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How to protect half of Earth to ensure it protects sufficient biodiversity

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ECOLOGY

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It is theoretically possible to protect large fractions of species in relatively small regions. For plants, 85% of species occur entirely within just over a third of the Earth's land surface, carefully optimized to maximize the species captured. Well-known vertebrate taxa show similar patterns. Protecting half of Earth might not be necessary, but would it be sufficient given the current trends of protection? The predilection of national governments is to protect areas that are "wild," that is, typically remote, cold, or arid. Unfortunately, those areas often hold relatively few species. Wild places likely afford the easier opportunities for the future expansion of protected areas, with the expansion into human-dominated landscapes the greater challenge. We identify regions that are not currently protected, but that are wild, and consider which of them hold substantial numbers of especially small-ranged vertebrate species. We assess how successful the strategy of protecting the wilder half of Earth might be in conserving biodiversity. It is far from sufficient. (Protecting large wild places for reasons other than biodiversity protection, such as carbon sequestration and other ecosystem services, might still have importance.) Unexpectedly, we also show that, despite the bias in establishing large protected areas in wild places to date, numerous small protected areas are in biodiverse places. They at least partially protect significant fractions of especially small-ranged species. So, while a preoccupation with protecting large areas for the sake of getting half of Earth might achieve little for biodiversity, there is more progress in protecting high-biodiversity areas than currently appreciated. Continuing to prioritize the right parts of Earth, not just the total area protected, is what matters for biodiversity.

INTRODUCTION

Human impacts dominate Earth (*1*), eliminating many species from large areas of the land (*2*) and ocean (*3*) and driving the current rate of species extinction to 1000 times its natural rate (*4*). The principal solution for stemming biodiversity loss is the establishment of protected areas. On land, they have grown from a few million square kilometers in the 1960s to >20 million km^2 today (*5*–*7*)—between 13 and 15% of the Earth's land surface, depending on whether one considers ice-covered areas like Antarctica and how one defines "protected." The Convention on Biological Diversity's Aichi Biodiversity Targets include the protection of at least 17% of terrestrial areas, conserving them with ecologically representative and well-connected systems of protected areas, and halving the rate of current habitat loss (*6*). The Global Strategy for Plant Conservation hopes to protect 60% of plant species (*8*).

Beyond these near-term targets are aspirational ones such as Wilson's "Half Earth" (*9*) and Dinerstein *et al.*'s considerations of what it would take to do that on an ecoregion-by-ecoregion basis (*10*). Wilson's heuristic suggests that protecting half of Earth might protect 85% of its species and be a "safe limit" for human impacts. These efforts expand on a tradition going back at least to Odum and Odum (*11*), the Wildlands Project in the United States (*12*), and others who assert that much larger areas must be protected than at present.

Half Earth aspirations are composed of two interrelated goals—protecting 50% of the surface of the planet and 85% of its species. Now, there are important reasons to protect large, contiguous areas without a necessary focus on the numbers of species they contain. These areas likely retain their natural ecosystem processes and the services they provide humanity. For example, unconstrained Amazon deforestation might have catastrophic consequences to climate (*13*), somewhat separate from the issue of how many species might be lost. Some species—large predators are obvious examples—must roam over large areas for their populations to be viable, and even small-bodied species may thrive in large areas but suffer in small ones. Here, we count all species as being equal and consider the fractions of species that protected areas encompass. We return to the caveats in this approach at this paper's end. There, we will also consider why this species counting approach has practical utility.

We are concerned that simply protecting half of Earth without strict attention to the specific places protected and the species they contain will not achieve the larger aspirational goals and indeed might harm them. To address this concern, we must answer several questions.

1) Is it theoretically possible to protect large fractions of species in relatively small regions? At least for plants, the answer is known to be yes; 85% of species occur entirely within just over a third of the land surface, if carefully optimized to maximize the species captured (*8*). Well-known vertebrate taxa show similar patterns (*14*, *15*). Simply, protecting half of Earth is not necessary to protect 85% of species, but would it be sufficient if protected areas were not "carefully optimized"?

2) How well has the existing network of protected areas captured biodiversity, particularly those species with small geographical ranges that suffer disproportionate threats of extinction?

The predilection of national governments is to protect areas that are "wild," that is, typically remote, cold, or arid (*16*, *17*). Unfortunately, those areas often hold relatively few species. Wild places also afford the easier opportunities for the future expansion of protected areas. The expansion of protection into human-dominated landscapes will surely be the greater challenge. This leads to our final question.

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3) Were we to expand protection to the wilder half of the Earth's ice-free land, what fraction of species live in such places and so might contribute to the Half Earth goals?

Here, we identify what fractions of species ranges are already within protected areas. Furthermore, we consider what fractions are in wild regions that are not currently protected. Other things being equal, these places might afford the best chances for expanding the global network of protected areas and further increases in the fractions of species protected. Lewis *et al.* (*7*) underscore the urgency of this. They show that extensive degazetting of protected areas over the past decade has offset much of the newly protected area and led to only modest increases in the total area protected. Our paper's key objective is to assess how successful the strategy of protecting additional wild places might be in conserving biodiversity.

We will show that expanding protection to the wilder half of Earth is far from sufficient to protect biodiversity. Unexpectedly, we will also show that, despite the substantial bias in establishing protected areas in wild places to date, enough protected areas are in biodiverse places that they partially protect substantial fractions of species. So, while a preoccupation with protecting large areas for the sake of getting half of Earth might achieve relatively little for biodiversity, there is more progress in protecting high-biodiversity areas than currently appreciated. Quality, not just size, matters.

Defining protected areas and wilderness

We start with Wilson's definition of wilderness—"regions with small human populations, and particularly indigenous ones." There are numerous efforts to define these places, including McCloskey and Spalding (*18*) who estimated 37 million km^2, Hannah *et al.* (*19*) who estimated 36 million km^2, Sanderson *et al.* (*20*) who estimated 55 million km^2, and Watson *et al.* (*21*) who estimated 28 million km^2. These estimates typically exclude Antarctica, Greenland, and other areas of mostly rock and ice and differ because of their different assumptions as to what constitutes wilderness.

A first set of problems for wilderness is conceptual. These may remain insoluble, because there is no indisputable boundary between human-dominated and wilderness. The answer depends on the species of interest and the time span over which one poses the question.

For example, one might define wilderness as only those places with a full complement of a region's original species. If so, one would include only 3.4 million km^2 of the ~10 million km^2 of savannah Africa that has lions. That would exclude areas with low densities of people and several national parks (*22*). Requiring natural densities of savannah elephants as a criterion for wilderness would exclude many more national parks (*23*). Yet, large areas of savannah Africa have extensive areas with few people or livestock, and they afford substantial opportunities for conserving biodiversity.

For a second example, consider the difficulty in interpreting whether fires are the result of natural or human-planned ignitions. The question might be unanswerable, although fire data are global, frequent, and spatially highly resolved (*24*). Fires have likely been a feature of Africa's savannahs perhaps since human origins. Should one exclude extensively and frequently burned areas of drylands, considering that a sufficiently low human density is within any practical definition of wilderness? Indigenous people also burn huge swaths of Australia. Its initial use coincided with a massive loss of native species following human colonization 50,000 years ago (*25*), but how much was caused by direct burning? The colonists also removed most large mammals including herbivores, leading to marked changes in the vegetation (*26*).

A second set of problems in defining wilderness is that the data to define it vary substantially in quality and reliability. Forest cover data are highly resolved spatially (*27*), but there is substantial disagreement about what constitutes a forest (*28*). Distinguishing a naturally sparse forest from one where human actions have thinned the forest is not always possible. Moreover, remote sensing does not readily distinguish forests of tree plantations, such as rubber, teak, *Eucalyptus*, pines, and oil palm from natural forests. Data sets for other land covers have similar issues.

Both human population data (*29*) and livestock data (*30*) are much less spatially resolved. They often show obvious differences at administrative boundaries, often essentially "counties," that can cover large areas. This is especially true of livestock data, which assume constant densities within these areas. Moreover, we are most interested in areas with low human and livestock densities, because we might putatively consider these areas to be wilderness. A priori, we expect data in these sparsely populated areas to be less reliable than in higher-density areas. Here, those high densities also associate with smaller and better-documented administrative areas.

Recognizing these and many other caveats, a consensus on what constitutes wilderness is unlikely. We chose to go with the human footprint index because it is readily accessible and recent, and the rules that establish it are transparent (*31*). To select half of Earth, we started with the areas that are already protected (13.3% of the ice-free land) and then considered additional areas with the lowest human footprint to constitute close to 51.9% of the land surface. This was as close to half as we could get, given the discrete values of the human footprint index (Fig. 1). Hereafter, we call this 51.9% of the land "protected plus wilderness."

RESULTS

Figure 1 maps the distribution of areas that we deem to be wilderness (human footprint index $\leq$ 3.3) or protected under various categories (see definition in Materials and Methods). A Venn diagram summarizes their relationships. The figure juxtaposes what has broadly been noted before—the distribution of protected areas is highly nonrandom with respect to different kinds of ecosystems (*16*)—with explicit mapping of the areas with the least human footprint. Protected areas are predominantly in wilderness—often cold, dry, or otherwise remote from centers of human population and impact. Approximately 65% of the protected area has a human footprint of $\leq$3.3, and protected areas overall have a median human footprint of 1.3. We consider all protected areas, regardless of their footprint index value, as contributing toward Half Earth.

We next consider how many species of birds, mammals, and amphibians that protected areas and wilderness encompass. These data consist of 5311 terrestrial mammal species, 10,079 terrestrial bird species, and 6397 amphibian species. An example is the red-faced warbler, *Abroscopus albogularis*. Its total range is ~1.7 million km^2, and this includes ~6100 km^2, 10,500 km^2, 11 km^2, 24,000 km^2, 200 km^2, and 25,800 km^2 of the six International Union for Conservation of Nature (IUCN) protected area categories, respectively, from most (I) to least (VI) restrictive, 9500 km^2 with no IUCN category, plus 26,000 and 18,900 km^2 of the two China nature reserve categories (national and local). Some 65,100 km^2 of the range is in wilderness. The remainder is in areas with higher human impact.

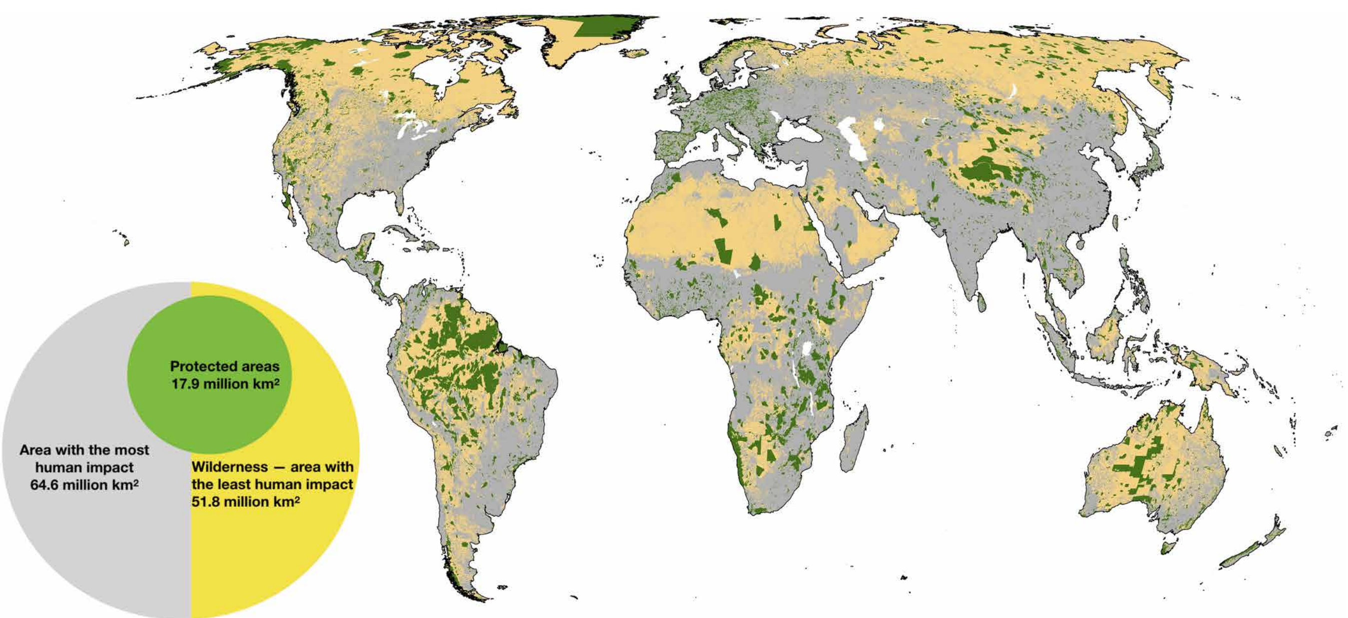

Fig. 1. Protected areas (green) plus the areas having the lowest human footprint index (≤3.3), which we call "wilderness" (buff), up to a combined extent that is as close to half of the Earth's land surface as we could make it (51.9%) given the discrete nature of the index. In the Venn diagram, protected areas are composed mostly of wilderness (65%) but also include some more heavily affected areas (35%).

What should we expect?

If the protected areas were random with respect to species ranges, one would expect 13.3% of each species range to fall within them—the same proportion as the terrestrial Earth as a whole. For the warbler, this would be 228,171 km^2. Similarly, 51.9% of each species range should be in protected areas and wilderness. The corresponding expected value for the warbler is 888,468 km^2.

To summarize these data for all species, we calculate the $\log_{10}$ of the size of each species' geographical range. We grouped the results into half $\log_{10}$ bins, labeling each with the floor of the area size interval. For example, areas between 100,000 km^2 ($\log_{10} = 5$) and 316,228 km^2 ($\log_{10} = 5.5$) are in the figures and tables as in the 100,000 km^2 bin. We added 1 km^2 to all areas.

Figure 2 summarizes the data for mammals, and tables S1 to S6 contain the tabulated data for mammals, birds, and amphibians. In Fig. 2 (top), the black bars are the number of species against the bin of geographical range sizes. For all three taxa, the distributions of their range sizes are broadly lognormal but with a long tail of small values (*4*). The modes are range sizes between 100,000 and 316,228 km^2 for mammals, 1,000,000 and 3,162,278 km^2 for birds, and 3162 and 10,000 km^2 for amphibians.

At the mid-left of Fig. 2 (and tables S1 and S2, third column), the gray bars plot the numbers of species that we would expect in these bins if protected areas encompassed 13.3% of each species range. At the bottom left, we do likewise for species in protected areas plus wilderness, where the proportion is 51.9%.

What we observe

In the example of this warbler, the total area of its range in protected areas, 121,723 km^2, is less than one would expect, and the total area within both protected areas and wilderness, 181,864 km^2, is substantially less than the expected. At the right of Fig. 2 (in color), we show the actual distribution of the species in protected areas (mid-right) and in protected areas and wilderness (bottom right). To facilitate comparison to the expected distributions, we repeat those distributions at the right in light gray.

The salient features are the numbers of species that have <1 km^2 of their ranges outside of protected areas or protected areas plus wilderness. So, for example, the mid-right shows, in various colors, the 319 species (6%) of mammals having <1 km^2 of their ranges within protected areas. This compares to the 36 species expected if ranges protected were at random, as shown in gray in the mid-left figure. The comparable numbers for birds are 314 (3%) compared to 51 expected, and those for amphibians are 1176 (18%) compared to 437 expected.

Across all three taxa, these fractions of species with essentially no protection are substantially higher than one would expect if protected areas were distributed randomly across species distributions (Fig. 2). Nonetheless, most species do have a portion of their ranges in protected areas. Only a small fraction of bird species lie completely outside of protected areas. There are much larger fractions of amphibian and mammal species (tables S1 to S6).

At the lower right of Fig. 2 (and tables S1 and S2, fourth column), we repeat these calculations for mammal species within protected plus wilderness. Some 165 species (3%) have <1 km^2 of their ranges within protected plus wild areas, compared to 11 expected. The comparable figures for birds are 186 (2%) compared to 20 expected, and those for amphibians are 814 (13%) compared to 108 expected. Finally, Fig. 2 and tables S1 and S2 (columns 5 to 20) break down the distributions of ranges within protected areas (top right) and within protected plus wilderness areas (bottom right) by the original range size of the species involved.

Figure 3 summarizes a subset of these data in an alternative format. It shows the average fractions of ranges protected (blue circles), and in protected plus wild areas (green circles), as a function of the species original range size. For example, on average, about 40% of the ranges of mammal species with ranges <10 km^2 are protected, while for amphibians, it is about 35% for these small-ranged species, and for birds, it is between 45 and 80% of the species. Overall, protected areas do consistently better at protecting species than one would expect, especially so for species with range sizes of <10,000 km^2. The dashed blue line shows the expected values. In contrast, adding in wild areas makes only modest contributions to increasing the fractions of species ranges included, and they perform poorer than expected (shown by the dashed green line).

What do these results tell us about the goals of Half Earth, specifically the objective of protecting 85% of species? To answer this question, we must decide on how well covered a species' range should be for us to consider it "sufficiently protected." Table 1 shows the percentages of mammal species captured when considering two criteria: a minimum amount of area protected within the species range and a minimum percentage of the range protected. One could imagine other metrics: There is nothing special about the specific thresholds used here. Results for birds and amphibians are in tables S7 and S8.

What Table 1 shows is that existing protected areas do not reach the 85% goal except when using the lowest of thresholds (1% of the range and 100 km^2 or less). For example, if a species must have at least 1 km^2 and 1% of its range protected, we capture 92.3% of mammal species in existing protected areas. Increasing the requirement to 100 km^2 and 10% of its range, they capture only 62.2% of mammals. Even when expanding coverage to wilderness, the numbers are not encouraging (10% and 100 km^2 or less to capture 85% of species), considering that half the planet is now included.

Given that current protected areas are still far from the goal of covering 85% of species, and further expansion to wild areas is an inefficient strategy, where should the focus be? At www.biodiversitymapping.org, we map the richness of species of mammals, birds, and amphibians, plus maps of the halves of those species that have smaller than the median range size. For convenience, we repeat the latter maps in Fig. 4A and figs. S1 and S2. The distribution of species with small ranges closely approximates Myers *et al.*'s definition of biodiversity hotspots (*14*, *15*) as well as a large fraction of species threatened with extinction. These concentrations of small-ranged species include not

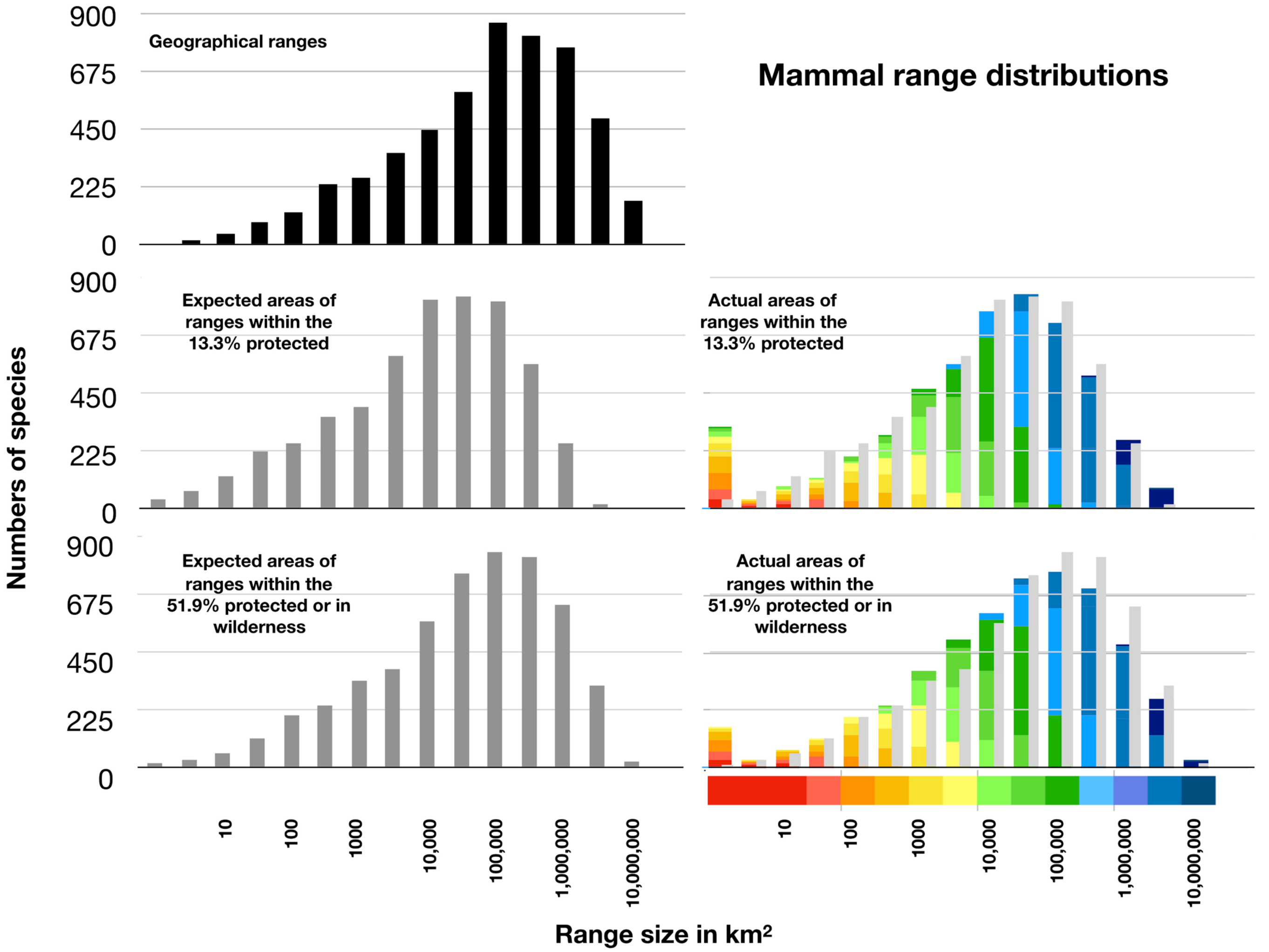

Fig. 2. Distribution of geographical range sizes of mammals, the expected areas within the 13.3% of the land surface (mid-left), and, in Half Earth, the 51.9% of the land surface. (**Right**) Actual fractions of the species within these two classes. We color-code the actual areas by the species' original range size. So, for example, we expect only 36 species to have <1 km^2 of their ranges in protected areas (gray bars, mid-left), yet 319 species do so. Most of these have geographical ranges of <10,000 km^2 (colored yellow to red). Some have large ranges (colored green or blue). The bins are such that the value shown for (say) 10 km^2 encompasses ranges from that value ($\log_{10} = 1$) up to 31.62 km^2 ($\log_{10} = 1.5$).

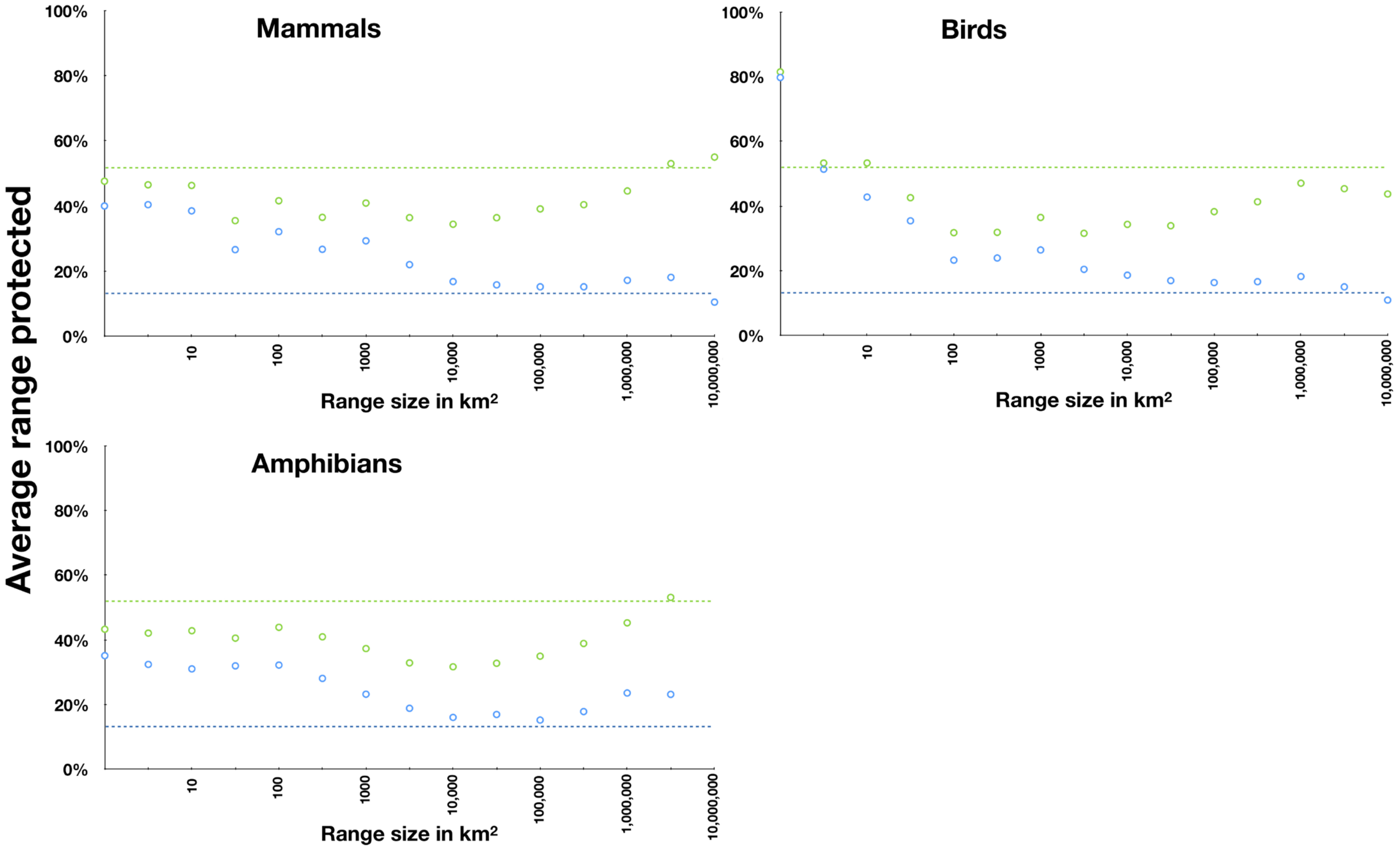

Fig. 3. The average percentages of ranges protected (blue) and in protected plus wild areas (green) as a function of the original range size for mammals, birds, and amphibians. The horizontal lines show the expected values of 13.3% for protected areas and 51.9% for protected plus wild areas. (We do not display the confidence intervals on these fractions because they are very broad, with some species completely protected and others having no protection at all—as Fig.2 shows.)

Table 1. Percent of terrestrial mammal species with a given minimum area and percentage of their range covered by protected or protected plus wild areas. Combinations of criteria, where more than 85% of species are included, are bolded. For species whose original entire ranges are smaller than the minimum area requirement, we include them once 100% of their range is covered.

Mammals (% of 5311 species)		Percent range protected			
		≥1%	≥5%	≥10%	≥50%
Area protected	≥1 km^2	**92.3%**	82.6%	63.9%	8.2%
	≥100 km^2	**88.9%**	80.6%	62.2%	7.4%
	≥10,000 km^2	61.6%	58.2%	45.3%	2.8%
	≥1,000,000 km^2	7.3%	7.3%	6.8%	0.8%
Mammals (% of 5311 species)		**Percent range protected + wild**			
		≥1%	**≥5%**	**≥10%**	**≥50%**
Area protected + wild	≥1 km^2	**96.5%**	**92.8%**	**87.6%**	31.4%
	≥100 km^2	**93.0%**	**90.5%**	**85.8%**	30.6%
	≥10,000 km^2	68.7%	67.8%	65.8%	23.9%
	≥1,000,000 km^2	15.9%	15.9%	15.9%	9.2%

only half of all species found entirely within them but also a considerable number of other more wide-ranging species.

Figure 4B also shows where these species live in areas that are outside of protected areas but in wilderness—the putatively easier targets for strategically expanding protected areas. Few such places are extensive, but examples are in the western Andes and in insular tropical Asia and New Guinea. These wild but diverse areas should certainly be among global priorities for conservation.

DISCUSSION

Caveats and limitations

The data we present are for birds, mammals, and amphibians. Combined, these species represent about 1% of the 2 million species that taxonomists have described. In turn, these may be only 10% of the very uncertain numbers of all species (*32*). Why is there no analysis for insects that constitute perhaps 90% of all species? Simply, there are no suitable data. What few data we have on insect distributions likely are about relatively widespread species, because taxonimists describe these species first (*4*). The problem with the plant data is that, while only an estimated 15% more species are likely to be as yet unknown (*33*), the distributional data for known species are still far too coarse to estimate overlaps with protected areas and wilderness (*8*).

Might protecting large, wild areas better encompass the great majority of species for which we do not have geographical data? We think this is unlikely. The coarse data on plant distributions suggest that concentrations of endemic species match those for the taxa we describe here (*8*). Moreover, models of species discovery rates suggest that these concentrations are where taxonomists will eventually describe the currently unknown taxa (*33*).

Some conservation organizations prioritize large-bodied charismatic species. For instance, the website of the World Wildlife Fund lists giant pandas, tigers, elephants, gorillas, polar bears, and rhinos as its terrestrial species of concern. All have very large geographical ranges. These six mammals, while entirely deserving of protection, are an even smaller fraction of the world's total biodiversity. Certainly, in protecting the giant panda, Chinese authorities have protected substantial fractions of their endemic vertebrates (*34*) and done so in areas rich in endemic plants (*8*). There is little compelling reason though that these six species, or other similar ones, might protect biodiversity more generally than the ~20,000 species we consider here.

Finally, we recognize that, while protected areas encompass large fractions of especially small-ranged species, they may not do so adequately. This is a concern that applies a fortiori to wilderness into which human activities can expand unfettered. (New Guinea is an obvious example.) Evaluating adequate protection is beyond the scope of this paper, but a first step is to identify which species have no protection at all.

Conclusions

We have presented several results expected from previous studies and some new and unexpected ones. We can conclude the following.

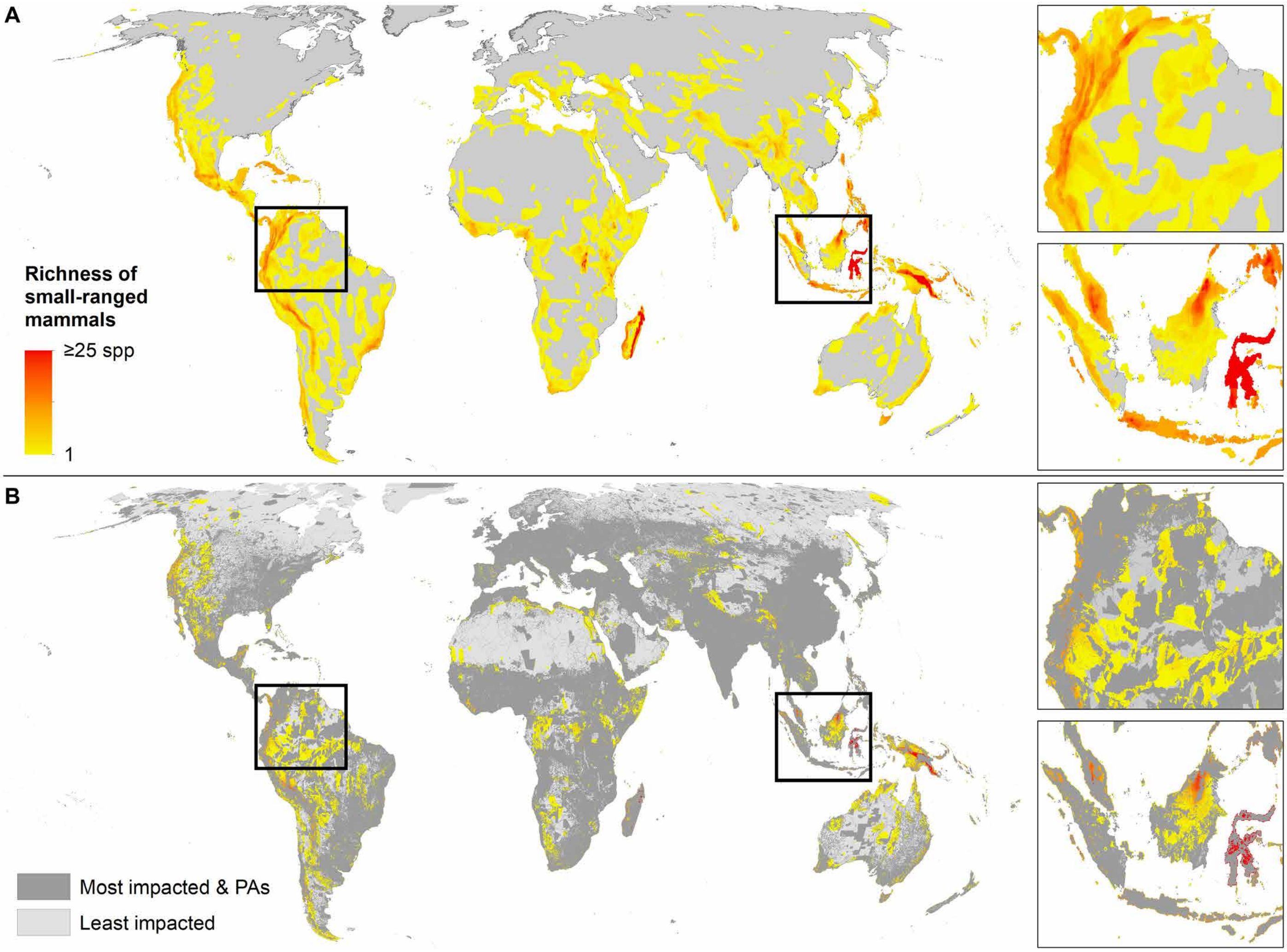

Fig. 4. Map of small-ranged mammal species and unprotected small-ranged mammal species. Numbers of terrestrial mammal species with less than the median range size (**A**) and those that are in unprotected wilderness (**B**). Right: Details for parts of South America and Southeast Asia. Figures for birds and amphibians are shown in the Supplementary Materials.

1) Achieving the goal of protecting large fractions of biodiversity is theoretically possible in relatively small fractions of the Earth's surface, because small-ranged species are geographically concentrated. With their protection comes the inclusion of more wide-ranging and generally much less threatened species.

2) The aspirational target of protecting half of the Earth's land surface may be broadly attainable. There are large areas that still have low human impacts. They are most extensive in the Arctic and boreal regions, deserts, and the few remaining large blocks of tropical moist forest (*31*).

3) Most current protected area is in these wild places (Fig. 1). The key question is whether it is practical to protect large fractions of species with area targets such as those of Half Earth (*9*, *10*). Obviously, it depends on which areas are selected. Protecting large landscapes has many benefits, not least for the ecosystem services that they provide. Our concerns, however, are with the implication that protecting half of Earth will also protect substantial fractions of species. In general, only wilderness of tropical moist forests supports locally high diversity. This begs our question of how much biodiversity will we protect if the trend to protect wild places continues.

4) Wild places do less than expected by chance at protecting species (Fig. 3). Moreover, very few wild places house concentrations of small-ranged species not already protected by existing protected areas (Fig. 4B and figs. S1B and S2B). Simply, achieving conservation goals by creating more protected areas in current wilderness might locally be helpful, but it is not sufficient to protect biodiversity at large.

5) On a species-by-species basis, the efficacy of existing protected areas is nuanced. Existing protected areas completely fail to encompass from 3% (birds) to 18% (amphibians) of species. That birds do so much better may well be due to deliberate efforts to establish protected areas that house small-ranged, threatened bird species (for example, BirdLife's Important Bird and Biodiversity Areas).

6) In contrast, for the most vulnerable species—those with small geographical ranges—protected areas are surprisingly inclusive, with much greater fractions of species' ranges covered than expected. This is particularly striking for species with ranges of <10,000 km^2. The explanation for this apparent contradiction is surely that there are many relatively small protected areas that strongly focus on areas with concentrations of small-ranged species.

7) For species with larger range sizes—that is, 100,000 km^2—the fractions of species' ranges currently protected are close to what one would expect by chance if protected areas were placed randomly (Fig. 3).

Three large, species-rich countries—Brazil (8.5 million km^2), China (9.6 million km^2), and the United States (9.6 million km^2)—exemplify the concerns our results prompt. All three have substantial wild areas and globally important concentrations of small-ranged species in their southeast (Brazil and United States) or southwest (China and plant species in California). With the exception of southwest China, these concentrations are also where many people live.

Much of the Amazon basin lies within Brazil. It contains the largest species-rich wilderness on Earth with much of it protected, inter alia, by indigenous reserves. They are effective at protecting forest cover at least (*35*, *36*) but, based on current knowledge, hold relatively few small-ranged species. These species are concentrated in Brazil's coastal forests along with a large fraction of the country's threatened species (*37*), albeit often in small, isolated protected areas. The fate of these species will likely depend on the ability to enforce that protection and to reconnect habitats in this massively fragmented landscape (*38*).

China has extensive protected areas in the sparsely populated, high, and arid west. Its endemic species concentrate in the southwest where, fortuitously, they extensively overlap with the iconic giant panda (*34*). Future improvements in protecting China's biodiversity will require a targeted expansion of the current protected areas and a recognition that other species besides pandas can act as umbrella species for conservation.

The United States has extensive protected areas, also in its sparsely populated, high, and arid west. There are very few large protected areas in the southeast where important concentrations of endemic species live. The United States also has an extensive network of private land conservancies, especially in the east. These tend to protect green spaces in wealthy counties in the northeast, rather than economically poorer, but species-rich areas in the southeast (*39*).

In sum, the preoccupation with summarizing the total area protected can be misleading—quality, not quantity, matters. Protected areas, to date, have been more effective at including species than commonly thought. Whether we can achieve large-scale protection of biodiversity will depend much on the details of how countries set priorities for protection.

MATERIALS AND METHODS

For protected areas, we follow (*6*) except for China, where we used data in (*34*) and 2014–2017 updates from the China Ministry of Environmental Protection (now the Ministry of Ecology and Environment) website. From the World Database on Protected Areas, only areas listed as designated and national or regional were included. In the case of overlaps, we ranked the area as the strictest of the overlapping categories. We did not consider protected areas having only point data as we are interested in precisely where land is protected relative to species ranges. Consequently, our estimate of total area protected is slightly lower than if including the areas represented only as points.

The Human Footprint Index (*31*) scales from 0 to 50. We defined wild areas as those with values ≤3.3 for doing so meant that the area encompassed combined with protected areas came as close to half of the land surface as practical, not including Antarctica. Had we chosen to ignore the protected areas, values of ≤3.8 would have encompassed half of the land surface.

Species range data were from (*40*, *41*). We took the ranges of all extant birds, mammals, and amphibians and, for each, calculated how much of their range was in protected areas of IUCN categories I to VI, protected but lacking an IUCN category, or unprotected but wild. We considered only the extant ranges of species. We used ArcGIS 10.5 and the Eckert IV equal-area projection for analyses.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/4/8/eaat2616/DC1

Fig. S1. Map of small-ranged bird species and unprotected small-ranged bird species.

Fig. S2. Map of small-ranged amphibian species and unprotected small-ranged amphibian species.

Table S1. Mammals in protected areas.

Table S2. Mammals in protected areas plus wilderness.

Table S3. Birds in protected areas.

Table S4. Birds in protected areas plus wilderness.

Table S5. Amphibians in protected areas.

Table S6. Amphibians in protected areas plus wilderness.

Table S7. Percent of terrestrial bird species with a given minimum area and percentage of their range covered by protected or protected plus wilderness.

Table S8. Percent of terrestrial amphibian species with a given minimum area and percentage of their range covered by protected or protected plus wilderness.

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