

Cost-effective global conservation spending is robust to taxonomic group

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Priorities for conservation investment at a global scale that are based on a single taxon have been criticized because geographic richness patterns vary taxonomically. However, these concerns focused only on biodiversity patterns and did not consider the importance of socioeconomic factors, which must also be included if conservation funding is to be allocated efficiently. In this article, we create efficient global funding schedules that use information about conservation costs, predicted habitat loss rates, and the endemism of seven different taxonomic groups. We discover that these funding allocation schedules are less sensitive to variation in taxon assessed than to variation in cost and threat. Two-thirds of funding is allocated to the same regions regardless of the taxon, compared with only one-fifth if threat and cost are not included in allocation decisions. Hence, if socioeconomic factors are considered, we can be more confident about global-scale decisions guided by single taxonomic groups.

biodiversity hotspots | costs | dynamic planning | priority regions | congruence

Recent global-scale analyses have found that the geographic species richness patterns of different taxonomic groups have low congruence (1–3). These results cast doubt on the generality of global conservation priority regions, which are often delineated based on a single taxon (1–5). These sets of high-priority regions offer conflicting conservation investment priorities because the most effective funding allocation depends on the taxon used to measure biodiversity. However, the biodiversity value of a region is only one of a number of factors that influence where conservation funds should be spent to best safeguard biodiversity (2). Both the cost of conservation action and predicted rates of habitat loss vary greatly across space (6–8), and these factors interact with biodiversity value to determine the relative priority of different regions (6, 9–11).

To test whether conservation spending priorities are sensitive to the taxon used to measure biodiversity, we efficiently allocated funding between the world's 34 terrestrial “biodiversity hotspots” (Fig. 1*a*; ref. 12) by using seven different taxonomic measures of biodiversity [the number of endemic mammals, amphibians, birds, reptiles, freshwater fishes, tiger beetles, and vascular plants (12)]. An allocation schedule was also calculated by using all terrestrial vertebrates combined. We used the biodiversity hotspots as a test case because they are regions of exceptional biodiversity value (each contains >0.5% of all vascular plant species as endemics) that are under threat (>70% of their original habitat has already been destroyed), but do not account for the relative cost of conservation in each region. We determined efficient funding allocation schedules for the hotspots by integrating biodiversity, conservation costs, and habitat loss rates into a dynamic decision-theory framework (13), with the objective of minimizing total species loss.

For each of the seven taxonomic groups, we planned a 20-year schedule for efficiently spending an annual budget of US\$310

million. (We chose this funding rate because it is equivalent to the amount made available in the fourth phase of the Global Environment Facility. See ref 14.) Each year, funds were allocated among the regions by using a heuristic that minimizes the short-term loss of biodiversity (ref. 13; [supporting information \(SI\) Text](#)). Although habitat destruction is the most significant driver of biodiversity loss (15), there are no global datasets on ongoing rates. We therefore estimated habitat loss rates by using quantitative predictions of extinction risk for endemic vertebrates in each region (ref. 16; [SI Text](#)). We assumed that the cost of creating new protected areas is a useful predictor of the costs of mitigating habitat loss in general, and applied recently developed statistical models to estimate the cost of establishing new protected areas within each region (refs. 8 and 11; [SI Text](#)).

Results and Discussion

On average, only 8 of the 34 regions were allocated funding during the first 20 years (Fig. 1, Table S1). Species extinctions are minimized by initially targeting a small subset of regions, before funds are extended to other regions. Some targeted regions received sufficient funding to protect all of the land available for conservation before other regions were allocated any funding. For example, the Eastern Afrotropical received approximately \$110 million, regardless of which of the seven taxa were used to set priorities. This is the amount of funding estimated to safeguard all remaining land of conservation value in that region.

Funding allocation schedules based on the richness of endemic species in each of the seven taxonomic groups shared many similarities (Fig. 1*b*; Table 1), a result that is insensitive to the total amount allocated (Fig. S1). Five regions received significant funding regardless of the biodiversity measure (Coastal Forests of Eastern Africa, Eastern Afrotropical, Guinean Forests of West Africa, Madagascar/Indian Ocean Islands, and Tropical Andes). Three additional regions were targeted for funding when at least four of the taxonomic groups were used to set priorities (East Melanesian Islands, Horn of Africa, and Western Ghats/Sri Lanka). On average, two-thirds of funds allocated based on any particular taxon would have been allocated the same way by using any other taxon (Table 1). More generally, measuring biodiversity by using either the number of endemic vertebrates or the number of endemic plants results in very similar funding allocations (81.5% of funding in common). The lack of conflict between

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Table 2. Similarity of different funding schedules, measured by the proportion of funding that is directed to the same hotspots in both schedules, expressed as a percentage: Funding schedules that do not consider regional variation in socioeconomic factors

	Birds	Amphibians	Reptiles	Freshwater fishes	Tiger beetles	Vascular plants
Mammals	38.2	8.8	0	0	0	0
Birds	—	8.8	14.7	0	14.7	32.5
Amphibians	—	—	67.7	23.6	23.6	0
Reptiles	—	—	—	0	21.2	21.2
Freshwater fishes	—	—	—	—	78.8	0
Tiger beetles	—	—	—	—	—	21.2

Average similarity is 20.5%.

When variation in threat and cost is ignored, conservation spending priorities diverge widely between different taxa. On average, only 20.5% of funding was shared between schedules based on different taxa. No region was allocated funding using more than four of the seven taxonomic groups (Table 2; see Table S2 for full results and descriptions of the two null models).

These null models emphasize the importance of considering socioeconomic factors when determining priorities for biodiversity conservation. The dynamic nature of conservation landscapes means that, to minimize future species extinction, initial funding should be allocated to regions with little remaining habitat and high rates of habitat degradation (17). We can also ensure greater conservation returns by directing funding to regions where the cost of conservation action is low (6). All of the priority regions that cost $< \$30,000 \text{ km}^{-2}$ (with the exception of Cerrado and the Mountains of Central Asia) were allocated funding regardless of the taxa. Our results demonstrate that, although the global variation in the distribution of different taxa is important from a variety of perspectives, its impact on conservation decision making is tempered by socioeconomic considerations. The similarity of efficient allocation schedules that account for socioeconomic factors suggests that conservation actions in global priority regions can proceed before debates about the appropriate taxonomic measure of biodiversity value are completely resolved.

How sensitive are these conclusions to uncertainty in key parameters? Although efficient conservation decisions are robust to the choice of taxon, inaccuracies in the input data will still lead to suboptimal funding allocation. Given the deficit of global-scale data on threats and costs, we used coarse approximations of these measures. To guide future information gathering, we performed numerical sensitivity analyses to determine whether error in the biodiversity, threat, or cost data would have the greatest detrimental effect on conservation outcomes (*SI Text*). Conservation outcomes were most sensitive to uncertainty in the land cost data, followed by the habitat loss rates, and finally the biodiversity data. Errors in the cost data lead to inefficient funding strategies that could result in 20 times as many extinctions as errors of the same proportional size in the biodiversity data, and six times as many extinctions as errors of the same proportional size in the habitat loss rates (*SI Text*).

Although some information does exist on the cost of conservation actions in many regions, it has not been collated systematically and is not readily accessible. Given the dearth of direct cost information currently available, and the sensitivity of conservation outcomes to errors in these data, improving the quality of information about the cost of conservation will lead to rapid improvements in the efficiency of conservation spending.

The conservation priorities outlined here are based on substantial simplifications. Available global-scale data, in particular,

on socioeconomic factors, are uncertain and likely to remain so in the future (3, 6). Our analyses also do not include external factors that are expected to influence the success of biodiversity conservation, such as regional political stability (18), feedback between conservation spending and land costs (19, 20), and implementation capacity (21). Additionally, our analyses treated land in each of the regions as homogeneous. Finer-scale priorities may exist within these regions, as well as outside (22). For example, the California Floristic Province is situated in both the United States and Mexico. Conservation actions that target the less expensive Mexican part of this hotspot will probably result in much greater returns on investment than would be indicated by the average hotspot attributes shown here. Such caveats highlight the fact that our results should be seen as indicative, not prescriptive.

Although varying conservation costs are increasingly being considered in systematic conservation planning (6), our results are the first example of cost and dynamic threats being incorporated into decisions about conservation spending among a set of global biodiversity priority regions. More importantly, these results are the first to indicate that geographic variation in species richness between taxa does not necessarily translate to different decisions about how we should allocate conservation resources. Although better data will refine the relative priority of the biodiversity hotspots and funding allocation schedules, this taxonomic robustness has important implications for conservation decision making. Efficiency gains will be most marked if conservation research focuses on obtaining better information on socioeconomic factors such as the costs of conservation action. Although biodiversity data on all taxa will remain essential to global conservation prioritization, our results demonstrate that efficient conservation decisions can be made using just one taxon.

Methods

Conservation funding is allocated to minimize the short-term loss of species (ref. 13; *SI Text*). This method requires four datasets: First, the biodiversity value of each priority region is measured by using endemic species richness (Table S3). Second, the costs of conservation in each region are assumed to be equivalent to the costs of creating new protected areas. We employ a model for estimating the cost of reserve acquisition from national economic indicators (Table S4). Third, future habitat loss rates are predicted by using quantitative estimates of threatened species extinction probabilities, and the species-area relationship (*SI Text*). Fourth, data on the proportion of reserved, available, and degraded habitat in each priority region are taken from literature sources (*SI Text*). The implementation of the two null models is explained in detail in the *SI Text*.

The effect of parameter error on conservation outcomes is tested by perturbing the regional biodiversity values, costs, and habitat loss rates. These sensitivity analyses were performed for all two-region combinations of the 34 biodiversity hotspots, allowing the use of optimal allocation schedules, rather than the minimize-loss heuristic (13). Estimated vascular plant endemism, habitat loss rates, and land costs are assumed to represent “true” parameter values. Conservation funding is then allocated

based on “false” values that vary proportionally about the true values. Allocation is continued until all available land has been either protected or converted. The sensitivity of the results to data uncertainty is calculated by the difference between the number of species remaining extant when allocation proceeds according to true parameter values, and the number remaining extant when allocation proceeds according to incorrect parameter values. For each parameter, we fit a linear regression to the difference between the outcomes for each of the 561 combinations. The mean

regression slope measures the sensitivity of the different parameters (*SI Text*). Varying the parameters in all regions simultaneously does not qualitatively alter this result.

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