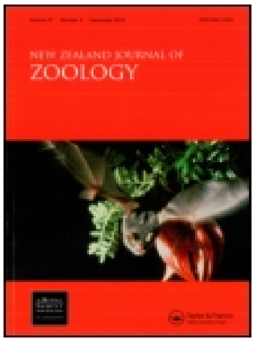

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A method of ranking species and sites for conservation using presence-absence data and its application to native freshwater fish in New Zealand

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Abstract Rareness or percent occurrence for species is derived from presence/absence matrices (sites × species) and used to calculate a set of indices for ranking sites and species. The indices are designed to weight for sites with greater species richness and presence of rare species. New Zealand native freshwater fish distributions are used as an example. Map quadrants and catchment areas with high index values are identified. The ranks are compared with selections made by experts and found to agree closely. The advantages and disadvantages of the method are discussed along with its place in reserve design.

Keywords Index values; ranking; conservation; *Galaxias*; indices

INTRODUCTION

Much of conservation theory has been centred on the theory of island biogeography as developed by MacArthur & Wilson (1967) and others. The well-known links between island area and species richness (the numbers of different species), and species-area curves, have been extensively examined, e.g., Kobayashi (1985). Species-area curves have also been examined for nature reserves; it was found that correlations are weaker than those of islands (Usher 1973). Rafe et al. (1985) found a derivative link between bird species richness and areas of certain habitat types, e.g., woodlands, wetlands, etc. in British bird reserves. There is, however, still a shortage of quantitative methods by which species and/or sites can be ranked to set conservation priorities. Often there is a heavy reliance on the considered opinions of experts. Where possible, means must be sought for supporting and reinforcing the work of experts.

Conservation efforts are often focussed on species that are rare numerically or have limited distributions, and/or sites that contain a high species richness in a relatively undisturbed state. Further, it is often only possible to obtain species presence-absence data for a series of potential conservation sites. The biotic data may be augmented with data on site characteristics such as area, surficial geology, mean annual rainfall, etc. Reserve planners and others must then decide which sites, if protected, would most achieve their conservation objectives.

Here I present a numerical method of ranking species and sites using species presence/absence and auxiliary site data. I have assumed that the conservation objectives are: to protect species with limited distribution; and to maintain sites that support the greatest richness of the species assemblage under consideration. The method is applied to the assemblage of native freshwater fish in New Zealand. The assemblage is limited as result of the size and long isolation of New Zealand (McDowall 1978). The landscape of New Zealand has undergone considerable change (Anderson 1978). Prior to European colonisation, the Maoris cleared much of the lowland native forest. The Europeans cleared more land, began intensive farming, and introduced numerous species of plants and animals including a number of fish species. Introduced salmonids including brown and rainbow trout are widely distributed. Many native fish have limited distributions that have doubtless been reduced by colonisation, both human and faunal. There is a need to identify species and sites needing protection to conserve the native assemblage.

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METHOD

The problem of ranking species and sites must first be bounded by defining the species assemblage and the total set of sites. The species assemblage may be any set of species, e.g., all pulmonate snails, all deciduous trees, all rodents, all vertebrates, etc. The set of sites may be of any size or scale, e.g., all lakes within a state or province, all forests in a country, all 100 hectare blocks in a region bound by one degree of latitude and longitude, etc. In the application presented later, the species assemblage is all native freshwater fish in New Zealand.

The required input data may be described as follows:

Sites	Attribute	Species assemblage						
i	weights j =	1,	2,	3,	•	•	•	m
1	W_1	S_{11},	S_{12},	S_{13},	•	•	•	S_1m
2	W_2	S_{21},	S_{22},	S_{23},	•	•	•	S_2m
3	W_3	S_{31},	S_{32},	S_{33},	•	•	•	S_3m
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	S_{ij}	•	•
•	•	•	•	•	•	•	•	•
n	W_n	S_{n1}	$Sn2$	$Sn3$	•	•	•	Snm

where n = number of sites; m = number of species; W_i = attribute weight of site i (auxiliary site data); and S_{ij} = presence (1)/absence(0) of species j at site i.

The proportional occurrence (P_j) of species j across n sites weighted by site attributes W_i's is

$$P_j = \sum_{i=1}^{n} S_{ij}W_i / \sum_{i=1}^{n} W_i \tag{1}$$

The conservation priority (Q_j) of each species is assumed to be the complement of its rareness, P_j,

$$Q_j = 1.0 - P_j$$

Species which occur at all sites have a priority (Q_j) of zero while species only occurring at one site have a $Q_j=(n-1)/\mathrm{n}$. As the distribution of a species diminishes, so its conservation priority increases. Theoretically, a recently extinct, or thought to be extinct species, would have a priority of one. The species in the assemblage can be ranked by their Q_j values.

When rating sites, given our conservation objectives, it is logical to weight for rare species. The relative importance (I_i) of a site is defined as the sum of priorities of species present divided by the sum of priorities for all assemblage species.

$$I_i = \sum_{j=1}^{m} S_{ij}Q_j / \sum_{j=1}^{m} Q_j \tag{2}$$

Of course this index is sensitive to the richness of the site. To compensate for that, a second site index is calculated which is the average priority ($\dot{Q}_i$) of species present,

$$\dot{Q}_i = \sum_{j=1}^{m} S_{ij}Q_j / \sum_{j=1}^{m} S_{ij} \tag{3}$$

The importance index (I_i) can vary between 0 and 1 whereas the average priority ($\dot{Q}_i$) can vary in the range of species priorities (Q_j), roughly between 0 and 1. Sites with a large portion of assemblage species present will tend to have high I and intermediate $\dot{Q}$ values. Sites with a few rare species will have intermediate I and high $\dot{Q}$ values. Sites with a few common species will have low I and $\dot{Q}$ values. Sites can be ranked according to I or $\dot{Q}$ values, or if both species richness and rarity are to be ranked the indices can be combined $(I+\dot{Q})/2$.

The site attributes or weights (W_i) are used to refine the estimates of priority (Q_j). Such weights could include site area, assemblage abundance per unit area, or assemblage abundance by site. Other site attributes could be used to reorder the I, $\dot{Q}$ or $(I+\dot{Q})/2$ rankings. For instance, inaccessibility might be a desired site attribute with regard to ensuring conservation goals. The rankings could then be multiplied by an access factor ranging from 0 to 1, and rankings reordered.

APPLICATION TO NEW ZEALAND FRESHWATER FISH

An analysis of distribution data for New Zealand native freshwater fish illustrates the potential use of the I, $\dot{Q}$ and $(I+\dot{Q})/2$ indices. Presence/absence matrices for fish species were prepared using entries in the New Zealand Freshwater Fish Survey database (McDowall & Richardson 1983; Minns 1986). The database currently (22 November 1985) contains 6461 entries on over 5100 sites throughout New Zealand. Matrices were prepared in two ways:

(1) by catchment groupings in the New Zealand Land resource inventory (NWASCO 1975–79),
  (a) with weights equal to 1
  (b) with weights equal to catchment area,
(2) by sheets in the New Zealand Map Series #1.

Only catchment groups with five or more entries in the fish data base were considered. Larger catchments were dealt with singly whereas smaller catchments were dealt with in groups. Ideally, all catchments would be considered singly. The catchment weight was taken as to be the area (ha) per catchment. In all, 156 catchment groups were considered, of which 105 were single catchments. The 156 sites covered 221 042 km² or 83.4% of the New Zealand catchment area (Anderson 1978). Using the New Zealand Map Series #1 sheets, there were 296 sites for which species lists were available. All sheets were weighted equally (W_i=1) for ranking calculations.

Rankings obtained with the numerical method were compared with selections made by experts. Four scientists with Fisheries Research Division at

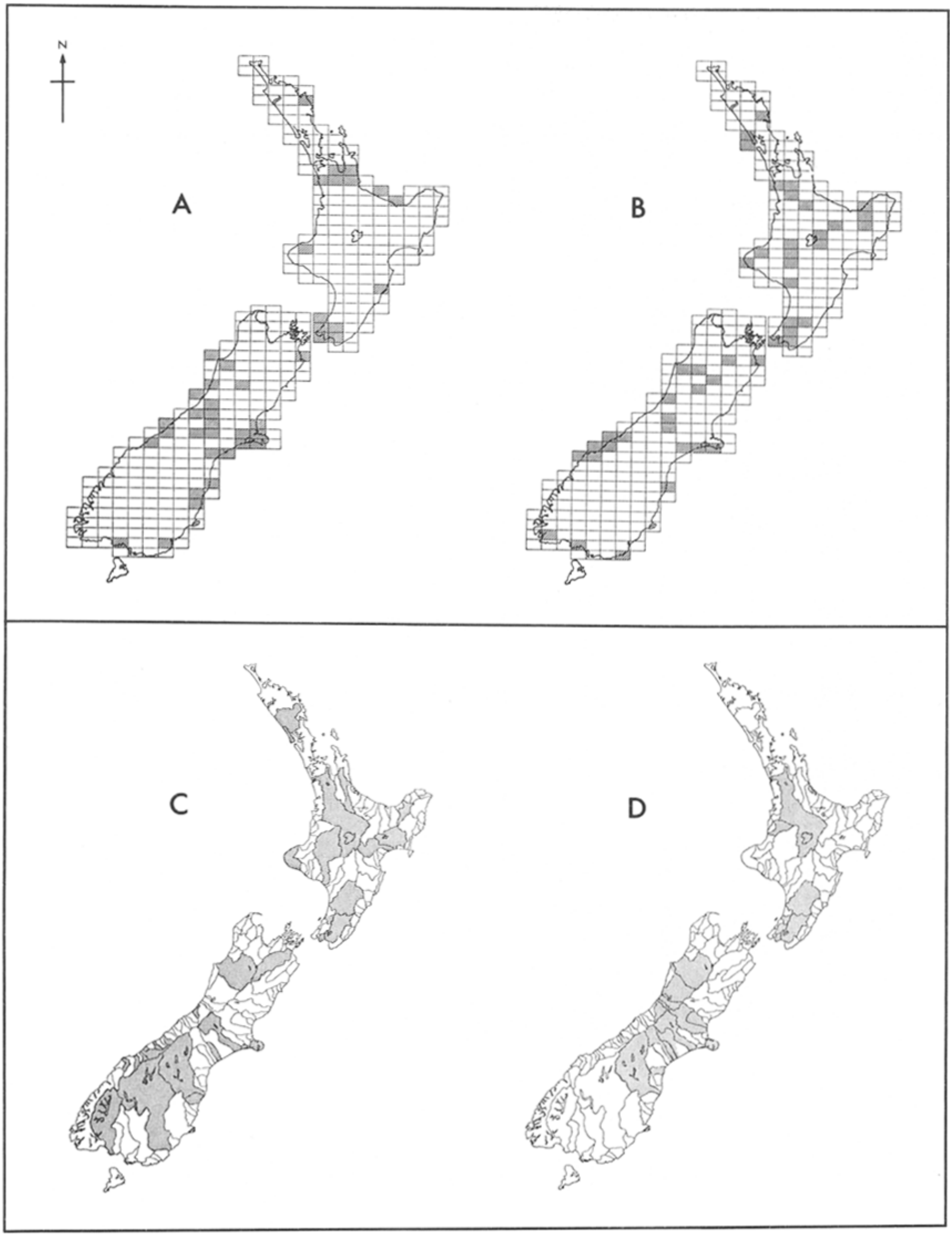

Fig. 1 Regions of New Zealand selected by ranking and by experts.
A — map sheets with $(I+Q)/2 \geqslant \bar{x}+s$
B — map sheets selected by experts
C — catchments with $(I+Q)/2 \geqslant \bar{x}+s$.
D — catchments selected by experts

Christchurch, New Zealand, were asked to select up to 10 catchment groups and 10 map sheets for each of the North and South Islands of New Zealand. They were instructed to select sites using their experience and knowledge with emphasis on the preservation of rare native species and the maintenance of greater richness, on a national scale. In addition they were asked to choose five species in greatest need of conservation measures.

RESULTS

In all 26 New Zealand native freshwater fish species were considered (Table 1). Species priorities (Q_j) for all three methods are in close agreement with the pairs of catchment values showing the greatest similarity (Table 1). The area-weighted catchment values show the greatest range. *Galaxias gracilis* is the rarest species while the longfinned eel, *Anguilla dieffenbachii*, is the most common, in all three priority sets. The experts had no difficulty picking out the species with the highest rankings (Table 1), picking 6 species in the top 10.

The site I, $\bar{Q}$, and $(I+\bar{Q})/2$ values cover similar ranges and have similar means and standard deviations, regardless of data set or weighting (Table 2). For comparison with the experts' choices, index values obtained for sheet areas and catchments, area-weighted, were sorted into four classes defined by the mean and one standard deviation for each index.

With both sheet areas and catchments, the experts consistently picked more sites with higher index

Table 1 Priority (Q_j) values for 26 New Zealand native freshwater fish species.

	Priorities (Q_j)				
		Catchment groups			
Species	NZMS #1 sheets	Unweighted	Area-weighted	Overall[1] rank	Expert selections*
Geotria australis	0.743	0.622	0.402	16	0
Anguilla australis	0.429	0.212	0.113	24	0
Anguilla dieffenbachii	0.220	0.077	0.020	26	0
Retropinna retropinna	0.605	0.462	0.308	19	0
Stokellia anisodon	0.983	0.968	0.906	3	0
Galaxias argenteus	0.814	0.647	0.545	15	3
Galaxias fasciatus	0.652	0.449	0.544	18	0
Galaxias postvectis	0.868	0.756	0.737	10	4
Galaxias brevipinnis	0.547	0.417	0.253	22	0
Galaxias maculatus	0.537	0.243	0.229	23	0
Galaxias vulgaris	0.760	0.846	0.587	13	0
Galaxias gracilis	0.990	0.994	0.998	1	4
Galaxias divergens	0.919	0.923	0.838	8	1
Galaxias prognathus	0.966	0.968	0.890	4	1
Galaxias paucispondylus	0.949	0.942	0.827	7	0
Neochanna apoda	0.943	0.910	0.912	6	0
Neochanna burrowsius	0.966	0.955	0.962	2	4
Neochanna diversus	0.966	0.955	0.891	5	3
Cheimarrichthys fosteri	0.588	0.449	0.308	20	0
Gobiomorphus huttoni	0.574	0.263	0.413	21	0
Gobiomorphus gobioides	0.865	0.795	0.734	9	0
Gobiomorphus cotidianus	0.375	0.115	0.077	25	0
Gobiomorphus hubbsi	0.797	0.654	0.714	14	0
Gobiomorphus breviceps	0.625	0.673	0.421	17	0
Gobiomorphus basalis	0.811	0.782	0.746	12	0
Rhombosolea retiaria	0.899	0.782	0.630	11	0
Total priorities	19.392	16.859	14.933		
Mean priority	0.746	0.648	0.574		
Number sites	296	156	156	–	–

[1] = average of three priorities (1 — high, 26 — low).
* = maximum possible is 4.

Table 2 Minimum, maximum, mean ($\bar{x}$), and standard deviation (SD) of site I, $\dot{Q}$ and $(I+\dot{Q})/2$ indices.

Site	Index	Minimum	Maximum	Mean	SD	n
NZMS #1	I	0.0	0.587	0.196	0.126	296
	$\dot{Q}$	0.0	0.868	0.553	0.117	296
	$(I+\dot{Q})/2$	0.0	0.628	0.375	0.102	296
Catchments unweighted	I	0.0	0.576	0.225	0.114	156
	$\dot{Q}$	0.0	0.814	0.402	0.092	156
	$(I+\dot{Q})/2$	0.0	0.560	0.314	0.092	156
Area-weighted	I	0.0	0.551	0.215	0.109	156
	$\dot{Q}$	0.0	0.717	0.341	0.081	156
	$(I+\dot{Q})/2$	0.0	0.504	0.279	0.085	156

Table 3 Comparison of the distributions of ranked areas with those selected by experts, A=catchments map sheets and B=catchments (area-weighted indices).

		Group frequencies								
Index	Source[a]	1	$\bar{x}-s$	2	$\bar{x}$	3	$\bar{x}+s$	4	N[a]	χ^2b
A-map sheets			0.070		0.196		0.322			
I	Sample (S)	35		133		82		46	296	
	Experts (E)	5		13		16		33	67	44.95*
			0.436		0.553		0.670			
$\dot{Q}$	S	18		119		137		25	296	
	E	5		10		48		4	67	23.52*
			0.273		0.375		0.477			
$(I+\dot{Q})/2$	S	32		121		102		41	296	
	E	6		10		18		33	67	52.36*
B-catchments			0.106		0.215		0.324			
I	S	23		70		39		24	156	
	E	4		13		18		23	58	27.21*
			0.260		0.341		0.422			
$\dot{Q}$	S	19		66		53		18	156	
	E	0		14		25		19	58	35.84*
			0.194		0.279		0.364			
$(I+\dot{Q})/2$	S	22		67		41		26	156	
	E	4		14		17		23	58	21.72*

a = Sample size, not all experts gave 20 selections.
b = G-test (Sokal & Rohlf 1981) with 3 df.
* = Significant at p = 0.01.

values (Table 3). In all six cases, indices by data type, the expert frequency distributions differed significantly (P=0.01) from the sample distributions. There is appreciable overlap of map sheets and catchments selected by the experts and those with $(I+\dot{Q})/2$ values greater than $\bar{x}$+s (Fig. 1). These results suggest that the indices I and $\dot{Q}$ reasonably approximate the selection process used by the experts.

DISCUSSION

The importance (I) and average priority ($\dot{Q}$) indices offer an objective means of ranking sites for identifying areas with greater species richness and concentration of rare species. There are advantages and disadvantages in the methodology. Also, such a ranking system can only be part of the overall process of reserve design and selection.

The method is based on the recognition that conservation is a relative process with arbitrary bounds on the sites and species to be considered. Use of such a method decreases reliance of reserve planners on limited expertise. The criteria for ranking are on view and therefore more readily subject to criticism and refutation. Used in conjunction with an extensive database, species and sites can be ranked in terms of national importance. Experts rarely have such a broad base of experience and knowledge.

However, I and $\bar{Q}$ index values are sensitive to the quality of the presence/absence data. All potential sites must have been surveyed and the species lists must be complete. In the case of New Zealand freshwater fish, there are a number of sheet areas and catchments for which no, or insufficient, data are available. There is also some evidence that some catchment species lists are incomplete despite five or more locations having been surveyed (Minns 1986). Significant sites may be denied protection because of inadequate surveys while rare species are easily missed. All species are not equally vulnerable to detection, regardless of sampling method. Thus, some species may be more widely distributed than known and have a lower than estimated priority.

With regard to the application of the method to native freshwater fish there are some difficulties. Some species have both sea-run and landlocked populations each with distinct life history features (McDowall 1978). To accommodate this, the assemblage could be revised with the two types being assigned distinct priorities (Q_j). Alternatively a rating scheme could be applied to lake sites only.

Further, the use of assemblage abundance weightings does not allow a distinction to be drawn between widely distributed species with large populations, e.g., *Galaxias brevipinnis,* and widely distributed species with limited populations, e.g., *G. argenteus* and *G. postvectis* (McDowall 1978; Jellyman pers. comm.). Another criterion that could be considered with the New Zealand fish assemblage is conservation of indigenous and commericial fisheries for eels and whitebait (the young of several galaxiids, especially *G. maculatus*). The difficulty would lie in designing a weighting scheme which give both very common exploitable and very rare species similar priorities.

Analyses such as I and $\bar{Q}$ ranking should only be part of a series of analyses that leads to the selection of sites worthy of conservation. In the case of New Zealand freshwater fish, McDowall (1984) put forward six criteria to be considered when designing reserves, i.e., naturalness, size, permanence of water, absence of exotic species and of exploitation, and, for most species, access to and from the sea. The I and $\bar{Q}$ can be used to select larger areas. Then the more specific criteria can be used to select among locations within an area. Analyses similar to the I and $\bar{Q}$ rankings could be applied to the distribution data on introduced fish species which are considered to have impacted the native fish (McDowall 1978). Then sites heavily infested with exotic species could be identified and excluded from selections.

Both the ranking method and the experts tended to select map areas near large urban centres and catchments with large areas. The first bias is no doubt due to more extensive data collection near to workbases. The reasons for the second bias include:
(a) the 'species-area' effect;
(b) the tendency for larger systems to have received more attention.

The latter cause also brings out the problem that many river systems in the selected larger catchments have been greatly modified by dams, diversions, and sometimes pollutants. Obviously, extensions to the scheme of site attribute weightings for indices can overcome this immediate weakness.

The method presented here offers an objective means of ranking species and sites for conservation purposes. The basic presence-absence data is often the most readily available. The use of various weighting factors gives the method considerable versatility. The components of the method can be subjected to tests as was done using the expert comparison. Such methods must play an increasing role in conservation science as the need for conservation grows.

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