Biological Conservation 174 (2014) 47–54

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Balancing phylogenetic diversity and species numbers in conservation prioritization, using a case study of threatened species in New Zealand

Joseph R. Bennett [a,*], Graeme Elliott [b], Belinda Mellish [c], Liana N. Joseph [d], Ayesha I.T. Tulloch [a], William J.M. Probert [a,e], Martina M.I. Di Fonzo [a], Joanne M. Monks [c], Hugh P. Possingham [a,f], Richard Maloney [c]

[a] Centre for Biodiversity and Conservation Science, University of Queensland, Brisbane 4072, Australia
[b] Department of Conservation, Private Bag 5, Nelson 7010, New Zealand
[c] Department of Conservation, Private Bag 4715, Christchurch Mail Centre, Christchurch 8140, New Zealand
[d] Wildlife Conservation Society, 2300 Southern Boulevard, Bronx, NY 10460, USA
[e] Center for Infectious Disease Dynamics, Pennsylvania State University, 208 Mueller Lab, University Park, PA 16802, USA
[f] School of Life Sciences, Silwood Park Imperial College London, Ascot, Berkshire, UK

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 17 March 2014
Accepted 24 March 2014
Available online 19 April 2014

Keywords:
Conservation planning
Prioritization
Threatened species
Evolutionary distinctiveness
Phylogenetic diversity
New Zealand

ABSTRACT

Funding for managing threatened species is currently insufficient to assist recovery of all species, so management projects must be prioritized. In attempts to maximize phylogenetic diversity conserved, prioritization protocols for threatened species are increasingly weighting species using metrics that incorporate their evolutionary distinctiveness. In a case study using 700 of the most threatened species in New Zealand, we examined trade-offs between emphasis on species' evolutionary distinctiveness weights, and the numbers of species prioritized, as well as costs and probabilities of success for recovery projects. Increasing emphasis on species' evolutionary distinctiveness weights in the prioritization protocol led to greater per-species costs and higher risk of project failure. In a realistic, limited-budget scenario, this resulted in fewer species prioritized, which imposed limits on the total phylogenetic diversity that could be conserved. However, by systematically varying the emphasis on evolutionary distinctiveness weight in the prioritization protocol we were able to minimize trade-offs, and obtain species groups that were near-optimal for both species numbers and phylogenetic diversity conserved. Phylogenetic diversity may not equate perfectly with functional diversity or evolutionary potential, and conservation agencies may be reluctant to sacrifice species numbers. Thus, we recommend prioritizing species groups that achieve an effective balance between maximizing phylogenetic diversity and number of species conserved.

1. Introduction

Global biodiversity loss is accelerating (Butchart et al., 2010), and current funding levels are inadequate to reverse this trend (McCarthy et al., 2012). Funding tends to be allocated unevenly, with taxonomic biases towards charismatic vertebrate species (Martín-López et al., 2009; Laycock et al., 2011). Both scientists and conservation agencies increasingly recognize that systematic prioritization schemes must be developed to efficiently allocate funding to minimize biodiversity loss (e.g. Bottrill et al., 2008; Wilson et al., 2011; IUCN, 2013). A number of frameworks exist for prioritizing threatened species management based on criteria such as threat level (Master, 1991; Carter et al., 2000), socio-political significance (Rodríguez et al., 2004), ecological importance, and potential for recovery (Marsh et al., 2007).

Phylogenetic diversity is considered a key component of biodiversity, reflecting life's evolutionary heritage, its functional diversity and potentially its ability to adapt to future conditions (Vane-Wright et al., 1991; Cadotte and Davies, 2010). Thus, the evolutionary distinctiveness of species has repeatedly been proposed as a key consideration in conservation prioritization, under the assumption that distinct species with few extant relatives are more important to maintaining phylogenetic diversity than species from diverse lineages, which are assumed to have greater genetic redundancy (e.g. May, 1990; Vane-Wright et al., 1991; Crozier, 1997).

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* Corresponding author. Tel.: +61 466424589.
E-mail address: j.bennett5@uq.edu.au (J.R. Bennett).

http://dx.doi.org/10.1016/j.biocon.2014.03.013

In attempts to shift the emphasis of conservation programmes from maximizing the total number of species conserved to maximizing conserved phylogenetic diversity, a variety of prioritization schemes have been proposed that weight species according to metrics incorporating their evolutionary distinctiveness. Redding and Mooers (2006) proposed a scheme that weights species according to the 'equal splits' distinctiveness metric, which divides evolutionary time of a branch equally among daughter branches, as well as probability of extinction. Isaac et al. (2007) designed a similar scheme, which weights species according to a slightly different measure of evolutionary distinctiveness (see *Methods* below) and International Union for Conservation of Nature (IUCN) threat status. Other methods (e.g. Vane-Wright et al., 1991; Faith, 1992, 2008) consider phylogenetic complementarity of the prioritized suite of taxa, with the goal of choosing a species group that protects as much total phylogenetic diversity as possible. Rosauer et al. (2009) and Cadotte and Davies (2010) proposed methods that explicitly consider both evolutionary distinctiveness and species ranges when prioritizing areas to maximize retained phylogenetic diversity. Cofré and Marquet (1999) designed a conservation priority index that includes an ordinal metric of taxonomic singularity, which assigns higher values to taxa with fewer closely-related species. Their metric also considers endemism and additional aspects such as threat status and geographic distribution. Joseph et al. (2009) devised a method that integrates prioritization of species based on distinctiveness as well as cost, probability of project success and expected change to probability of species' survival.

Given limited budgets, a shift in emphasis towards conserving phylogenetic diversity of a planning area by prioritizing evolutionarily distinct species may result in trade-offs leading to fewer individual species being conserved. If conserving maximum phylogenetic diversity in a planning area is the primary goal, this trade-off may be unimportant. However, the evolutionary distinctiveness of species may not be a perfect reflection of their long-term ecological importance. In particular, phylogenetic clustering of extinction risk in some older lineages (Gaston and Blackburn, 1997; Vamosi and Wilson, 2008) raises the possibility that such lineages may be maladapted to current conditions, and that prioritizing according to evolutionary distinctiveness could sacrifice the rapid evolutionary potential contained in some diverse, recently-radiated clades. Although conserving phylogenetic diversity may be an important consideration in setting conservation priorities, the trade-offs with other factors such as cost and probability of management success must also be explored.

The potential for such trade-offs when conserving phylogenetic diversity versus species richness was noted by Davies and Buckley (2011), who found a disconnect between patterns of species richness and phylogenetic diversity in Neotropical mammals. In addition, Joseph et al. (2009) found in limited tests that a prioritization strategy that weighted species based exclusively on their evolutionary distinctiveness could lead to fewer species being prioritized for management versus other strategies. Such trade-offs have not previously been demonstrated in realistic prioritization scenarios involving an entire suite of threatened species being considered for prioritization.

Here, we use systematic prioritization scenarios from a dataset of 700 of the most threatened species in New Zealand to examine trade-offs when there is increasing emphasis on species' evolutionary distinctiveness. We examine the relationships between emphasis on individual species' evolutionary distinctiveness, and number of species prioritized, cost and probability of project success. We also examine the relationships between the total evolutionary distinctiveness weights of prioritized species (a measure of the phylogenetic diversity conserved) and the number of species conserved, cost and probability of project success. We examine these patterns using three alternative evolutionary distinctiveness weights: an iteratively-updated method that accounts for endemism, an additional iteratively-updated method that incorporates probability of extinction, and a static method that accounts for threat level. Our aim is to derive efficient prioritization solutions that minimize the potential loss of both phylogenetic and species diversity, recognizing the potential importance of conserving both aspects of biodiversity.

2. Methods

2.1. Dataset

We designed prioritization scenarios using potential recovery projects for 700 of the most threatened species in New Zealand, encompassing all species in New Zealand's 'Threatened' and 'At Risk' categories that have declining populations (Hitchmough et al., 2005). Each species had an associated 'project', which included the specific actions that, based on expert opinion, would be necessary to ensure reasonable probability (~95%) of the species' persistence over 50 years, as well the costs, assumed benefits and probability of project success. The New Zealand government has used this dataset to help prioritize budget allocations (NZ Department of Conservation, 2011), using a protocol developed by Joseph et al. (2009). New Zealand represents an excellent test case for prioritization, as it is undergoing an extinction crisis that may forecast future global patterns (Jenkins, 2003), and for which there is currently insufficient funding to protect all threatened species.

2.2. Prioritization protocol

We used the project prioritization protocol (PPP) framework of Joseph et al. (2009), which ranks the efficiencies of threatened species projects based on species' evolutionary distinctiveness weight, project benefits to species, probabilities of project success, and cost:

$$E_i = \frac{W_i \times B_i \times S_i}{C_i}, \tag{1}$$

where E_i is the project efficiency for species i; W_i is the species' evolutionary distinctiveness weight; B_i is the project benefit to the species, defined as the difference between the estimated probabilities that a species will be secure in 50 years with and without the project; S_i is the estimated probability of project success; and C_i is the cost of all actions associated with the species project. Costs of actions that benefit multiple species are shared among the beneficiaries. Values were assigned to B_i, S_i and C_i through consultation with >100 threatened species experts. Further details regarding estimation of these parameters are found in Joseph et al. (2009).

The prioritization process begins with all species being funded, then sequentially removes species with the lowest project efficiencies until pre-determined targets for budget or number of species prioritised are reached. At each stage, cost and phylogenetic weight parameters for remaining species are updated, both of which may increase as species are excluded.

2.3. Evolutionary distinctiveness weights (W_i)

While a variety of methods exist for assigning species weights that incorporate evolutionary distinctiveness (e.g. May, 1990; Vane-Wright et al., 1991; Redding and Mooers, 2006; Isaac et al., 2007), a major distinction among them is whether they consider complementarity of the species group, updating weights according to changes in the prioritized species list, or whether they statically assign distinctiveness weights to species based on original