Targeting global conservation funding to limit immediate biodiversity declines

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Inadequate funding levels are a major impediment to effective global biodiversity conservation and are likely associated with recent failures to meet United Nations biodiversity targets. Some countries are more severely underfunded than others and therefore represent urgent financial priorities. However, attempts to identify these highly underfunded countries have been hampered for decades by poor and incomplete data on actual spending, coupled with uncertainty and lack of consensus over the relative size of spending gaps. Here, we assemble a global database of annual conservation spending. We then develop a statistical model that explains 86% of variation in conservation expenditures, and use this to identify countries where funding is robustly below expected levels. The 40 most severely underfunded countries contain 32% of all threatened mammalian diversity and include neighbors in some of the world's most biodiversity-rich areas (Sundaland, Wallacea, and Near Oceania). However, very modest increases in international assistance would achieve a large improvement in the relative adequacy of global conservation finance. Our results could therefore be quickly applied to limit immediate biodiversity losses at relatively little cost.

ecological/environmental policy | CBD | sustainability | foreign aid | governance

Faced with the recent failure of the Convention on Biological Diversity (CBD) signatories to "significantly reduce" rates of biodiversity loss by 2010 (1), the world conservation community must urgently decide how to target its next efforts to halt the current extinction crisis. The CBD parties repeatedly listed lack of financial resources as one of the main barriers to meeting CBD goals in the run-up to the 2010 failure (2). Academic studies have also documented the global inadequacy of conservation spending and its relationship to increased rates of species imperilment (3–7). To improve the chances of fulfilling the new 2011–2020 strategic goals (8), and in particular the goal of effecting a rapid and substantial reduction in the rate of biodiversity loss, the main funding institutions need to target additional finance (3, 4, 7, 9).

To target the allocation of global conservation finance effectively, assessments of relative underfunding across countries are essential (10–12). The short time period remaining to achieve the new strategic goals also implies that underfunding assessments are urgent. However, 20 y after the original Rio agreement, most countries are still unable to quantify the relative adequacy of their levels of conservation finance, or use widely differing criteria and even guesswork to do so (4, 9, 12, 13). Even baseline data on current conservation spending by country have proved difficult to collate and are highly incomplete (4, 9–13). Biodiversity declines have progressed rapidly (1), and further delays in improving finance are likely to lead to even greater global extinction risks, the opposite of what is needed to make progress on Aichi biodiversity targets (4, 8, 14). We therefore need tools that can rapidly and consistently estimate current levels of underfunding by country but are also robust to current uncertainties in data and knowledge.

Here, we first assemble the most complete database of global conservation spending yet published, including country-specific data for \$19.8 billion (bn) annually of major conservation funding (at current values; *SI Appendix*), flowing from a broad range of international donors, domestic governments, and other important sources (*Methods Summary* and *SI Appendix*). We then create a statistical model that uses current conservation prioritization factors to explain 86% of the variation in global spending patterns across countries for the period 2001–2008. Finally, we establish relative levels of funding adequacy across countries and highlight countries where biodiversity conservation seems most severely underfunded, by comparing known current levels of spending with the model's expectation of spending. We also test the underfunding assessments for sensitivity to the widely recognized uncertainties in conservation finance data (4, 12, 13), and to choice of allocation model.

A recent assessment suggested that global funding would need to increase by at least an order of magnitude to meet CBD biodiversity targets (without suggesting how that funding should be distributed among countries) (3). However, such a large increase may not be politically achievable in time to meet 2020 targets, in which case we would need to know how to proportionally allocate a limited pool of resources (15). Our model is therefore designed to estimate proportional levels of underfunding, making it applicable to the targeting of any size of change in global conservation finance resources.

The model is based on four main considerations known to be important in prioritizing global conservation spending (10–12, 16–21): threatened biodiversity, cost, cost effectiveness (the likelihood of investment success), and the size of the area to be conserved (Table 1 and *Methods Summary*). We develop a politically equitable biodiversity measure, the threatened global biodiversity fraction (GBF) (Fig. 1*A* and *SI Appendix*, Fig. S2), that considers countries responsible for stewarding the fraction of total global biodiversity found within their borders (22) (*SI Appendix*, Fig. S3). Raw GBF is calculated as the sum of all range fractions in each country, using global Mammalia—a major target of biodiversity funding (23)—as our biodiversity surrogate (*SI Appendix*). We developed GBF rather than use simple species counts (7, 10, 11) because species are often distributed very unevenly between countries, and yet simple counts allocate equal responsibility irrespective of proportional

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Table 1. The best-fitting model to explain global conservation spending across countries

Predictor	Slope	t*	P
Biodiversity	0.29	2.56	0.012
Country size	0.39	3.60	0.00005
Government effectiveness	Spline	10.71	<0.000001
Political stability	Spline	3.79	0.003
NPL (cost)	0.52	2.53	0.013
% land protected	0.46	5.81	<0.000001
GDP	0.36	2.64	0.010
GDP (quadratic)	0.15	1.95	0.054

Information-theoretic analysis was used but for reader information, we include t and P values (n = 121, $\alpha = 0.05_{\text{2-tailed}}$, *$F$ value and approximate p for splines) and standardized partial β coefficients for comparability. See *Methods Summary* for data transformations.

distributions. Our final measure, threatened GBF, weights raw GBF by risk of extinction (24) (*SI Appendix*).

The likelihood of investment success (cost effectiveness) at the country level should be strongly associated with governance quality (7, 16, 18, 20), so we tested several possible governance indicators as potential spending drivers (*SI Appendix*). We also tested three possible cost measures and, finally, country size and the extent of protected areas as candidate drivers of conservation budget allocation decisions (*Methods Summary* and *SI Appendix*).

Our model premise is therefore that global biodiversity conservation spending patterns represent multiple integrated professional views about what constitutes effective conservation investment, with some variation in allocations due to political and historical preferences (4, 20, 25, 26) and, importantly, variation due to lack of information on the summed global spending patterns themselves. To identify some of the political and historical biases that might be driving departures from the model, we also tested post hoc for largely donor-driven biases in regional allocation (26), and for reduced funding to Islamic (predominantly Muslim) countries, particularly Islamic countries in the Arab world and central Asia (Afghanistan and neighbors) (*SI Appendix*).

Results and Discussion

We estimate that the total annual expenditure on global biodiversity was approximately \$21.5bn for 2001–2008 (2005 US dollars, nonmarket flows; *SI Appendix*). Of this amount, approximately \$17bn could be traced to country level (2005 US dollars, \$19.8bn at current values). The unknown \$4.5bn largely represents government spending by Mediterranean countries and spending by local communities (Fig. 1*B* and *SI Appendix*). However, the final analysis of financial shortfalls was carried out on \$16bn, excluding \$1bn of nongovernmental organization (NGO) spending due to inconsistent geographic coverage (*SI Appendix*). Traceable NGO flows were strongly correlated with other donor flows (r = 0.85), suggesting this omission is unlikely to have biased results (*SI Appendix*).

A total of \$14.5bn of the \$16bn analyzed represented domestic spending, allocated among the four World Bank income categories (upper, upper-middle, lower-middle, and lower income) in the proportions 94%, 4%, 2%, and 0.5% (*SI Appendix*). These data suggest that domestic spending by developing countries is only about 10% of previous estimates (27) (*SI Appendix*). A further ~\$1bn annual expenditure represented international biodiversity aid. The major biodiversity aid donors were the Global Environment Facility (22% of biodiversity aid spending) and the World Bank (19%; see *Dataset S1* and data deposition for all donor expenditure). The largest bilateral donors for biodiversity were the United States (7.5%) and Germany (5%). The \$1bn figure is based on an explicit categorization of 75,000 aid projects and is again appreciably lower than the broader "biodiversity-related aid" often reported by aid donors (7) (*SI Appendix*). The remaining \$0.5bn is from other sources including conservation trust funds (*SI Appendix*).

For the drivers of spending, our best-fitting model explained 86% of the variance in biodiversity conservation investment. We found that more threatened biodiversity, larger area requiring conservation (both country area and percentage protected area within country), higher costs, and higher GDP all drove higher spending (Table 1), explaining 76% of the variation (deviance) on their own (*SI Appendix*). An additional 10% of variation is explained by two governance indicators: spending increased nonlinearly in countries with better "government effectiveness" (better policy formulation and implementation; Table 1 and *SI Appendix*, Fig. S1) (28). Once other variables including government effectiveness were controlled for, spending was higher in countries that had been more politically unstable in 2001–2008 (Table 1 and *SI Appendix*, Fig. S1).

Fig. 1*B* highlights how far actual spending departed from expected spending in each country (the residual), and Table 2 shows the 40 most severely underfunded countries (see *SI Appendix*, Table S1, for all countries). Owing to the imprecision of financial data (4,

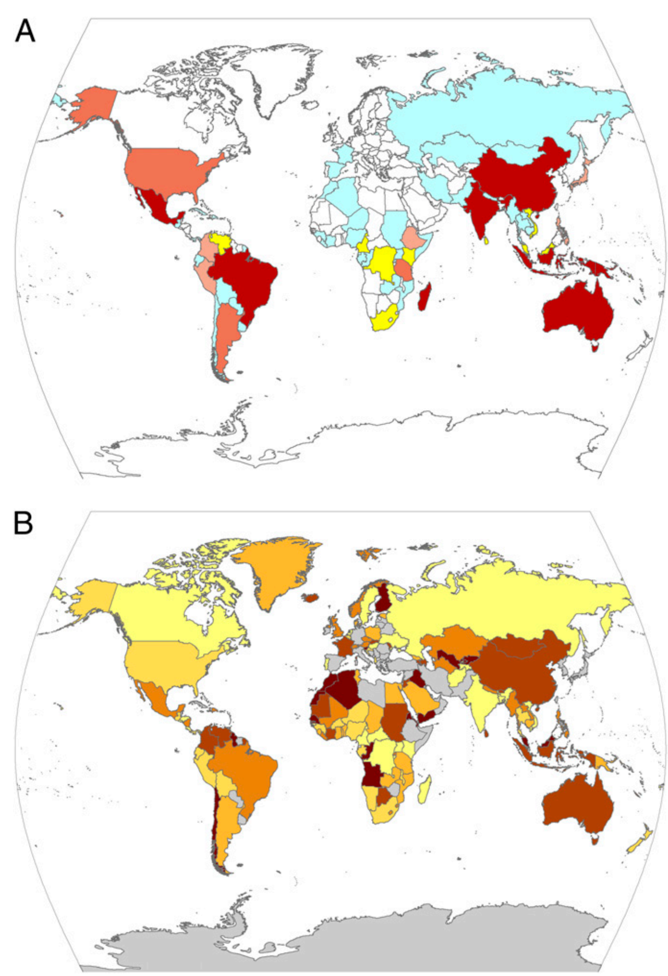

Fig. 1. (*A*) Levels of threatened global biodiversity (measured as threatened mammal GBF; see text and *SI Appendix*) stewarded by each country. Color coding is in blocks of 0.5 SDs, with white and blue showing very low and low threatened diversity (<0.25 SD, −0.25–0.25 SD); yellow, medium diversity; and the four red colors, high diversity (0.75 SD to >2.3 SD, darker reds indicating higher values). (*B*) Underfunding levels from the predictor model (darker colors indicate worse underfunding, in blocks of 20 countries). Somalia was not analyzed but is probably also highly underfunded (*SI Appendix*).

Table 2. The most highly underfunded countries for biodiversity conservation

Rank	Country	Data error robustness	Model variation robustness	Difference from expected, $m
1	Iraq	100	100	−0.7
2	Djibouti	100	100	−0.65
3	Angola	100	100	−3.59
4	Kyrgyzstan	100	100	−2.06
5	Guyana	100	100	−4.74
6	Solomon Islands	99.6	100	−0.4
7	Malaysia	98.8	100	−53.3
8	Eritrea	99.2	100	−0.8
9	Chile	98.8	100	−55.44
10	Algeria	100	100	−13.34
11	Senegal	98.8	100	−20.98
12	Trinidad and Tobago	98.4	100	−4.38
13	Vanuatu	97.2	100	−0.6
14	Uzbekistan	96	100	−1.12
15	Morocco	98.4	100	−8.36
16	Slovenia	94.8	100	−6.19
17	Finland	93.6	100	−69.76
18	Congo	91.6	100	−1.35
19	Yemen	95.2	100	−1.33
20	Comoros	92	100	−0.07
21	Ivory Coast	93.2	100	−7.02
22	Mauritania	92.4	100	−1.95
23	Bhutan	86	100	−4.75
24	Slovakia	83.2	100	−9.98
25	Mongolia	90.4	100	−4.34
26	Iceland	70.4	96.4	−30.36
27	Colombia	85.2	89.3	−72.73
28	Venezuela	76	100	−25.02
29	Armenia	80.8	100	−2.44
30	Moldova	72.4	100	−0.34
31	Indonesia	66.4	100	−24.14
32	Jordan	62	96.4	−2.09
33	Azerbaijan	64.4	100	−1.24
34	Sudan	63.6	89.3	−2.14
35	Botswana	58	96.4	−11.41
36	France	64.8	96.4	−355.49
37	Sri Lanka	51.6	75	−6.08
38	Australia	62	71.4	−275.36
39	China	39.6	75	−75.31
40	Austria	46.4	89.3	−53.08

The 40 most highly underfunded countries are shown, in rank order, along with the percentage of times that they ranked in the bottom 40 when data were perturbed (column 3) or the model was varied (column 4). The last column shows the difference between expected and observed spending in $US millions. See *SI Appendix* for all countries analyzed.

12, 13), a reasonable policy interpretation would be that countries with bigger negative residuals (shown as darker colors in Fig. 1*B*) form a broad group of highly underfunded countries under current priorities. We do not regard small differences between individual country rankings as robustly interpretable. Data were still too sparse to estimate shortfalls for all 198 countries, but we were able to determine relative spending adequacy for 124, including all of the world's top-50 biodiversity nations (measured using our GBF index) except Japan and Somalia (*SI Appendix*).

Table 2 also shows raw dollar differences between expected and observed spending. All countries are likely underfunded in terms of conservation (3, 4, 7), so the dollar values shown are unlikely to be sufficient to halt biodiversity decline by 2020 (8) and above-average spending should in no way be seen as "overfunding." However, in the event that the large amount of extra funding needed to fully achieve Aichi targets (3, 8) is delayed, deficiencies presented here could be used in a rapid global triage approach (10, 11, 15) as a proportional guide to the approximate funding improvements appropriate for each country when resources are limited.

Policymakers should be particularly concerned by highly underfunded countries that steward high amounts of threatened biodiversity, so we further extracted all countries found in both the bottom quartile of relative funding and the top quartile of threatened biodiversity (measured as threatened mammal GBF). These were Chile, Malaysia, the Solomon Islands, and Venezuela.

Highly underfunded countries are often neighbors (Fig. 1*B*), creating areas where underfunding affects taxa across their entire ranges. This trend is of particular concern in the geographical grouping of Malaysia–Indonesia–Australia, a region that holds a very large amount of threatened biodiversity (Fig. 1*A*). There is also a pattern of underfunding in arid and semiarid lands across Central Asia, Northern Africa, and the Middle East, suggesting the possibility of global degradation of these biomes.

The positive influence of political instability on spending was only detectable when government effectiveness was also included in the model (otherwise spending tended to be lower in less stable countries). Instability considerations may therefore only represent a minor priority adjustment to the general pattern on investing more in better-governed countries. Indeed, a sizeable fraction of the countries identified as highly underfunded have suffered recent (and in some cases ongoing) armed conflicts, e.g., Iraq, Somalia (*SI Appendix*), and several countries in central Asia, North and West Africa, and South East Asia (29), suggesting that a net donor reticence to investing in countries in conflict still exists overall (29). Globally, countries in conflict have high levels of both biodiversity and threat (29, 30). Donor reticence therefore deserves careful consideration because removal of funding may make a bad situation even worse.

Table 2, perhaps surprisingly, includes some developed countries, e.g., Finland, France, Iceland, Australia, and Austria. We note that, toward the end of the study period and in forward-looking budget plans, many of those countries made very large increases in their biodiversity funding allocations (*SI Appendix*), although in the case of Australia and France such increases are still smaller than the modeled shortfalls in Table 2. We discuss developed country patterns further in *SI Appendix*. We also modelled developed and developing/emerging countries separately. The results were extremely similar to the all-country analysis presented here, with the same developing countries being listed as highly underfunded whether or not developed countries were included in the model (with the one exception of China; *SI Appendix*).

When testing for political and historical biases, we found that predominantly Islamic Arab/central Asian countries had only 49% of the funding that countries in the rest of the world received for similar levels of biodiversity, size, cost, and governance ($t = -3.31$, $P = 0.001$; *SI Appendix*). Donors are the main source of funding for these countries and so an underfunding pattern may reflect donor bias. The pattern may also help explain the severe underfunding of arid biomes globally and deserves further investigation. There was a similar but weaker pattern of reduced funding with increasing percentage of Muslim population globally (*SI Appendix*). Regional funding differences were detectable, but were dropped from the model when terms related to the predominance of Islam were included (*SI Appendix*).

Decision makers may need to further investigate subnational or country-specific investment contexts when targeting allocations at a finer scale (16, 31). They should also be aware that the investment efficiency of current institutional weightings for factors such as cost effectiveness (governance) remains largely untested in the scientific literature. Nevertheless, underfunding patterns under the model remain surprisingly consistent even when governance terms are omitted (e.g., 75% of the countries in Table 2 remain unchanged; *SI Appendix*). No country-level breakdown was available for the estimated \$2bn spent by local developing-country communities annually on conservation (32) and no quantitative sensitivity test of how this might affect the results was possible.

Over the longer term, scientists and policymakers will achieve better funding, more comprehensive data, and more sophisticated allocation tools. For example, mathematical efficiency algorithms have been developed, principally suggesting how to allocate resources for the purchase and capitalization of new protected areas, e.g., by 2030–2040 (16). Theoretically, it should be possible to develop a similar but broader algorithm to estimate efficient funding allocations for all conservation actions globally, including finance needs for existing protected area maintenance, future land purchases, and the full range of conservation activities outside protected areas. Nevertheless, such an approach will require comprehensive and accurate global data, extensive testing of whether the conclusions are sensitive to the precisely specified priorities and weightings, and global political consensus on exact weightings, a currently infeasible combination of conditions (16, 20, 33). Developing and applying such an algorithm could therefore take several years.

In the meantime, rapid methods that work robustly within current uncertainties could significantly reduce short-term biodiversity losses (14) and also reduce the need for future expenditures (4), especially if the methods also reflect current institutional priorities. Our estimates of relative underfunding levels proved robust to possible data inaccuracies and competing allocation models (see *Methods Summary*, Table 2, and *SI Appendix*, Table S1, for qualitative robustness). Judicious application of the underfunding patterns revealed here may therefore reduce short-term biodiversity losses with appreciably greater efficiency than would current spending patterns.

Short-term biodiversity losses may indeed be substantial if funding patterns are not improved: the 40 most highly underfunded countries in our analysis steward 32% of all threatened global biodiversity (threatened mammal GBF), including many of the species that moved into a higher category of extinction risk between 1996 and 2008 (1). However, most of these highly underfunded countries are developing nations, where only a modest absolute dollar investment would generate a large correction in relative underfunding (Table 2 and *SI Appendix*, Table S1). Our results therefore suggest that international conservation donors have the opportunity to act now, in a swift and coordinated fashion, to reduce an immediate wave of further biodiversity declines at relatively little cost.

Methods Summary

We collated a database of country-level conservation funding flows from multiple sources including government, donors, trust funds, and self-funding via user payments, and then calculated average annualized spending 2001–2008 (in constant 2005 US dollars). Formally speaking, global conservation finance data represent an unknowable population for statistical modeling (4, 9, 13), and the database represents a very large sample, an order of magnitude larger and more representative than previous comparable work (10, 11) (*SI Appendix*). We created candidate regression models using threatened mammal GBF, country area, percent protected area, gross domestic product (GDP), the cost measures national price level (NPL), and the conservation action unit (the recurrent cost of maintaining 100 km^2 of protected area for 1 y; *SI Appendix*), five possible governance indicators and an Island term, and then used information-theoretic approaches to test model fits. Diagnostic plots suggested nonlinearities (especially in governance and GDP responses) and nonnormality, so we ln(x + constant)-transformed all variables except NPL and percent protected area, added several generalized additive mixed models with cubic splines to the candidate model set, and tested possible quadratic terms. Residuals were tested for spatial autocorrelation by semivariogram plots and by adding several possible spatial covariance structures and comparing Akaike information criterion (AIC) values. There was no strong collinearity and no spatial autocorrelation in the residuals. Relative funding adequacy was defined as the residuals from the model, scaled by total spending. We repeated the regression 1,000 times with perturbed spending data, drawing each perturbed amount from a random normal distribution with mean of the original value and 1 SD = 25% of the original value. We also reran the analysis for all 26 models that provided a medium to good fit (ΔAIC < 10). We tested post hoc for improvement in fit when percentage Muslim population (globally or in Arab/central Asian countries only) and/or political region were added to the model. See *SI Appendix* and *Dataset S1* for further details.

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