selected. The PPP provides a transparent approach to project selection that promotes scrutiny of decisions such as this.

Department of Conservation policy

New Zealand's Department of Conservation is using the PPP to enable efficient allocation of resources among management projects for its work on threatened species and ecosystems. Initial prioritization is aimed at maximizing the number of species secured from extinction. Additional objectives include restoring threatened species to self-sustaining populations and maximizing ecological integrity. They have used PPP to assess management projects and generate a rank-ordered list of species projects to guide senior managers in resource allocation decisions for more than 2000 species. The process has taken <1.5 years and 105 experts have been consulted. We do not believe this process is beyond the capabilities of any national government department, including mega-diverse countries, where data are limited. If there is enough data to list the species on threatened species lists, then there should be enough data to rank management projects with project prioritization protocol.

Conclusion

Our protocol for prioritizing management actions integrates biological data, financial and technical constraints,

and social and/or biological values. The framework provides a systematic, transparent, and repeatable method for prioritizing actions to minimize the number of extinctions. Clearly stating the steps used to make decisions presents an opportunity to scrutinize and improve the decision-making process; initiates a forum for the explicit examination of management principles and limitations, including the development of unambiguous working objectives; and reveals knowledge gaps and uncertainty in the system. We demonstrated that to select management actions that maximize conservation outcomes, it is insufficient to prioritize species based solely on threat status or species value. Correspondingly, return on investment of conservation dollars is substantially improved by incorporating management costs, benefits, and likelihood of management success. Consequently, the number of species managed and the expected overall benefit to threatened species is increased remarkably.

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