Supplementary Materials for

Protected Areas and Effective Biodiversity Conservation

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Published 15 November 2013, *Science* **342**, 803 (2013)
DOI: 10.1126/science.1239268

This PDF file includes

Other Supplementary Material for this manuscript includes the following:

Table S1 as zipped archive:
Table S1. Irreplaceability scores and ranks per protected area. Values are provided for each of the 173,461 current protected areas and for each of the 2059 sites listed as "proposed" in the World Database on Protected Areas. Scores and ranks were calculated either across multiple taxa or separately for birds, mammals and amphibians, and either for all species (threatened or nonthreatened) or just for threatened species (available: http://irreplaceability.cefe.cnrs.fr/SM/TableS1.zip).

Materials and Methods

Protected Area Data

Data on protected areas, including World Heritage sites, were taken from the World Database on Protected Areas (WDPA), the most comprehensive global data set on marine and terrestrial protected areas. This database is a joint product of the International Union for Conservation of Nature (IUCN) and the United Nations Environment Programme (UNEP), prepared by the UNEP World Conservation Monitoring Centre (UNEP-WCMC) and the IUCN World Commission on Protected Areas (WCPA), working with governments and collaborating nongovernmental organizations. The WDPA is mandated by the United Nation's Convention on Biological Diversity, and is used by signatory countries to report on and track progress toward the Convention's targets on protected areas. The WDPA is the best available data on the global network of protected areas, but it is necessarily imperfect, including missing information and mistakes in the spatial delimitation of individual sites.

This analysis used the October 2012 version of the WDPA (*9*), which contains site boundaries and other information for 173,461 designated protected areas [recognized or dedicated through legal or other effective means—such as through recognized traditional rules or by established nongovernmental organizations—implying specific binding commitment to conservation in the long term (*22*)] and for an additional 2059 sites of "proposed" status (in a process to gain recognition or dedication through legal or other effective means) (*23*). This included protected areas of all designation types, management categories, or governance types recorded in the WDPA, including all 217 existing World Heritage sites inscribed under one or more of the four natural World Heritage criteria [as of December 2012 (*15*)]. These data are accessible on ProtectedPlanet.net (www.protectedplanet.net), the interactive web interface of the WDPA (*9*).

Species Data

Data on species' distributions and global conservation status were obtained from the 2012.2 version of the *IUCN Red List of Threatened Species* (*10*). The IUCN Red List is the most comprehensive global approach for evaluating the conservation status of plant, animal and fungi species, produced by the IUCN Global Species Programme working with the IUCN Species Survival Commission. We focused on three groups that have been comprehensively assessed and mapped: amphibians, mammals, and birds. Species are classified according to their Red List conservation status into Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), or Data Deficient (DD). Species classified as either Extinct (EX) or Extinct in the Wild (EW) were excluded from this analysis. Species classified as VU, EN, or CR are said to be "threatened." Overall, 21,419 species were included in the analysis: 6240 amphibians (including 1922 globally threatened); 5263 nonmarine mammals (1096 threatened) and 9916 birds (1311 threatened). However, for 123 extremely widespread bird species (range > 220,084 km^2), the geographic information system (GIS) intersection analysis for calculating the percentage of each species' distribution in each protected area failed consistently (i.e., did not reach completion after very long processing times; probably a result of the excessive amount of vertices included in the extremely detailed coastlines that form part of species range distribution boundaries), and thus these species did not

contribute to the irreplaceability scores of any protected areas. These species are, however, very unlikely to affect the irreplaceability calculations, because very small fractions of their distributions (< 1.1% of the distribution in 99% of the species' cases) are present in any individual protected area, and these have little weight on the irreplaceability scores (see below).

Species' global distribution data were available as broad polygons, encompassing the known, inferred, or projected sites of present occurrence for the species. These polygons may include relatively extensive areas from which the species is absent (e.g. freshwater habitats within a terrestrial species' distribution) and are therefore likely to overestimate the species' true area of occupancy. As with the WDPA, although these species distribution polygons represent the best available data concerning the global limits of distribution of these species and have been widely and extensively used in various previous studies [e.g., (*2, 18, 24–25*)], they too are necessarily imperfect, and may include erroneous or missing information and mistakes. However, the IUCN Red List process is iterative, and the data are continually being improved and revised.

In this work, as in previous analyses of the same data [e.g., (*2*, *18*, *24–25*)], we included only those parts of each species' distribution where it is considered to be extant or probably extant (presence codes 1 and 2; hence, we excluded areas from where species are extinct, possibly extinct, or of uncertain presence in order to ensure species are only considered present in PAs within their present area of distribution), and where the species is native, including where it has been reintroduced (origin codes 1-2; hence, we excluded areas where species are introduced, present as vagrants, or of uncertain origin because these populations were considered of low conservation interest). In addition, for birds, only areas where species occur as resident, breeding, or nonbreeding were included (seasonality codes 1 to 3, which thereby excluded areas of migratory passage or presence at uncertain seasons for which the spatial data are of lower accuracy) [for a description of the categories of origin, presence, and seasonality, see (*26*)].

Other data available from the IUCN Red List include current population trends, habitat preferences, major threats, and ongoing conservation actions. These data were not used in the analysis presented here but are available from each species' page within the IUCN Red List of Threatened Species Web site (http://www.iucnredlist.org), and provide useful context to protected area managers.

Species distribution data for mammals and amphibians are available through the IUCN Red List Web site (http://www.iucnredlist.org/). Distribution data for birds can be obtained from BirdLife International's Data Zone page (http://www.birdlife.org/datazone/home). Conservation status and other Red List data can be obtained from the IUCN Red List Web site.

Combining PA and Species Data

The spatial data on the distribution of species from the IUCN Red List of Threatened Species (*10*) was combined with the spatial data for each protected area from the IUCN/ UNEP-WCMC World Database on Protected Areas (*9*) using ArcGIS (*27*). The percentage of each species' global distribution overlapping the boundaries of each protected area was obtained through spatial intersections between the two types of data, from where the irreplaceability of each protected area was then calculated.

Irreplaceability Measure

Protected area irreplaceability was defined in this study as an aggregated measure of the degree of dependence of species' on the protected area. This measure can inform the extent to which each protected area is important to preventing global species' extinctions, and it was calculated from the percentage of each species' global distribution overlapping the boundaries of each protected area. This measure is related to, but different from, other measures of irreplaceability previously proposed in the conservation literature (see below).

The irreplaceability score, I, of each site, p, was calculated as a weighted species richness, i.e., the sum across species i of weights w_{ip} for each species in each site p (equation 1). These weights were obtained first by transforming the percentages of each species' global distribution in each site, x_{ip}, according to function $f1$ (equation 2; fig. S2), followed by rescaling these values (as per equation 3), to ensure that the final weights w_{ip} vary between 0 (for a species whose distribution overlaps 0% with the site) and 1 (for a species 100% contained within the site).

$$I_p = \sum_i w_{ip} \qquad \text{(equation 1)}$$

$$f1(x) = \frac{1}{1 + e^{-\left(\frac{x-39}{9.5}\right)}} \qquad \text{(equation 2)}$$

$$w_{ip} = \frac{f(x_{ip}) - f(0)}{f(100) - f(0)} \qquad \text{(equation 3)}$$

The irreplaceability score obtained (I_p) reflects thus both the number of species in the PA and the degree to which the species present depend on the PA (as measured by the percentage of their range in the site).

Irreplaceability scores were obtained for each protected area by considering all species whose distributions overlap the site ("overall irreplaceability"), as well as just the subset of threatened species whose distributions overlap the site ("threatened species irreplaceability"). Irreplaceability scores were obtained across all taxa combined, as well as separately for each of the taxonomic groups analyzed: birds, mammals, and amphibians. Protected areas were ranked in decreasing order of each of these scores, as information on their global importance in relation to other existing protected areas. In the case of ties (protected areas with the same irreplaceability score), the average rank was obtained. These scores and ranks are presented for all 173,461 currently designated protected areas in Table S1.

Protected area establishment is not always immediate: It may occur years after a site is first proposed. Sites in the WDPA with status "proposed" are not yet legally protected, but they should be in a process of gaining such recognition (*23*). For each of these 2059 sites, we also calculated irreplaceability scores and ranks. Scores were obtained as described above; ranks correspond to the position each site would have if already protected. These scores and ranks are also presented in Table S1.

Supplementary Text

Choice of the Transformation Function

The specific transformation function ($f1$, equation 2) used to convert the percentages of each species' global distribution in each site, x_{ip}, into a weight w_{ip} was arbitrarily chosen, but took into account two principles. First, we chose a monotonically increasing function, in order to ensure that the irreplaceability value of protected areas is higher for those that have species that have higher percentages of their distributions within the site. In reality, this may not always be the case, because species are not randomly distributed within their ranges (*28*), for example, because of variations in habitat quality; therefore, some PAs may be disproportionately valuable in relation to their area. However, in the absence of better information on each species distribution and abundance within their ranges, we assumed that the higher the percentage of overlap the more each species depends on the protected area for its long-term persistence. If better information does become available for particular species, it can be integrated into the current approach by adjusting weights to reflect the real degree of species' dependence on each PA within its range.

Second, we attempted to reduce the effect of commission errors [considering a species as present in a protected area when it is not; (*24*)] on the irreplaceability values. The coarse nature of the distribution data used in this analysis means that such errors are particularly likely for protected areas that overlap only a very small percentage of a given species' distribution. Indeed, this typically happens for small protected areas that overlap the distribution of widespread species, which may fall wholly within a gap within the species' true area of occupancy (e.g., a protected area without suitable freshwater habitats within the distribution of a freshwater specialist). Commission errors are less likely for higher percentages of overlap: either because protected areas are larger (and so more likely to include the diversity of suitable habitats needed by all species whose distributions overlap it) and/or because species distributions are smaller (less prone to commission errors because boundaries are necessarily mapped with higher precision than for widespread species). Accordingly, we chose a sigmoid transformation function (parameters: $\mu = 39$; $s = 9.5$) that gives very little weight to low and a disproportionately large weight to high percentages of overlap (Fig. S2). For example, a species with a percentage overlap of $x = 1\%$ in a given protected area contributed only $w = 0.0018$ to the areas' irreplaceability, whereas a species with $x = 50\%$ contributed $w = 0.76$. In practice, this means that the irreplaceability scores of each protected area were dominated by the extent to which it covers the distribution of species with relatively narrow distributions.

Sensitivity of Irreplaceability Results to the Shape of the Transformation Function

The specific parameters that shape the transformation function used in this analysis are somewhat arbitrary, chosen as described above to obtain a sigmoid function that reduces commission errors by giving low value to species with very small percentages of overlap. To test the effect of the choice of these parameters on the results, we calculated irreplaceability scores using a wide diversity of monotonically increasing functions (Fig. S2) that vary in the relative weights given to species according to their percentages of overlap. These functions comprised two other sigmoid functions ($f2$ and $f3$), which also give very little value to species with very small percentages of overlap; an exponential function ($f4$), which only gives high weights to species with a very high percentage of

overlap; a negative exponential function ($f5$), which gives a high weight to almost all species present; a linear function ($f6$), where weight is the untransformed percentage of overlap; and the square root function ($f7$), which gives moderately high weights to all species present. A sensitivity analysis compared the overall irreplaceability scores obtained across all 173,461 protected areas (using the Spearman rank correlation coefficient), as well as the identity between the top 100 sites identified using each transformation function. We found the irreplaceability scores to be robust to the variations in the shape of the transformation function (Table S3). Overall, irreplaceability ranks across all 173,461 protected areas were almost perfectly correlated for all functions tested, which indicated that the relative position of PAs (of low/medium/high irreplaceability) is not much affected by the specific choice of monotonically increasing transformation function. The identity of the top 100 sites in terms of irreplaceability (calculated across all species) was more sensitive to the transformation function, but was always very high (at least 78 out of 100 sites in common) within sigmoid functions ($f1$, $f2$, $f3$), which suggests that the specific parameters used in the transformation function employed do not substantially affect the results. Furthermore, there were over two-thirds of sites in common in the top 100 most irreplaceable sites obtained from all functions that give disproportionate lower weight to small percentages of overlap (functions $f1$, $f2$, $f3$, and $f4$), or from the linear function ($f6$). Less agreement was found with functions that give great weight to small percentages of overlap ($f5$ and $f7$) but these are less suitable transformation functions because they are likely to be highly affected by commission errors (i.e., irreplaceability estimates inflated by species that may not even occur within the site and/or for which the site has little global responsibility).

Relation Between the Concept of Irreplaceability in This Study and the systematic Conservation Planning Literature

The concept of irreplaceability applied in this analysis is related to, but different from, the concept of irreplaceability that has become a key principle in systematic conservation planning, defined as either "the potential contribution of a site to a reservation goal" or "the extent to which the options for reservation are lost if the site is lost" (*2*, *29*). First, whereas this definition of irreplaceability (herein termed irreplaceability sensu Pressey) is applied to sites not yet protected, as a measure of their potential contribution to completing the existing protected area system, in our analysis, we calculate an irreplaceability score for already protected sites, as a measure of their importance to consolidate the existing network. Second, for irreplaceability sensu Pressey, the value in each site depends on the specific "reservation goal" (or conservation target) predefined for the future overall protected area network, and so it changes as other sites become protected. In our analysis, irreplaceability can be calculated for each protected area irrespective of the degree of species coverage within other protected areas. Furthermore, for any given taxonomic group, irreplaceability values can be directly compared across sites worldwide.

Hartley *et al*. (*8*), in their assessment of African protected areas, have also calculated an irreplaceability value for each protected area based on their coverage of amphibian, mammal, and bird species. However, they calculated irreplaceability (herein termed irreplaceability sensu Hartley) as the sum of the inverse frequency of each species across all protected areas where it occurs. This measure differs from ours in two main ways.

First, it is a measure of the irreplaceability of each protected area within the current protected area network, whereas we measure irreplaceability within a global context (including information on species distribution within both protected and unprotected areas). Hence, a species may contribute highly to the value of protected area irreplaceability sensu Hartley (if it only occurs in a single PA) yet contribute little to irreplaceability in our study (e.g., if only 1% of its range overlaps that PA). Conversely, a species may have a relatively low weight to the irreplaceability value of a PA sensu Hartley (e.g., if it occurs in 100 other PAs) but a high weight to the irreplaceability value of a PA in our study (e.g., if that PA overlaps 90% of the species' range). Our measure, therefore, is informative of the importance of protected areas for avoiding global species extinction, whereas irreplaceability sensu Hartley is informative of the importance of protected areas for avoiding species extinction within the existing protected area network. Second, irreplaceability sensu Hartley only considers the number of protected areas in which a species is represented, irrespective of their relative sizes and variable degrees of responsibility toward the species. Everything else being equal (i.e., the number of other protected areas where the species occurs being the same), it will consider as equally irreplaceable a very large protected area covering substantial percentages of species' distributions and a very small protected area covering tiny percentages of these ranges. Given that the vast majority of records of species' overlap with protected areas correspond to very small percentages (99% correspond to $x < 1\%$ overlap), the measures of irreplaceability sensu Hartley will be highly affected by commission errors and by species for which the protected area has little overall responsibility. In contrast, our measure of irreplaceability is dominated by species for which each protected area has the most responsibility, with little contribution by species that overlap the site by very small percentages.

The irreplaceability measure presented here is also related to some measures of rarity previously used in the literature, such as range-size rarity, calculated as the sum of each species' inverse range size [e.g., (*30*)]. However, the transformation function applied to convert percentage of species' range into weights (equation 2) has been introduced to deal with the spatial limitations of the data, in particular, the fact that the coarseness of the species' data results makes them highly susceptible to commission errors. So rather than providing a rarity index for each protected area, the measure of irreplaceability proposed here highlights protected areas of particular importance for avoiding the extinction of species (those with relatively high fractions of species ranges within them). It is therefore conceptually closer to the idea of irreplaceability than that of rarity.

Finally, a key concept in the systematic conservation planning literature is that of complementarity, defined as a measure of the extent to which an area, or set of areas, contributes unrepresented features to an existing area or set of areas (*31*). Because irreplaceability is calculated here for each individual protected area, it does not explicitly take into account complementarity. In principle, sites of high irreplaceability are likely to be highly complementary, because they will have large fractions of species' range sizes which (by definition) are unlikely to be found elsewhere. However, although each site in this analysis corresponds to an individual record in the WDAP (*23*), there is overlap (total or partial) between several of these sites. For example, there is very extensive overlap between Gunung Lorentz National Park (http://www.protectedplanet.net/sites/1500, a

nationally designated area); Lorentz National Park World Heritage Site (http://www.protectedplanet.net/sites/198298, part of the global network of sites designated under the World Heritage Convention); and Lorentz National Park ASEAN Heritage Park [http://www.protectedplanet.net/sites/901245, part of the regional network of Heritage Parks created by the Association for Southeast Asian Nations (ASEAN)]. We calculated individual irreplaceability values for each site in the WDPA because they correspond to separate formal management units, potentially under different (even if spatially overlapping) administration regimes. This means that two highly irreplaceable protected areas may be redundant rather than complementary. We eliminated this problem from the analysis that highlights sites of high irreplaceability by grouping them into clusters whenever there was spatial overlap between sites (see below; Table S2), which ensures high complementarity between the resulting clusters and/or sites. When providing information for individual PA managers, on the other hand (*19*), it makes sense that it is available at the level of each of the existing administrative units.

Limits and Caveats of the Irreplaceability Measure

Irreplaceability values based on the percentage of distribution overlap implicitly assume that species are homogeneously distributed within their ranges. In practice, abundance is likely to vary within each species' distribution (*29*), and some areas may be particularly important within the species' meta-population dynamics (e.g., source areas and corridors). The percentage of a species' distribution within a protected area may therefore either underestimate or overestimate its true responsibility to the global conservation of the species; the former is more likely to be true in regions of high human activity, where protected areas are sometimes islands of relatively high quality habitat within a highly transformed landscape. Measures of protected area irreplaceability can be greatly improved by using finer data on species' distribution whenever available.

In this study, irreplaceability was calculated solely from data on taxonomic groups that have already been globally assessed for the IUCN Red List (i.e. amphibians, birds and mammals) and for which distribution maps were recorded in the 2012.2 version of the IUCN Red List (*10*). In the absence of better information, these were used as first surrogates to global terrestrial and freshwater biodiversity. However, as other taxa are assessed for the IUCN Red List (*32*), the approach proposed here can be extended to include information on them too. Overall irreplaceability values will change as more taxa are included in the irreplaceability calculations, which may in turn change relative irreplaceability scores. For example, protected areas in regions of high plant endemism but not of outstanding vertebrate endemism (e.g., in Mediterranean ecosystems) are likely to include sites of extremely high overall irreplaceability that have not been highlighted in this study. As data on marine protected areas and marine taxa improves (*33*), this irreplaceability analysis can be extended to the marine realm too.

Whereas overall irreplaceability (across all biodiversity) will certainly vary substantially as new groups are analyzed, the irreplaceability for each of the taxonomic groups already analyzed (birds, mammals, and amphibians) is likely to be relatively stable. However, even this will change for particular areas as a result of new knowledge (e.g., new species described, taxonomic changes, better data on the distribution of species), as species undergo changes in their distributions (e.g., extirpated from a

particular protected area), or, for the case of irreplaceability for threatened species, as species' conservation status changes (from threatened to nonthreatened or vice-versa).

Larger protected areas will (everything else being equal) have higher irreplaceability values than smaller ones, which is as expected because their share of responsibility in avoiding species extinctions is higher. However, they will also tend to have higher management costs (*34*), even if the relation between costs and area is unlikely to be linear, both because of geometric effects (smaller PAs have a relatively larger boundary to defend) and because the largest PAs tend to be located in remote regions with less competition for land-use. The irreplaceability information we provide here is therefore only part of the information needed to support management decisions, and it should complement information on management costs and benefits across and within protected areas.

Protected areas are the cornerstones of biodiversity conservation (*35*), but on their own, they are not sufficient to prevent species' extinctions. The results presented here should be interpreted while taking into account that PAs are not necessarily effective in reducing some types of pressures faced by species, such as climate change (*36*).

The World Heritage Convention

Adopted in 1972, and (as of December 2012) signed by 190 countries, the convention concerning the Protection of the World Cultural and Natural Heritage (the "World Heritage Convention") embodies the visionary idea that some places are so important that their protection is not only the responsibility of a single nation but is also the duty of the international community as a whole—and not only for this generation but for all those to come (*15*). The primary mission of the convention is to encourage the identification and conservation of the world's natural and cultural heritage properties considered to be of "Outstanding Universal Value." The process for inscribing new World Heritage Sites is bottom-up: States parties to the convention submit nomination proposals to the World Heritage Committee, which will inscribe the site if it meets the necessary criteria. To be deemed of Outstanding Universal Value, sites must meet one or more of the ten cultural and/or natural World Heritage criteria, the corresponding conditions of integrity and/or authenticity, and protection and management requirements (*15*). Of particular relevance to the present study is criterion (x) of the convention, applicable to sites that "contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of Outstanding Universal Value from the point of view of science or conservation." As of December 2012, 962 properties in 157 States Parties were inscribed on the World Heritage List, including 745 cultural, 188 natural, and 29 "mixed" (cultural and natural) properties. Among the natural and mixed sites, 132 were inscribed under criterion (x). Conditions of authenticity are only applied to cultural heritage, whereas integrity is a measure of the wholeness and intactness of both natural and/or cultural heritage. Given the rigorous integrity, protection, and management requirements that natural and mixed World Heritage Sites must meet at the time of inscription and must sustain or enhance over time (*15*), seeking to obtain and maintain World Heritage status can therefore be a powerful mechanism for ensuring the appropriate conservation management of sites. The relatively strong monitoring mechanisms of the WHC include reactive monitoring by UNESCO and IUCN, who carry out monitoring missions and "state of conservation"

reports, periodic reporting by state parties, the List of World Heritage in Danger, and the reinforced monitoring mechanism (see http://whc.unesco.org/ for further details). Furthermore, World Heritage status brings international attention to the outstanding value and/or management challenges of a site and may therefore serve as an incentive to mobilize resources in order to keep its integrity. For example, eligible state parties may benefit from economic support (through the International Assistance funding scheme of the World Heritage Fund) to help them protect the World Heritage sites located on their territories (http://whc.unesco.org/en/intassistance/).

Highly Irreplaceable Protected Areas Highlighted in this Study

A subset of the world's most irreplaceable protected areas is highlighted in this study (Fig. 1, Fig. S1, and Table S2), selected by combining the 100 sites of highest ranking in terms of overall irreplaceability with the top 100 sites in terms of irreplaceability for threatened species. Given that a total of 63 protected areas matched both criteria, the combined list resulted in 137 unique protected areas (Table S2). As discussed above, although these correspond to individual sites in the World Database on Protected Areas (*23*) there is overlap (total or partial) between several of these sites, and therefore, the 137 sites highlighted here are not completely independent units. For mapping purposes, overlapping sites and sites in close proximity (within 50 km of each other) were grouped into clusters (a total of 78 entities are therefore represented in Fig. 1 and Fig. S1; see also Table S2).

Of the 137 protected areas listed in Table S2, 29 are designated as World Heritage Sites under criterion (x) (sites in green in Table S2). Of the others, 39 protected areas overlap these 29 WHS, and two others (Palawan Game Refuge and Palawan Game Refuge and Bird Sanctuary) overlap the much smaller (57 km^2) Puerto-Princesa Subterranean River National Park WHS, which did not make it into the top 100 sites and is therefore not listed here (sites in yellow in Table S2). Overall, out of the 1.7 million km^2 covered by the highly irreplaceable 137 sites highlighted, over 850 thousand km^2 (50%) correspond to areas with World Heritage status. We encourage the respective nations and the World Heritage Committee to consider extending World Heritage recognition to the remaining highly irreplaceability territory highlighted here, either through the nomination of new World Heritage Sites, or through the extension of existing sites, as appropriate. These recommendations are formalized and presented in more detail in the associated report on Terrestrial Biodiversity and the World Heritage List, which was launched by IUCN at the meeting of the World Heritage Committee in June 2013 (*15*).

We furthermore highlight eight sites that currently have a status of "proposed" in the World Database on Protected Areas (*23*) and which would have been among the 100 highest ranked areas in terms of overall irreplaceability and/or within the top 100 for threatened species (e.g., Itombwe, Democratic Republic of the Congo) (Fig. S1, Table S2). We recommend that they receive urgent attention from their respective nations to be formally established as effectively managed protected areas and that, once this happens, they are considered priorities for nomination or expansion under the World Heritage Convention.

Data on Individual Protected Areas Made Available to PA Managers

As mentioned above, the irreplaceability scores and ranks of all designated protected areas and proposed sites in the WDPA are made available in Table S1. In addition and as a contribution to informing management priorities within protected areas, we make available, for a subset of the sites, the list of species for which the protected area is most responsible, linking these to the respective page in the IUCN Red List Web site. To reduce commission errors (considering a species as present when it is not; see above), we only provide these data for the species and protected areas for which there is ≥5% overlap. For lower values, we have low confidence in the extent to which percentage of overlap can inform local management priorities. Hence, data are only presented for 2178 current protected areas and 192 proposed sites, covering a total of 6117 species, with a maximum of 146 species per site. This information is available for each relevant protected area through their dedicated page in www.protectedplanet.net, the web interface of the WDPA. For the example discussed in the main text, Gunung Lorentz National Park, the Protected Planet link is http://www.protectedplanet.net/sites/1500, whereas the direct link to the irreplaceability information is http://irreplaceability.cefe.cnrs.fr/sites/1500. The 2370 sites for which this information is available can also be accessed and searched through the entry site http://irreplaceability.cefe.cnrs.fr.

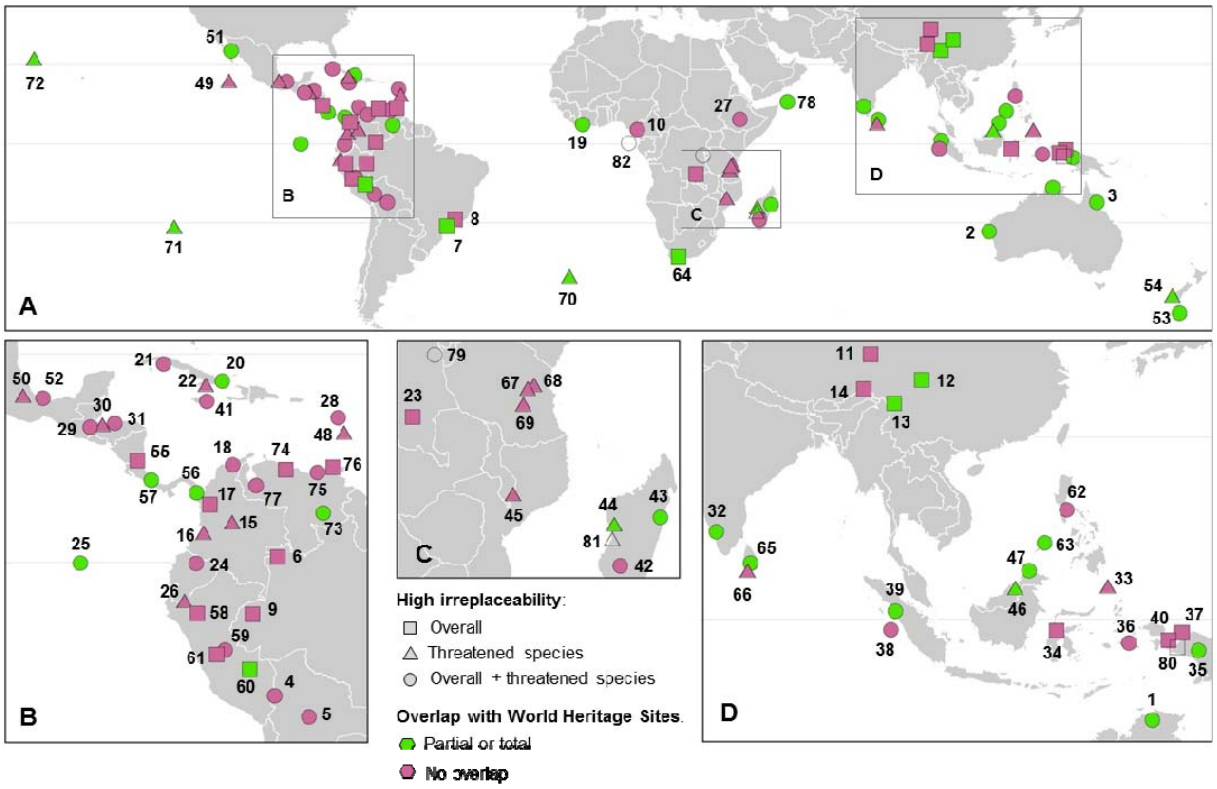

Fig. S1. The world's most irreplaceable protected areas for the conservation of amphibian, bird and mammal species. (**A**) Global distribution; (**B**) Central and South America; (**C**) East Africa; (**D**) southern and Southeast Asia. Sites were selected for being either within the 100 most irreplaceable areas in terms of overall irreplaceability (squares), or within the 100 most irreplaceable areas for threatened species (triangles), or both (circles). Green symbols correspond to sites/clusters that overlap (partially or totally) with a World Heritage site; areas in pink have no such overlap. Open symbols correspond to sites with "proposed" status (not yet formally protected areas, but in a process to gain recognition through legal or other effective means) which, if already designated, would have fallen within the high irreplaceability areas highlighted in this study. To facilitate representation, clusters of overlapping or nearby sites are presented here as a single symbol; see Table S2 for a full list of sites.

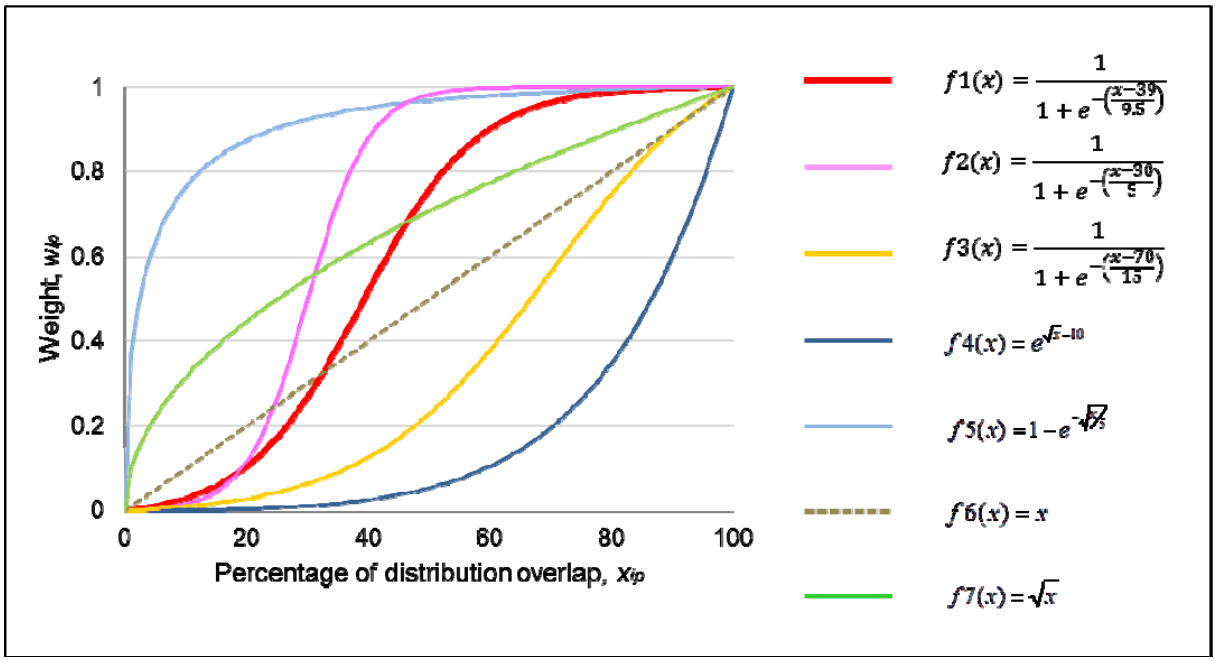

Fig. S2

Set of possible transformation functions *f* for converting the percentage of each species' distribution that overlaps each protected area, $x_{ip,}$ into a species' weight, w_{ip}, for computation of protected area irreplaceability. In all cases, values were rescaled (following equation 3) to ensure that w_{ip} falls between 0 and 1. The transformation function used in this analysis was $f1$, a sigmoid function. The other functions tested in the sensitivity analysis comprised: two other sigmoid functions ($f2$ and $f3$); an exponential function ($f4$); a negative exponential function ($f5$); a linear function ($f6$); and the square root function ($f7$).

Table S2. The world's most irreplaceable protected areas for the conservation of amphibian, bird, and mammal species, arranged by country, plus eight highly irreplaceable "proposed" sites. "WDPA ID" corresponds to the identification number of each of the individual sites in the World Database on Protected Areas. The 137 sites listed here were selected for being within the 100 sites with highest overall irreplaceability and/or within the 100 most irreplaceable areas for threatened species. Eight additional sites of "proposed" status (not yet formally protected areas, but in a process to gain recognition or dedication through legal or other effective means) would, if already designated, have fallen within these highly irreplaceable protected areas. For each of these 137 + 8 sites, irreplaceability scores are provided: either "Multitaxa" values (combining amphibians, mammals, and birds) or for each taxonomic group separately; and either for threatened and nonthreatened species together ("Overall") or for threatened species separately ("Thr."). Irreplaceability ranks [in square brackets] were calculated across all of the world's 173,461 current protected areas (averaged in case of ties); for "proposed" sites, these are the ranks they would have had if already designated. Sites that are already designated as World Heritage Sites are shaded in green; those that overlap totally or partially WHS are shaded in yellow. For representation purposes, clusters of overlapping or nearby sites were mapped under the same symbol and the same "Map ID" (Fig.1, fig S1). Symbol shapes and colors are as used in the maps: shape distinguishes between sites of high overall irreplaceability (squares), of high irreplaceability for threatened species (triangles), or both (circles); color distinguishes sites/clusters that overlap (or coincide with) a World Heritage site (green) from those that do not overlap (pink), with "proposed sites" as open symbols. "Proposed" sites adjacent to existing protected areas/clusters were given the same Map ID; four separate sites were given new Map IDs (from 79 to 82). Abbreviations: WHS = World Heritage Site; UNESCO-MAB BR, UNESCO-MAB Biosphere Reserve; WII, Wetland of International Importance (Ramsar Convention).

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multitaxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
●	1	Australia	Kakadu National Park (Commonwealth) (393)	19128	6.75 [66]	2.92 [102]	2.15 [154]	0 [94182.5]	3.26 [37]	1.88 [42]	1.34 [89]	1.04 [48]
		Australia	Kakadu National Park WHS (2572)	19231	6.76 [63]	2.92 [100]	2.15 [152]	0 [94182.5]	3.27 [35]	1.88 [39]	1.34 [87]	1.04 [46]
		Australia	Kakadu National Park WII (67763)	19128	6.75 [65]	2.92 [101]	2.15 [153]	0 [94182.5]	3.26 [36]	1.88 [41]	1.34 [88]	1.04 [47]
●	2	Australia	Shark Bay, Western Australia WHS (67724)	22100	5.08 [92]	3.97 [59]	0.99 [405]	0 [94182.5]	4.03 [22]	3.97 [8]	0.06 [983]	0.01 [798]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multitaxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
	3	Australia	Wet Tropics of Queensland WHS (17757)	8988	32.49 [6]	10.51 [8]	20.05 [5]	9.41 [3]	9.51 [6]	1.1 [72]	2.94 [40]	0 [1928]
	4	Bolivia	Apolobamba Integrated Management Natural Area (303893)	4881	6 [82]	4.12 [49]	5.22 [50]	4.05 [26]	0.27 [404]	0.01 [862]	0.51 [214]	0.05 [294]
	5	Bolivia	Carrasco National Park (20037)	6953	15.95 [24]	7.31 [19]	13.63 [12]	6.37 [13]	1.05 [158]	0.77 [152]	1.28 [94]	0.18 [174]
	6	Brazil	Alto Rio Negro Indigenous Area (352258)	80570	8.49 [47]	0.88 [409]	3.87 [76]	0 [6350]	1.51 [98]	0.87 [138]	3.12 [39]	0.02 [507]
	7	Brazil	Serra do Mar State Park (4904)	3054	8.26 [49]	1.38 [225]	7 [31]	0.84 [240]	0.59 [297]	0.02 [667]	0.67 [178]	0.53 [115]
		Brazil	Serra do Mar State Environmental Protection Area (19472)	567	5.3 [91]	0.01 [2014]	5.26 [49]	0 [94182.5]	0.01 [2863]	0 [2288]	0.03 [1435]	0.01 [762]
		Brazil	Atlantic Forest Southeast Reserves WHS (198293)	4432	6.33 [72]	1.41 [223]	3.57 [88]	0.01 [893]	2.14 [65]	1.02 [81]	0.62 [195]	0.38 [133]
	8	Brazil	Itatiaia National Park (70)	282	5.79 [85]	0.04 [1127]	5.71 [43]	0.01 [833]	0.04 [1114]	0 [3698]	0.04 [1265]	0.02 [440]
		Brazil	Serra da Mantiqueira Environmental Protection Area (18733)	4238	9.03 [44]	2.89 [103]	6.69 [33]	1 [199]	2.02 [71]	1.88 [40]	0.32 [291]	0.02 [453]
	9	Brazil	Vale do Javari Indigenous Area (33920)	85904	6.35 [71]	0.09 [835]	1.19 [302]	0.01 [1002]	3 [41]	0.07 [344]	2.16 [51]	0.01 [747]
	10	Cameroon	Mont Cameroun National Park (555547994)	586	8.4 [48]	7.28 [20]	1.62 [232]	1.59 [112]	4.89 [15]	3.92 [9]	1.9 [64]	1.78 [31]
	11	China	Sanjiangyuan Nature Reserve (315729)	303608	8.65 [46]	0.67 [462]	0.2 [698]	0.01 [888]	4.86 [16]	0.44 [196]	3.59 [36]	0.22 [153]
	12	China	Sichuan Giant Panda Sanctuaries - Wolong, Mt Siguniang and Jiajin Mountains WHS (902902)	9861	4.99 [94]	0.44 [528]	2.95 [113]	0.36 [311]	1.67 [89]	0.07 [332]	0.37 [267]	0.01 [671]
	13	China	Three Parallel Rivers of Yunnan Protected Areas WHS (900881)	21134	9.48 [42]	2.39 [121]	4.8 [59]	1.63 [110]	3.61 [34]	0.29 [216]	1.06 [111]	0.46 [124]
	14	China	Yaluzangbudaxiagu Nature Reserve (315616)	9003	11.72 [30]	0.03 [1251]	11.33 [16]	0 [94182.5]	0.12 [602]	0.03 [508]	0.27 [337]	0 [2087]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
▲	15	Colombia	Chingaza Natural National Park (143)	788	3.6 [162]	3.33 [79]	3.14 [105]	3.02 [50]	0.08 [730]	0 [1941]	0.39 [259]	0.31 [139]
▲	16	Colombia	Los Farallones De Cali Natural National Park (138)	2079	4.5 [110]	3.42 [75]	3.68 [84]	3.26 [44]	0.08 [715]	0.02 [692]	0.74 [167]	0.15 [188]
■	17	Colombia	Páramo Urrao National Protective Forests Reserves (100722)	301	5.52 [88]	1.6 [206]	4.9 [57]	1.02 [159]	0.02 [1587]	0 [1711]	0.6 [196]	0.57 [111]
●	18	Colombia	Sierra Nevada De Santa Marta Natural National Park (132)	4050	25.64 [11]	16.18 [1]	12.99 [14]	9.32 [4]	1.03 [166]	0.98 [115]	11.62 [9]	5.89 [4]
●	19	Côte d'Ivoire	Taï National Park (721)	4321	6.14 [73]	2.98 [97]	5.83 [41]	2.9 [56]	0.18 [483]	0.05 [401]	0.12 [579]	0.03 [382]
		Côte d'Ivoire	Taï National Park WHS (5003)	3482	4.72 [99]	2.44 [120]	4.48 [63]	2.38 [68]	0.14 [541]	0.04 [451]	0.1 [693]	0.02 [434]
●	20	Cuba	Cuchillas del Toa UNESCO-MAB BR (12465)	1996	7.46 [56]	7.21 [22]	6.4 [35]	6.32 [16]	0.83 [248]	0.79 [147]	0.23 [372]	0.1 [223]
		Cuba	Alejandro de Humboldt National Park (168260)	710	3.99 [137]	3.91 [60]	3.78 [79]	3.76 [35]	0.13 [560]	0.12 [276]	0.08 [800]	0.03 [356]
		Cuba	Cuchillas del Toa Protected Area of Managed Resources (317045)	2028	7.5 [54]	7.25 [21]	6.43 [34]	6.35 [14]	0.82 [249]	0.79 [148]	0.24 [364]	0.1 [219]
		Cuba	Alejandro de Humboldt National Park WHS (900628)	695	3.92 [143]	3.85 [62]	3.73 [81]	3.71 [36]	0.11 [620]	0.1 [301]	0.08 [796]	0.03 [354]
●	21	Cuba	Ciénaga de Zapata UNESCO-MAB BR (198339)	6503	6.8 [61.5]	5.24 [31.5]	1.19 [300.5]	1.11 [143.5]	1.14 [137.5]	1.02 [83.5]	4.47 [23.5]	3.11 [15.5]
		Cuba	Ciénaga de Zapata WII (900569)	6503	6.8 [61.5]	5.24 [31.5]	1.19 [300.5]	1.11 [143.5]	1.14 [137.5]	1.02 [83.5]	4.47 [23.5]	3.11 [15.5]
▲	22	Cuba	La Bayamesa National Park (13582)	243	4.1 [126]	3.08 [86]	4.08 [70]	3.08 [49]	0.01 [3726]	0 [2196]	0.02 [2346]	0 [1349]
■	23	D. Rep. of the Congo	Upemba National Park (1079)	13527	7.47 [55]	0.01 [2620]	5.94 [40]	0 [94182.5]	1.21 [126]	0 [2694]	0.32 [294]	0 [1092]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
●	24	Ecuador	Cayambe-Coca Ecological Reserve (183)	3730	9.53 [41]	6.32 [27]	7.71 [29]	5.62 [18]	1.15 [133]	0.61 [166]	0.67 [179]	0.09 [236]
		Ecuador	Sumaco Napo Galeras National Park (81072)	1957	7.8 [52]	5.18 [34]	7.18 [30]	5 [19]	0.06 [835]	0.01 [810]	0.56 [206]	0.17 [177]
●	25	Ecuador	Galápagos National Park (187)	7735	23.04 [19]	10.1 [11]	0 [148703.5]	0 [94182.5]	4 [28]	4 [7]	19.05 [3]	6.1 [3]
		Ecuador	Galápagos Islands WHS (191)	146679	24.39 [14.5]	11.02 [5.5]	0 [148703.5]	0 [94182.5]	4 [26.5]	4 [5.5]	20.39 [1.5]	7.02 [1.5]
		Ecuador	Archipielágo de Colón (Galápagos) UNESCO-MAB BR (10708)	146679	24.39 [14.5]	11.02 [5.5]	0 [148703.5]	0 [94182.5]	4 [26.5]	4 [5.5]	20.39 [1.5]	7.02 [1.5]
▲	26	Ecuador	Podocarpus National Park (7912)	1473	3.94 [138]	3.49 [71]	3.06 [108]	2.95 [55]	0.04 [1056]	0.01 [717]	0.84 [150]	0.52 [117]
		Ethiopia	Bale Mountains National Park (2281)	1579	4.37 [114]	4.04 [52]	2.84 [114]	2.8 [57]	1.49 [100]	1.24 [66]	0.04 [1259]	0 [2015]
●	27	Ethiopia	Bale Controlled Hunting Area (13759)	11817	6.07 [78]	3.03 [88]	1.94 [191]	0.62 [263]	3.81 [31]	2.4 [24]	0.32 [290]	0.01 [666]
		Ethiopia	Arsi Controlled Hunting Area (13760)	11694	6.85 [59]	2.16 [135]	2.09 [159]	0.05 [546]	4.48 [20]	2.09 [29]	0.28 [327]	0.01 [574]
●	28	Guadeloupe (France)	Guaoupe National Park - Buffer zone (147298)	2256	7.19 [58]	5.2 [33]	1.98 [187]	1.77 [105]	3.65 [33]	3.34 [10]	1.56 [79]	0.09 [229]
●	29	Guatemala	Sierra de las Minas UNESCO-MAB BR (67744)	2424	6.75 [64]	3.99 [58]	6.02 [39]	3.92 [29]	0.53 [310]	0.01 [1038]	0.19 [424]	0.06 [270]
		Guatemala	Sierra de las Minas Biosphere Reserve (342350)	2219	6.01 [81]	3.39 [76]	5.42 [45]	3.33 [42]	0.42 [346]	0.01 [1102]	0.17 [446]	0.05 [295]
▲	30	Honduras	Cusuco National Park (23306)	178	4.23 [123]	4.19 [48]	4.22 [68]	4.19 [25]	0 [5239]	0 [8412]	0.01 [3452]	0 [3376]
●	31	Honduras	Pico Bonito National Park (18810)	562	6.37 [70]	6.33 [26]	6.34 [36]	6.32 [15]	0.01 [3599]	0 [5414]	0.03 [1706]	0 [1891]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
●	32	India	Anamalai Sanctuary (1772)	1228	5.33 [90]	4.88 [41]	5.1 [54]	4.76 [21]	0.12 [593]	0.1 [302]	0.11 [627]	0.02 [424]
		India	Western Ghats WHS (555547990)	8165	24.03 [17]	14.58 [2]	20.34 [4]	11.93 [1]	1.99 [75]	1.86 [43]	1.7 [74]	0.79 [87]
▲	33	Indonesia	Karakelang Utara dan Selatan Wildlife Reserve (62609)	397	3.8 [151]	3.32 [80]	0 [12149]	0 [94182.5]	1.62 [92]	1.59 [55]	2.18 [50]	1.73 [32]
■	34	Indonesia	Lore Lindu National Park (3237)	2339	5.99 [83]	0.16 [703]	0.03 [1497]	0 [94182.5]	5.65 [13]	0.14 [266]	0.31 [298]	0.01 [586]
		Indonesia	Gunung Lorentz National Park (1500)	26300	29.08 [8.5]	3.68 [64.5]	10.77 [18.5]	0 [94182.5]	10.42 [4.5]	3.19 [12.5]	7.89 [14.5]	0.49 [119.5]
		Indonesia	Jayawijaya Wildlife Reserve (8073)	7765	5.08 [93]	0.11 [782]	3.36 [96]	0 [94182.5]	0.44 [336]	0.05 [384]	1.27 [95]	0.06 [277]
●	35	Indonesia	Foja Game Reserve (8100)	13973	5.57 [87]	1.14 [267]	2.45 [131]	0 [94182.5]	1.24 [119]	0.95 [120]	1.89 [66]	0.18 [171]
		Indonesia	Lorentz National Park WHS (198298)	23708	24.56 [13]	3.56 [68]	8.68 [26]	0 [94182.5]	8.77 [7]	3.11 [14]	7.1 [16]	0.45 [126]
		Indonesia	Lorentz National Park ASEAN Heritage Park (901245)	26300	29.08 [8.5]	3.68 [64.5]	10.77 [18.5]	0 [94182.5]	10.42 [4.5]	3.19 [12.5]	7.89 [14.5]	0.49 [119.5]
●	36	Indonesia	Manusela National Park (1499)	2353	10.65 [35]	4.3 [45]	0.08 [941]	0 [94182.5]	6.2 [9]	4.08 [3]	4.38 [25]	0.22 [151]
■	37	Indonesia	Pulau Yapen Tengah Nature Reserve (8117)	780	10.16 [39]	0.27 [601]	9.75 [22]	0 [94182.5]	0.37 [364]	0.27 [222]	0.04 [1377]	0 [2198]
●	38	Indonesia	Siberut National Park (17972)	1950	4.81 [97]	4.1 [50]	0.17 [728]	0.1 [450]	4.32 [21]	4 [4]	0.32 [295]	0 [3647]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
●	39	Indonesia	Kerinci Seblat National Park (4994)	13749	11.1 [32]	1.98 [166]	4.54 [62]	0 [1686.5]	4.53 [19]	1.21 [68]	2.03 [54]	0.77 [90]
		Indonesia	The Leuser Ecosystem Conservation Area (317139)	26272	11.01 [33]	3.67 [66]	1.3 [269]	0 [94182.5]	5.49 [14]	2.83 [21]	4.21 [27]	0.84 [84]
		Indonesia	Kerinci Seblat National Park ASEAN Heritage Park (901244)	14016	11.62 [31]	1.96 [172]	5.1 [53]	0.01 [1189]	4.53 [18]	1.21 [69]	1.99 [60]	0.74 [94]
		Indonesia	Tropical Rainforest Heritage of Sumatra WHS (902335)	25977	18.03 [23]	4.54 [44]	4.88 [58]	0 [1686.5]	7.87 [8]	3.23 [11]	5.28 [19]	1.31 [38]
■	40	Indonesia	Wondiwoi Nature Reserve (8101)	977	15.88 [25]	0 [3194]	15.77 [8]	0 [94182.5]	0.01 [2494]	0 [3427]	0.09 [717]	0 [1430]
●	41	Jamaica	Blue and John Crow Mountains National Park (28856)	498	6.84 [60]	5.8 [29]	5.19 [51]	4.43 [22]	0.13 [561]	0.12 [280]	1.52 [82]	1.25 [39]
		Jamaica	Blue Mountain Forest Reserve Forest Reserve (28905)	459	6.64 [67]	5.68 [30]	5.07 [55]	4.34 [23]	0.13 [566]	0.12 [279]	1.45 [85]	1.22 [40]
●	42	Madagascar	Isalo National Park (2312)	871	4.8 [98]	3.47 [74]	3.45 [93]	3.32 [43]	1.33 [108]	0.14 [264]	0.02 [2256]	0 [3747]
●	43	Madagascar	Masoala National Park (303695)	2107	5.47 [89]	3.18 [84]	4.03 [72]	2.49 [64]	1.25 [117]	0.59 [172]	0.18 [434]	0.1 [221]
		Madagascar	Rainforests of the Atsinanana WHS (903062)	4811	20.18 [20]	10.58 [7]	14.98 [11]	7.82 [8]	4.75 [17]	2.54 [23]	0.45 [233]	0.22 [155]
▲	44	Madagascar	Tsingy de Bemaraha Strict Nature Reserve WHS (26653)	1575	4.41 [111]	3.64 [67]	1.85 [207]	1.83 [99]	2.52 [53]	1.8 [45]	0.05 [1104]	0.01 [607]
▲	45	Malawi	Mulanje Forest Reserve (33177)	585	4.61 [102]	3.88 [61]	4.54 [61]	3.85 [33]	0.02 [1829]	0 [9267]	0.05 [1090]	0.04 [342]
▲	46	Malaysia	Mulu National Park (787)	555	3.94 [140.5]	3.36 [77.5]	3.87 [74.5]	3.35 [40.5]	0.04 [1130.5]	0.01 [985.5]	0.03 [1640.5]	0 [2181.5]
		Malaysia	Gunung Mulu National Park WHS (220293)	527	3.82 [148]	3.26 [81]	3.76 [80]	3.26 [45]	0.04 [1160]	0.01 [1018]	0.03 [1673]	0 [2247]
		Malaysia	Mulu National Park ASEAN Heritage Park (901238)	555	3.94 [140.5]	3.36 [77.5]	3.87 [74.5]	3.35 [40.5]	0.04 [1130.5]	0.01 [985.5]	0.03 [1640.5]	0 [2181.5]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
●	47	Malaysia	Kinabalu National Park (785)	770	10.18 [37]	4.95 [39]	5.39 [47]	3.89 [31]	4.01 [24]	1.06 [76]	0.79 [154]	0 [2495]
		Malaysia	Kinabalu Park WHS (220292)	770	10.18 [37]	4.95 [39]	5.39 [47]	3.89 [31]	4.01 [24]	1.06 [76]	0.79 [154]	0 [2495]
		Malaysia	Kinabalu National Park ASEAN Heritage Park (901237)	770	10.18 [37]	4.95 [39]	5.39 [47]	3.89 [31]	4.01 [24]	1.06 [76]	0.79 [154]	0 [2495]
▲	48	Martinique (France)	Martinique Regional Nature Park (147300)	647	4.36 [117]	2.99 [96]	1.1 [319]	1 [178.5]	0.64 [289]	0.5 [183]	2.62 [44]	1.49 [35]
▲	49	Mexico	Archipiélago de Revillagigedo Biosphere Reserve (101412)	6409	4 [133]	3 [94]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	4 [32]	3 [19]
		Mexico	Reserva de la Biosfera Archipiélago de Revillagigedo WII (902308)	6409	4 [132]	3 [93]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	4 [31]	3 [18]
▲	50	Mexico	Cañón de Río Blanco National Park (5385)	491	3.53 [169]	3.49 [72]	3.49 [90]	3.48 [37]	0.02 [1507]	0.01 [982]	0.02 [2022]	0 [5952]
●	51	Mexico	Islas del Golfo de California UNESCO-MAB BR (145509)	1499	3.99 [136]	3.03 [89]	0 [7441]	0 [94182.5]	3.99 [29]	3.03 [15]	0 [4437]	0 [4757]
		Mexico	Bahía de Loreto National Park (306777)	2080	2.97 [206]	2.96 [99]	0 [35450]	0 [94182.5]	2.96 [42]	2.96 [20]	0 [4940]	0 [4033.5]
		Mexico	Islas Marías Biosphere Reserve (306809)	6447	3.02 [203]	3 [92]	0.01 [3022]	0 [94182.5]	3 [40]	3 [17]	0.01 [3094]	0 [1420]
		Mexico	Islas del Golfo de California Flora and Fauna Protection Area (306810)	3337	6.11 [74]	5.09 [36]	0 [5185]	0 [13088]	6.1 [10]	5.09 [2]	0.01 [3065]	0 [3966]
		Mexico	Parque Nacional Bahía de Loreto WII (902309)	2068	3.01 [204]	3 [91]	0 [42416]	0 [94182.5]	3 [39]	3 [16]	0 [5064]	0 [4039]
		Mexico	Islands and Protected Areas of the Gulf of California WHS (902481)	22834	13.17 [28]	12.04 [4]	0.01 [2029]	0 [11804]	13.08 [3]	12.04 [1]	0.07 [845]	0.01 [957]
●	52	Mexico	Los Tuxtlas Biosphere Reserve (167051)	1557	8.22 [50]	8.03 [17]	6.15 [37]	6.03 [17]	1.02 [171]	1 [86]	1.05 [115]	1 [56]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
●	53	New Zealand	New Zealand Sub-Antarctic Islands WHS (168239)	14722	6.1 [77]	5.1 [35]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	6.1 [18]	5.1 [5]
		New Zealand	Auckland Islands / Motu Maha Marine Reserve (306163)	5593	4.07 [128]	3.08 [87]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	4.07 [28]	3.08 [17]
▲	54	New Zealand	Te Wahipounamu—South West New Zealand WHS (26652)	25139	4.37 [116]	3.55 [69]	0 [148703.5]	0 [94182.5]	0.04 [1176]	0.04 [438]	4.33 [26]	3.51 [13]
■	55	Nicaragua	Sureste de Nicaragua Biosphere Reserve (107238)	18426	7.58 [53]	0.83 [422]	4.27 [67]	0.76 [246]	1.36 [107]	0.01 [1075]	1.94 [62]	0.06 [272]
●	56	Panama	Darién National Park (236)	5717	24.31 [16]	6.42 [25]	10.05 [21]	2.51 [63]	6.04 [11]	0.95 [119]	8.22 [11]	2.96 [21]
		Panama	Darien National Park WHS (2554)	5502	23.54 [18]	6.3 [28]	9.57 [23]	2.46 [66]	6.03 [12]	0.95 [123]	7.94 [13]	2.9 [22]
●	57	Costa Rica	Internacional La Amistad National Park (2553)	1996	6.42 [69]	0.5 [505]	2.29 [142]	0.44 [294]	0.91 [237]	0.05 [388]	3.22 [38]	0.01 [589]
		Panama; Costa Rica	Talamanca Range-La Amistad Reserves / La Amistad National Park WHS (10903)	4073	29.21 [7]	8.93 [14]	15 [10]	8.32 [7]	3.89 [30]	0.57 [173]	10.32 [10]	0.04 [336]
		Panama	Palo Seco Protected Forest (17185)	1689	4.58 [104]	3.24 [82]	3.72 [82]	2.99 [52]	0.32 [380]	0.23 [231]	0.54 [210]	0.02 [467]
		Panama	La Amistad International Park (107315)	2095	13.48 [27]	7.17 [23]	10.48 [20]	6.67 [10]	1.15 [134]	0.48 [186]	1.85 [67]	0.02 [478]
		Costa Rica	Tapantí-Macizo Cerro la Muerte National Park (108173)	587	6.61 [68]	3.79 [63]	5.53 [44]	3.78 [34]	0.42 [344]	0.01 [895]	0.65 [182]	0 [1268]
		Panama	Escudo de Veraguas Protected Landscape (115101)	408	3 [205]	3 [95]	1 [383]	1 [172]	2 [74]	2 [34]	0 [22270]	0 [20866]
		Panama	Reserva de la Biósfera de La Amistad UNESCO-MAB BR (198343)	2192	15.29 [26]	7.51 [18]	12.1 [15]	6.9 [9]	1.3 [112]	0.59 [171]	1.89 [65]	0.02 [463]
■	58	Peru	Alto Mayo Protection Forest (20183)	1787	6.07 [79]	1.28 [241]	4.68 [60]	0.17 [389]	0.06 [858]	0.03 [515]	1.33 [91]	1.08 [44]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
●	59	Peru	El Sira Communal Reserve (303321)	6208	5.69 [86]	4.25 [46]	5.14 [52]	4 [28]	0.09 [699]	0.01 [1268]	0.46 [227]	0.25 [143]
■	60	Peru	Manu National Park (257)	17052	6.11 [76]	0.47 [521]	2 [184]	0.26 [351]	2.93 [44]	0.09 [318]	1.18 [100]	0.12 [206]
		Peru	Manú National Park WHS (17760)	[1743 16 11	6.11 [75]	0.47 [520]	2 [183]	0.26 [350]	2.93 [43]	0.09 [317]	1.18 [99]	0.12 [205]
■	61	Peru	Yanachaga-Chemillén National Park (12213)	1114	9.27 [43]	2.08 [143]	9.05 [24]	2.02 [80]	0.05 [953]	0.03 [479]	0.17 [447]	0.03 [361]
●	62	Philippines	Mounts Banahaw - San Cristobal National Park (841)	114	6.07 [80]	4.97 [37]	5.05 [56]	4.97 [20]	1 [186]	0 [2681]	0.01 [2635]	0 [1329]
●	63*	Philippines	Palawan Game Refuge (7249)	11848	35.64 [5]	10.15 [10]	8.49 [28]	3.37 [38.5]	14.22 [2]	2.98 [19]	12.93 [8]	3.79 [11]
		Philippines	Palawan Game Refuge and Bird Sanctuary (317297)	11848	35.64 [4]	10.15 [9]	8.49 [27]	3.37 [38.5]	14.22 [1]	2.98 [18]	12.93 [7]	3.79 [10]
■	64	South Africa	Cape Floral Region Protected Areas WHS (902347)	5601	4.67 [100]	2.14 [138]	4.3 [66]	2.12 [71]	0.15 [530]	0.01 [747]	0.22 [391]	0.01 [927]
●	65	Sri Lanka	Central Highlands of Sri Lanka WHS (555512000)	537	10.02 [40]	9.86 [12]	8.94 [25]	8.87 [5]	0.94 [222]	0.92 [128]	0.15 [507]	0.07 [255]
▲	66	Sri Lanka	Kanneliya Forest Reserve (27881)	62	4.09 [127]	4.02 [53]	4.08 [71]	4.02 [27]	0 [5200]	0 [2438]	0.01 [3297]	0 [1326]
▲	67†	Tanzania	Milindo Forest Reserve (301550)	86	3.04 [200]	3.02 [90]	3.01 [111]	3 [51]	0 [7518]	0 [17826]	0.03 [1516]	0.03 [401]
▲	68†	Tanzania	Nguru South Forest Reserve (303492)	198	3.26 [185]	3.14 [85]	3.22 [100]	3.12 [47]	0.02 [2059]	0.01 [795]	0.02 [2288]	0.01 [833]
▲	69†	Tanzania	Udzungwa Mountains National Park (19297)	2095	3.89 [146]	3.52 [70]	0.7 [481]	0.48 [286]	2.85 [47]	2.79 [22]	0.33 [284]	0.24 [145]
		Tanzania	West Kilombero Scarp Forest Reserve (301596)	1923	4.56 [106]	4.05 [51]	1.66 [226]	1.31 [130]	2.33 [56]	2.27 [25]	0.57 [204]	0.48 [122]
▲	70	United Kingdom	Gough and Inaccessible Islands WHS (93767)	3918	3.51 [170]	3.47 [73]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	3.51 [37]	3.47 [14]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
▲	71	United Kingdom	Henderson Island WHS (12896)	41	4 [135]	4 [56]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	4 [34]	4 [8]
		United States	Hawaiian Islands National Wildlife Refuge (8 sites) National Wildlife Refuge (2922)	2322	4 [134]	4 [57]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	4 [33]	4 [9]
▲	72	United States	Papahānaumokuākea Marine National Monument (220201)	363557	4.03 [131]	4.01 [55]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	4.03 [30]	4.01 [7]
		United States	Papahānaumokuākea WHS (555512001)	364793	4.03 [130]	4.01 [54]	0 [148703.5]	0 [94182.5]	0 [167254.5]	0 [108067.5]	4.03 [29]	4.01 [6]
		Venezuela	Canaima National Park (313)	30522	42.04 [2]	8.35 [15]	25.37 [2]	6.58 [11]	2.64 [49]	1.76 [46]	14.02 [5]	0.01 [602]
		Venezuela	Duida-Marahuaca National Park (4366)	1964	12.41 [29]	2.01 [159]	11.25 [17]	2 [84]	0.11 [618]	0.01 [1186]	1.05 [112]	0 [3134]
		Venezuela	Sur del Estado Bolívar Protective Zone (10772)	54248	10.86 [34]	2.04 [153]	4.14 [69]	1.92 [92]	1.55 [95]	0.1 [299]	5.17 [20]	0.02 [452]
		Venezuela	Imataca Forest Reserve (10779)	53631	28.93 [10]	4.7 [42]	18.19 [6]	2.96 [53.5]	2.74 [48]	1.71 [48]	8 [12]	0.03 [358]
●	73	Venezuela	El Caura Forest Reserve (10780)	51487	8.75 [45]	0.08 [867]	6.14 [38]	0 [94182.5]	0.8 [253]	0.05 [386]	1.81 [68]	0.02 [433]
		Venezuela	San Pedro Forest Plot (20106)	25980	25.35 [12]	4.67 [43]	16.88 [7]	2.96 [53.5]	2.18 [62]	1.7 [49]	6.28 [17]	0.01 [640]
		Venezuela	Alto Orinoco-Casiquiare Biosphere Reserve (30029)	31236	18.52 [22]	2.23 [130]	15.26 [9]	2 [84]	0.76 [264]	0.22 [234]	2.5 [46]	0.01 [654]
		Venezuela	Formaciones de Tepuyes Natural Monument (30030)	51352	58.42 [1]	12.78 [3]	37.07 [1]	10.85 [2]	3.72 [32]	1.9 [35]	17.62 [4]	0.02 [445]
		Venezuela	Canaima National Park WHS (61612)	29019	41.16 [3]	8.33 [16]	25.19 [3]	6.56 [12]	2.6 [50]	1.76 [47]	13.37 [6]	0.01 [620]
■	74	Venezuela	Henri Pittier National Park (323)	882	7.41 [57]	1.42 [219]	6.92 [32]	1.25 [134]	0.15 [531]	0.04 [405]	0.34 [282]	0.13 [203]
●	75	Venezuela	Macizo Montañoso del Turimiquire Protective Zone (20070)	4518	8.18 [51]	6.83 [24]	3.15 [103]	3.1 [48]	0.11 [617]	0.01 [927]	4.92 [21]	3.72 [12]

	Map ID	Country	Protected area name (WDPA ID)	Area km^2	Multi-taxa		Amphibians		Mammals		Birds	
					Overall	Thr.	Overall	Thr.	Overall	Thr.	Overall	Thr.
■	76	Venezuela	Península de Paria National Park (328)	589	4.86 [95]	2.33 [124]	2.72 [116]	0.27 [343]	0.01 [2062]	0 [4925]	2.12 [52]	2.07 [25]
●	77	Venezuela	Guaramacal National Park (15135)	254	3.28 [182]	3.22 [83]	3.23 [99]	3.21 [46]	0.03 [1415]	0.01 [820]	0.02 [1917]	0 [1743]
		Venezuela	Sureste del Lago de Maracaibo Sto. Domingo-Motatán Protective Zone (20081)	8520	19.42 [21]	9.46 [13]	13.09 [13]	8.58 [6]	2.46 [55]	0.51 [180]	3.87 [35]	0.38 [132]
		Venezuela	Río Capaz Protective Zone (30647)	462	5.92 [84]	4.25 [47]	5.77 [42]	4.23 [24]	0.09 [696]	0.02 [650]	0.07 [881]	0 [1182]
●	78	Yemen	Socotra Archipelago WHS (903138)	4108	4.85 [96]	2.98 [98]	0 [148703.5]	0 [94182.5]	0 [8009]	0 [108067.5]	4.85 [22]	2.98 [20]
	Map ID	**Country**	**"Proposed" site (WDPA ID)**	**Area km^2**	**Multi-taxa**		**Amphibians**		**Mammals**		**Birds**	
					Overall	**Thr.**	**Overall**	**Thr.**	**Overall**	**Thr.**	**Overall**	**Thr.**
○	21	Cuba	Ciénaga de Zapata Protected Area of Managed Resources (302627)	6493	6.81 [61]	5.24 [31]	1.19 [300]	1.11 [143]	1.14 [138.5]	1.02 [84.5]	4.47 [23]	3.11 [15]
○	79	D. Rep. of the Congo	Itombwe (72312)	6074	10.01 [41]	3.85 [62]	6.24 [37]	1.92 [93]	1.13 [140]	0.02 [558]	2.64 [44]	1.91 [30]
□	80	Indonesia	Pegunungan Weyland Nature Reserve (8068)	3102	5.53 [88]	0.01 [2136]	4.09 [70]	0 [14811.5]	1.17 [130]	0 [3233.5]	0.26 [340]	0.01 [760]
○	35	Indonesia	Jayawijaya (Extension - Southern) Other Area (98117)	4224	6.39 [70]	0.04 [1105]	5.52 [45]	0 [14811.5]	0.23 [439]	0.03 [531]	0.64 [187]	0.01 [574]
○	43	Madagascar	Fandrina Vondrozo (352246)	4981	10.71 [35]	4.3 [46]	5.65 [44]	1.48 [118]	4.68 [18]	2.68 [23]	0.39 [260]	0.14 [197]
○	43	Madagascar	Zahamena Ankeniheny (352256)	4483	6.34 [72]	1.75 [188]	4.78 [60]	1.25 [134]	1.09 [146]	0.33 [209]	0.46 [226.5]	0.17 [177]
△	81	Madagascar	Menabe (352251)	1256	4.32 [118]	3.29 [81]	1.93 [194]	1 [169]	2.35 [56]	2.27 [25]	0.04 [1293]	0.01 [557]
○	82	São Tomé and Príncipe	Obo National Park (124355)	261	11.39 [32]	8.12 [17]	1.32 [265]	0.55 [274]	1.38 [106]	0.83 [144]	8.69 [11]	6.74 [2.5]

Table S2 footnotes:

*Palawan Game Refuge and Palawan Game Refuge and Bird Sanctuary) overlap the much smaller (57 km^2) Puerto-Princesa Subterranean River National Park WHS, which did not make it into the top 100 sites and is therefore not listed here.

†There have been recent changes in the Tanzanian protected area network (Neil Burgess, pers. comm.) that have not yet been incorporated into the WDPA, but which are mentioned here as they affect the highly irreplaceable PAs highlighted in this analysis: Milindo Forest Reserve (site #67) is known as Mamiwa Kisara North Forest Reserve. Nguru South Forest Reserve (site #68) is now managed as part of the Mkingu Nature Reserve. The West Kilombero Scarp Forest Reserve (part of cluster #69) no longer exists as a separate designation and is now split between Udzungwa Mountains National Park (also included in cluster #69) and Kilombero Nature Reserve (which did not make it into the top 100 sites). Two other Tanzanian Protected Areas that were treated separately in our analysis, Uluguru North Forest Reserve (ranked 234 and 117 for overall and threatened species irreplaceability, respectively) and Uluguru South Forest Reserve (ranked 159 and 139) have been recently combined in the Uluguru Nature Reserve (not yet listed in the WDPA); if analyzed as a single unit, this would have been among the highlighted sites for overall irreplaceability (rank = 73) and for threatened species irreplaceability (rank = 41). These changes will be incorporated in future versions of the WDPA and in future iterations of this analysis.

Table S3. Sensitivity of protected area irreplaceability scores to the shape of the transformation function *f* for converting the percentage of each species' distribution that overlaps each protected area into a species' weight. See Fig. S2 for details of each function. The upper part of the table indicates the Spearman rank correlation coefficient between the irreplaceability values obtained for each transformation function, across all 173,461 protected areas. The lower part of the table indicates how many sites are in common between the top 100 sites for overall irreplaceability obtained using each transformation function.

function	$f1$	$f2$	$f3$	$f4$	$f5$	$f6$	$f7$
$f1$		1.00000	1.00000	0.98735	0.98674	1.00000	0.98694
$f2$	92		1.00000	0.98734	0.98673	1.00000	0.98693
$f3$	83	78		0.98735	0.98674	1.00000	0.98695
$f4$	71	66	88		0.99991	0.98736	0.99996
$f5$	36	34	32	26		0.98675	0.99999
$f6$	83	77	71	61	50		0.98696
$f7$	46	43	38	32	88	60	

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