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Supplementary Materials
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Financial Costs of Meeting Global Biodiversity Conservation Targets: Current Spending and Unmet Needs

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World governments have committed to halting human-induced extinctions and safeguarding important sites for biodiversity by 2020, but the financial costs of meeting these targets are largely unknown. We estimate the cost of reducing the extinction risk of all globally threatened bird species (by ≥1 International Union for Conservation of Nature Red List category) to be U.S. $0.875 to $1.23 billion annually over the next decade, of which 12% is currently funded. Incorporating threatened nonavian species increases this total to U.S. $3.41 to $4.76 billion annually. We estimate that protecting and effectively managing all terrestrial sites of global avian conservation significance (11,731 Important Bird Areas) would cost U.S. $65.1 billion annually. Adding sites for other taxa increases this to U.S. $76.1 billion annually. Meeting these targets will require conservation funding to increase by at least an order of magnitude.

After the failure of previous global commitments to reduce the rate of loss of biodiversity (*1*), parties to the Convention on Biological Diversity (CBD) recently adopted a new strategic plan, including 20 targets to be met by 2020 (*2*). Negotiations on financing the plan are not yet resolved, partly for lack of information on financial costs. We used data on birds, the best known class of organisms, to assess the financial costs of meeting two of the targets relating to conserving species and sites: (i) preventing the extinction of known threatened species and improving and sustaining their conservation status (Target 12) and (ii) effectively managing and expanding protected areas to cover 17% of terrestrial and inland water areas (and 10% of coastal and marine areas), "especially areas of particular importance for biodiversity" (Target 11) (*2*). These two targets align closely with the existing focus of much of the conservation sector; they are also among the most immediately urgent, involving discrete actions amenable to costing.

To assess the costs of species conservation, we sampled 211 globally threatened bird species [19% of all threatened bird species on the International Union for Conservation of Nature (IUCN) Red List (*3*)]. We asked experts on each species to estimate (i) recent expenditure on conservation actions, and (ii) a range of costs for conservation actions needed to achieve the minimum improvement in status necessary to reclassify ("downlist") each species to the next lowest category of extinction risk on the Red List (e.g., from Critically Endangered to Endangered). We modeled midrange cost estimates as a function of breeding distribution extent, degree of forest dependence, mean Gross Domestic Product per km^2 of breeding range states, and mean Purchasing Power Parity of breeding range states, and we used this model to estimate costs for all other globally threatened bird species (*4*) (fig. S1).

The median modeled annual cost per species for conservation actions required to achieve downlisting within 10 years was U.S. $0.848 million (range: U.S. $0.0387 to $8.96 million; all values adjusted to 2012 U.S. $) (Fig. 1A and table S1). This compares with a median of U.S. $0.219 million annually [range: U.S. $0.001 to $4.82 million, standardized to the same 10-year period and adjusted for inflation (*4*)] for 25 threatened species that were successfully downlisted during 1988–2008 because of genuine improvements in their status (i.e., directly resulting from conservation interventions) (*5*) (table S2). Costs for all but one of these species fell within the range of our sample of estimated costs (Fig. 1A), although the median was significantly lower [analysis of variance (ANOVA) of natural log–transformed values: $F_{1,\ 259} = 7.4$, $P < 0.01$]. This may simply be because conservationists often prioritize species with more tractable conservation needs (*6*) or because, relative to all globally threatened birds, a disproportionate number of those 25 species are found on oceanic islands (76 versus 35%; $\chi^2 = 16.2323$, df = 1, $P < 0.001$), thus tending to have smaller ranges and hence lower costs.

Assuming that the actions required for each species are independent, we estimate the total costs of downlisting 1115 globally threatened bird species to be U.S. $1.23 billion (U.S. $0.975 to $1.56 billion) annually over the next decade, excluding the costs of at-sea actions (*4*) (table S3). The estimated cost per species is <U.S. $3 million annually for 95% of species (<U.S. $1 million annually for 50%), and is lower for species in higher categories of extinction risk (Fig. 1B, ANOVA, $F_{2,\ 1112} = 74.4$, $P < 0.0001$) because they generally have smaller distributions. However, most costs are for actions (e.g., site protection) that will probably benefit other species whose distributions overlap; only 20% are for species-specific actions such as captive breeding. We therefore attempted to estimate the effects of such cost-sharing through a spatial analysis (*4*), which produced a revised minimum total of U.S. $0.875 billion annually, of which U.S. $0.379 to $0.614 billion (43 to 49%) is needed in lower-income countries [low- and lower-middle–income countries as classified by The World Bank (*4*)]: those with greatest need for funding assistance (Table 1 and Figs. 2 and 3).

Investment of such sums does not guarantee success, as multiple factors (both deterministic and stochastic) may influence conservation outcomes (*7*, *8*). Furthermore, many of these species will almost certainly require continued (and

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possibly even increased) funding to maintain any improvement in their status beyond 2020, particularly given the likely intensification of existing threats, the increasing impacts associated with climate change, and the emergence of potential new threats (*9*).

The median annual expenditure within the last decade for the 211 species in our sample was U.S. $0.065 million (range: $0 to $15.2 million), with the majority of resources spent on just a few species, which reflects a common pattern documented at national levels (*10*–*12*). This covered a median of 12% of the estimated required annual expenditure per species. Recent funding was adequate (>90% of estimated need) for only 3% of species (n = 7), and <50% of required expenditures were covered for 86% of species. Extrapolation suggests that, to cover the U.S. $0.875 to $1.23 billion annually required to meet the CBD target for birds, an additional U.S. $0.769 to $1.08 billion per year is needed (but only U.S. $0.314 to $0.509 billion, 41 to 47% in lower-income countries) (Table 1 and Fig. 2). Given that the species for which we could obtain data may be biased toward those that are already receiving funding, the true shortfall may be even greater.

Conservation costs per species appear to be lower for other taxa (except possibly mammals), presumably because they have smaller distributions on average than birds (tables S4 and S5). Data for 664 declining threatened species in New Zealand (63 birds, 601 mammals, amphibians, reptiles, fish, invertebrates, vascular plants, bryophytes, and fungi) show that annual costs for birds are 4.20 times larger than the median for other taxa (*4*). Threatened birds make up 7.65% of all threatened species on the global IUCN Red List (*4*, *13*), which suggests that the total annual costs of conserving all "known threatened species" as called for in the CBD target (*2*) by downlisting them by ≥1 Red List category may range from $3.41 billion (if the proportion of costs that are shared among birds is the same for all other taxa) to $4.76 billion (if one assumes no cost-sharing).

To estimate the costs of meeting the CBD target for site conservation, we carried out a separate analysis to quantify the costs of effectively conserving all terrestrial Important Bird Areas (IBAs). IBAs represent the largest systematically identified global network of important sites for biodiversity (*14*), as they make up 11,731 sites supporting populations of one or more of 4445 threatened, restricted-range, biome-restricted or congregatory species (*15*). Only 28% of IBAs are completely covered by existing protected areas, 23% are partially protected, and 49% are entirely unprotected (*14*). Protection [encompassing all types of protected area management and governance (*16*)] of all unprotected and partially protected IBAs (32% of which are in lower-income countries) would increase terrestrial protected area coverage to 17.5% and meet the CBD site target (*14*).

We estimated the costs of effectively managing IBAs by modeling required expenditure per hectare as a function of socioeconomic and site-specific variables (*4*), on the basis of data for 396

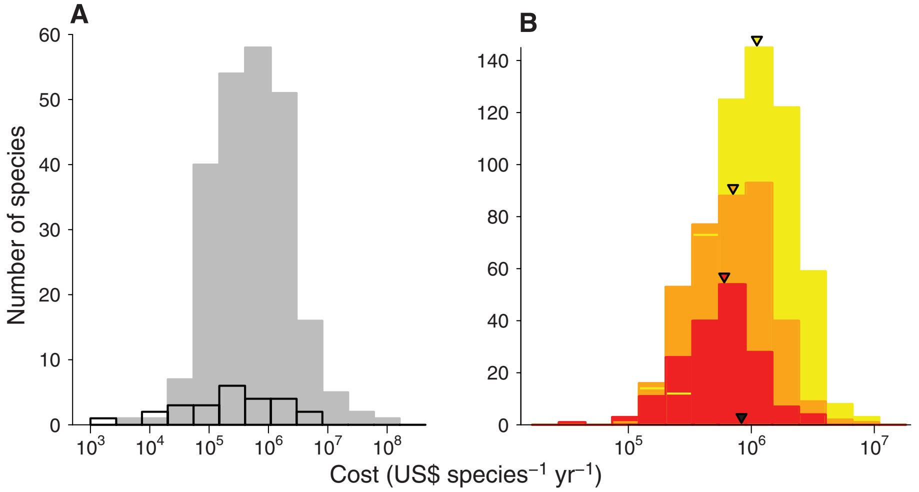

Fig. 1. (**A**) Estimated annual financial costs of conservation actions needed to downlist 211 globally threatened bird species to lower categories of extinction risk on the IUCN Red List within 10 years (solid bars), compared with actual costs of actions that led to successful downlisting of 25 species during 1988–2008 [outlined bars; corrected to the same 10-year period and adjusted for inflation (*4*)]. (**B**) Modeled annual costs per species of conservation actions needed to downlist 174 Critically Endangered species (red), 380 Endangered species (orange) and 561 Vulnerable species (yellow bars); horizontal colored lines indicate the height of obscured bars; arrows show medians (black indicates median across all 1115 bird species).

Table 1. Global costs of bird species conservation and site protection and management (billion U.S. $ per year over the next 10 years; figures in parentheses give the % of the global total in each income group). Low-income and lower-middle–income countries are referred to in the text as "lower-income" countries; high-income and upper-middle–income countries are referred to as "higher-income countries." Threatened bird species excludes taxa listed as Possibly Extinct or Vulnerable under criterion D2 (*4*). Minimum values for column 5 are the costs of effectively managing additional sites; maximum values include costs of expanding protected areas.

Location	Preventing extinctions and conserving species (n = 1115 threatened bird species)		Protecting and managing sites (n = 11,731 IBAs)			
	Total required	Current shortfall	Effective management of existing protected sites	Current shortfall for existing protected sites	Establishing and managing additional protected sites	Total required
High-income countries	0.190–0.220 (18–22%)	0.159–0.184 (17–21%)	4.69 (65%)	2.49 (64%)	3.54–24.2 (42–50%)	28.9 (44%)
Upper-middle–income countries	0.305–0.407 (33–35%)	0.289–0.386 (35–38%)	0.907 (13%)	0.332 (8%)	1.88–16.01 (26–28%)	16.9 (26%)
Lower-middle–income countries	0.320–0.527 (37–42%)	0.264–0.435 (34–40%)	1.29 (18%)	0.867 (22%)	1.34–12.7 (19–22%)	14.0 (22%)
Low-income countries	0.0594–0.087 (7%)	0.0501–0.074 (7%)	0.293 (4%)	0.221 (6%)	0.354–4.89 (5–8%)	5.19 (8%)
Global	0.875–1.24*	0.769–1.08	7.18	3.91	7.11–57.8	65.1

*Note rounding errors explain the difference between the maximum and the 1.23 quoted in the main text.

sites across 50 countries (table S6). Extrapolation suggests that the total cost worldwide would be U.S. \$7.18 billion annually for currently protected IBAs, of which U.S. \$1.58 billion (22%) is required in lower-income countries.

We assessed the costs of expanding protected area networks to cover all unprotected and partially protected IBAs using spatially explicit agricultural land values (gross economic rents) from Naidoo and Iwamura (*17*) as a proxy for purchase or compensation costs (*4*). This produced a total cost of U.S. \$50.7 billion annually (U.S. \$15.9 billion, 31%, in lower-income countries), which is comparable to previous estimates of protected area expansion costs in developing countries (*18*). Applying our management cost model (see above) to these sites yields an estimate of U.S. \$7.11 billion annually, resulting in a total figure of U.S. \$57.8 billion required annually for protecting and effectively managing all IBAs.

Globally important sites have also been systematically identified for mammals; amphibians; and certain reptile, fish, plant and invertebrate groups in 12 countries (*19*, *20*). Of these sites, 71% already qualify as IBAs and cover 80% of the total area (*14*). Assuming the areal relation holds worldwide and that such sites have a level of protection similar to that of IBAs, we estimate that protecting and effectively managing a more taxonomically comprehensive global network of terrestrial sites would cost U.S. \$76.1 billion annually (U.S. \$22.4 billion annually, 29% in lower-income countries) (Fig. 2).

We estimate that current annual expenditure on managing IBAs that are already under some form of protection falls short of requirements by U.S. \$1.09 billion annually in lower-income countries (31% of needs covered) and by \$2.82 billion annually in higher-income countries [50% of needs covered, although this figure is based on more limited data (*4*)]. Management of an expanded protected area network covering all currently unprotected or partially protected IBAs increases the estimated shortfall to \$2.78 billion for lower-income countries and \$8.24 billion for higher-income countries.

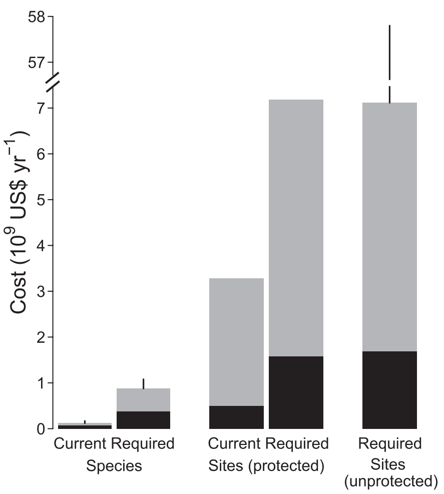

Fig. 2. Current expenditure and total required for conserving 1115 threatened bird species and safeguarding 11,731 important sites for birds in lower- and higher-income countries (black and gray bars, respectively). Bars for species show costs accounting for sharing between species, with vertical lines indicating costs excluding sharing. Bars for sites indicate management costs, with the vertical line for unprotected sites showing acquisition costs.

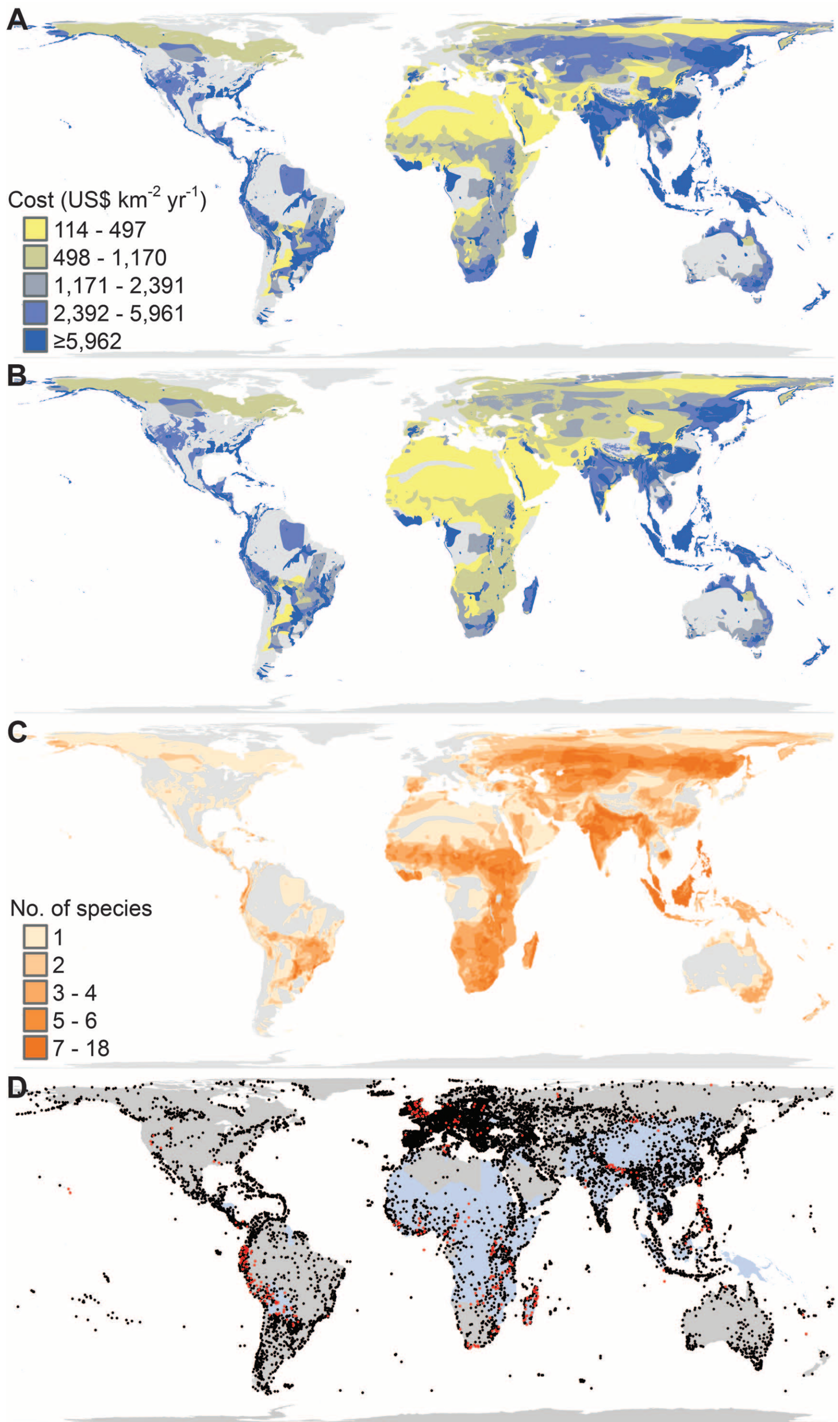

Fig. 3. Geographic patterns in the annual cost for conservation actions (U.S. \$ km^{-2}) for 1097 globally threatened bird species (**A**) assuming that actions for each species are independent and (**B**) assuming cost sharing; (**C**) number of species km^{-2}, and (**D**) distribution of IBAs (points; red indicating those for which management-cost data were included in the model) and lower-income countries (blue shading). Costs and number of species are divided into quantiles; areas with no globally threatened bird species present shown in gray in (A to C); Behrmann equal-area projection. Distribution maps for 18 globally threatened species are not available.

A proportion of the costs would be shared between the species and site targets considered here. Establishing protection and managing sites made up 50 to 55% of the total costs for sampled bird species. Discounting this proportion from the total cost of species conservation across all taxa, a combined cost needed to meet both species and site CBD targets may be in the order of U.S. $78.1 billion annually (Fig. 2). It is also highly likely that actions to meet these two targets will contribute to other targets in the CBD strategic plan, which are critical to delivering sustainable development and the safeguarding of global biodiversity in the long term (*4*).

Even with increased investment, careful prioritization will continue to be necessary to inform decisions about which areas to protect and which actions to undertake for species, e.g., using approaches that optimize returns on investment, given fixed budgets and defined objectives, for sites (*21*), species (*7*, *8*), and management actions (*22*). Our finding that species facing higher categories of extinction risk require less investment for downlisting than do those in lower categories suggests that in many cases such analyses will prioritize actions for the most-threatened species first. We also note that there is considerable global spatial variation in costs and the number of threatened species per unit area (Fig. 3). Although the shortfalls in higher-income countries are substantial, the greatest gains per dollar will be in lower-income countries (*23*).

Despite the limitations of the available data, the shortfalls we have identified clearly highlight the need to increase investment in biodiversity conservation by at least an order of magnitude, especially given the small, but growing, body of evidence linking spending and effectiveness (*24*, *25*). Nevertheless, the total costs are small relative to the value of the potential goods and services that biodiversity provides (*26*), e.g., equivalent to 1 to 4% of the estimated net value of ecosystem services that are lost per year [estimated at $2 to $6.6 trillion (*27*–*29*)]. More prosaically, the total required is less than 20% of annual global consumer spending on soft drinks (*30*).

These results should inform discussions among governments on the magnitude of the financing needs for implementing the CBD Strategic Plan for Biodiversity 2011–2020. A particular challenge will be how to address the current mismatch between the greater resources available in richer countries and the higher potential conservation gains in financially poor, biodiversity-rich countries (*31*, *32*). Resolving the ongoing conservation funding crisis is urgent; it is likely that, the longer that investments in conservation are delayed, the more the costs will grow (*23*, *33*), and the greater will be the difficulty of successfully meeting the targets (*6*, *34*).

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Supplementary Materials
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Supplementary Text
Figs. S1 to S2
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Pathological α-Synuclein Transmission Initiates Parkinson-like Neurodegeneration in Nontransgenic Mice

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Parkinson's disease is characterized by abundant α-synuclein (α-Syn) neuronal inclusions, known as Lewy bodies and Lewy neurites, and the massive loss of midbrain dopamine neurons. However, a cause-and-effect relationship between Lewy inclusion formation and neurodegeneration remains unclear. Here, we found that in wild-type nontransgenic mice, a single intrastriatal inoculation of synthetic α-Syn fibrils led to the cell-to-cell transmission of pathologic α-Syn and Parkinson's-like Lewy pathology in anatomically interconnected regions. Lewy pathology accumulation resulted in progressive loss of dopamine neurons in the substantia nigra pars compacta, but not in the adjacent ventral tegmental area, and was accompanied by reduced dopamine levels culminating in motor deficits. This recapitulation of a neurodegenerative cascade thus establishes a mechanistic link between transmission of pathologic α-Syn and the cardinal features of Parkinson's disease.

Parkinson's disease (PD) is a multisystem neurodegenerative disorder characterized by two major disease processes: the accumulation of intraneuronal Lewy bodies/Lewy neurites (LBs/LNs) containing misfolded fibrillar α-synuclein (α-Syn), and the selective degeneration of midbrain dopamine (DA) neurons in the substantia nigra pars compacta (SNpc) leading to bradykinesia, tremor, and postural instability (*1*). The etiology of these processes remains unclear, although in familial PD, autosomal dominant α-Syn gene mutations or amplifications directly

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Science

Financial Costs of Meeting Global Biodiversity Conservation Targets: Current Spending and Unmet Needs

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Costs of Conservation
In 2010, world governments agreed to a strategic plan for biodiversity conservation, including 20 targets to be met by 2020, through the Convention on Biological Diversity. Discussions on financing the plan have still not been resolved, partly because there is little information on the likely costs of meeting the targets. **McCarthy *et al.*** (p. 946, published online 11 October) estimate the financial costs for two of the targets relating to protected areas and preventing extinctions. Using data from birds, they develop models that can be extrapolated to the costs for biodiversity more broadly. Reducing extinction risk for all species is estimated to require in the region of U.S. $4 billion annually, while the projected costs of establishing and maintaining protected areas may be as much as U.S. $58 billion––although both sums are small, relative to the economic costs of ecosystem losses.