CONSERVATION

Protected Areas and Effective Biodiversity Conservation

Increasing the collective contribution of protected areas toward preventing species extinctions requires the strategic allocation of management efforts.

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Although protected areas (PAs) cover 13% of Earth's land (1), substantial gaps remain in their coverage of global biodiversity (2). Thus, there has been emphasis on strategic expansion of the global PA network (3–5). However, because PAs are often understaffed, underfunded, and beleaguered in the face of external threats (6, 7), efforts to expand PA coverage should be complemented by appropriate management of existing PAs. Previous calls for enhancing PA management have focused on improving operational effectiveness of each PA [e.g., staffing and budgets (6)]. Little guidance has been offered on how to improve collective effectiveness for meeting global biodiversity conservation goals (3). We provide guidance for strategically allocating management efforts among and within existing PAs to strengthen their collective contribution toward preventing global species extinctions.

Strategic Management Across PAs

PAs vary in the extent to which they can contribute to preventing extinctions. The notion of "irreplaceability" reflects a site's potential contribution to conservation goals or, conversely, the extent to which options for meeting those goals are lost if the site is lost (4). Irreplaceability has been extensively used to identify potential new PAs [e.g., (2, 4)] but can also be applied to inform allocation of management effort among existing sites (8). We highlight a set of exceptionally irreplaceable PAs for which we recommend a particularly high level of management effort and encourage global recognition as World Heritage sites.

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We estimated the irreplaceability of each of the world's 173,461 designated PAs, and of 2059 proposed sites (9), for ensuring representation of 21,419 vertebrate species, encompassing all amphibians, nonmarine mammals, and birds, of which 4329 are globally threatened (10, 11) [see the supplementary materials (SM)]. Irreplaceability was estimated from the fraction of the global distribution of each species that is contained within each PA, by following a new approach that reduces the effect of the commission errors (falsely assuming species presence

The Bale Mountains National Park in the Ethiopian highlands is home more than half of the world's estimated 366 Ethiopian wolves, *Canis simensis* (10) seen at right.

in PAs) inherent to the available spatial data (see SM). Irreplaceability scores and relative ranks were obtained both when considering all species (overall irreplaceability) or only those species that are globally at risk of extinction (threatened species irreplaceability), for all taxa combined (multitaxa), as well as separately for each taxonomic group (amphibians, mammals, and birds) (table S1). We highlight a subset of 137 PAs, covering 1.7 million km², identified by combining the 100 highest-ranking sites in terms of overall irreplaceability with the 100 most irreplaceable areas for threatened species (see the figure, fig. S1, and table S2).

Mainly located in tropical forest regions, particularly in mountains and on islands, these highly irreplaceable PAs encompass a wide diversity of other ecosystems. PA sizes range from 41 to 364,793 km² (table
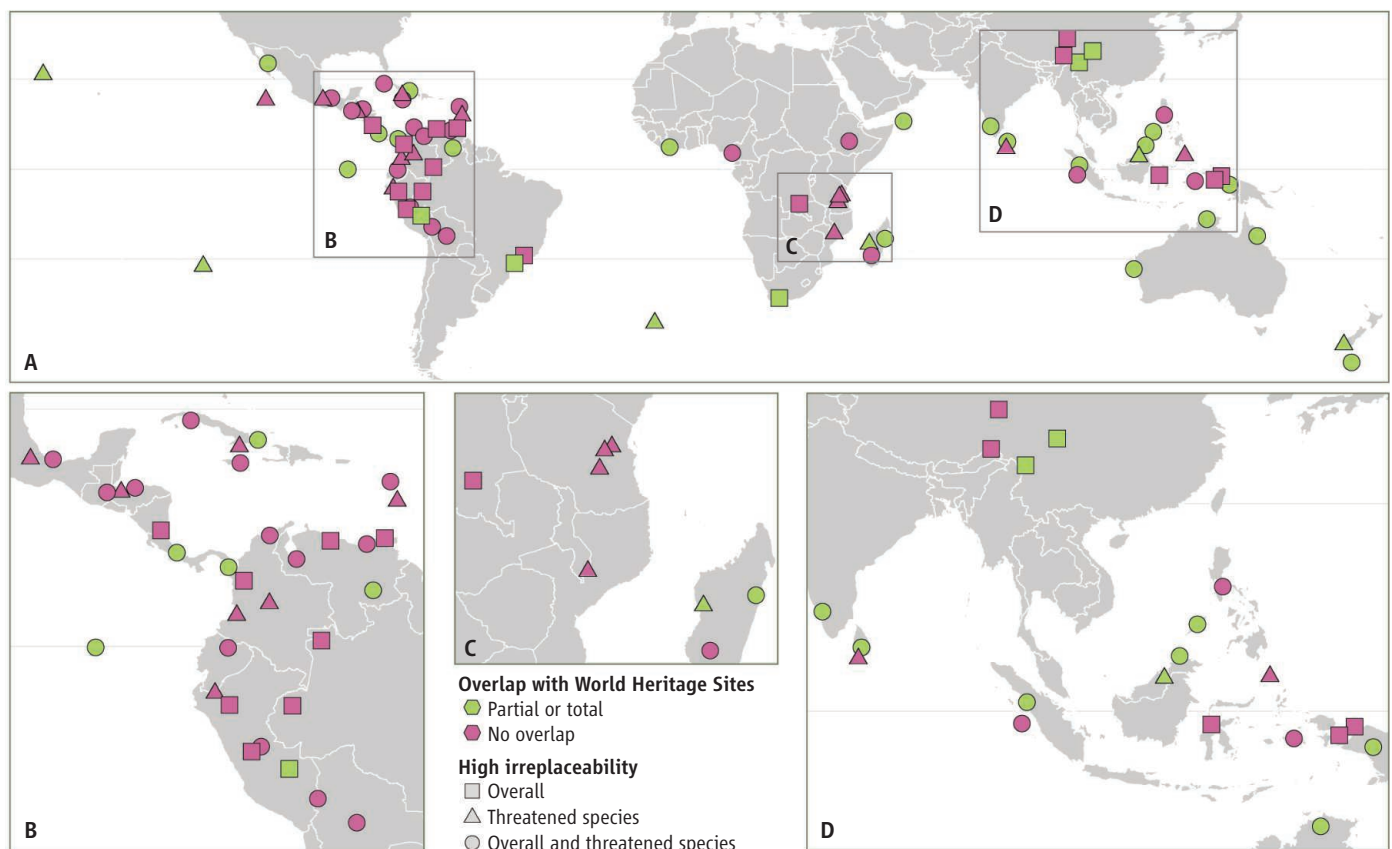
S2). Nearly all are located in biogeographic regions of exceptional levels of endemism (12) and nearly all have already been identified as key biodiversity areas (13). Collectively, they are responsible for the long-term conservation prospects of 627 species (119 birds, 385 amphibians, and 123 mammals), including 304 globally threatened species (60 birds, 179 amphibians, and 65 mammals) whose global distributions fall mostly (>50%) within these sites. For 88 of these PAs, the conservation stakes are particularly high, as they overlap sites previously identified as holding ≥95% of the global population of at least one highly threatened species, where species extinctions are imminent unless effective conservation action is implemented (14).

The United Nations World Heritage Convention (WHC) seeks to encourage the identification and conservation of natural and cultural heritage of "outstanding universal value." Among currently designated World Heritage Sites (WHS), 132 have been inscribed [under criterion (x)] as having outstanding universal value for the in situ conservation of biodiversity (see SM) (15). Their very high overall irreplaceability (91% are among the 95th percentile of PA irreplaceability for all species and/or for threatened species examined here) (table S1) suggests a remarkable agreement between outstanding universal value, as defined by the WHC, and

The world's most irreplaceable PAs for conservation of amphibian, bird, and mammal species. (**A**) Global distribution. (**B**) Central and South America. (**C**) East Africa. (**D**) Southern and Southeast Asia. To facilitate representation, clusters of overlapping or nearby sites are presented here as a single symbol; see fig. S1 and table S2 for a full list of sites comprising 137 protected areas in 78 clusters. See SM for details.

high irreplaceability. We thus recommend the inclusion of the latter as an operational indicator of the former in future assessments of World Heritage status for biodiversity (*16*).

However, at present only about half the combined area of the 137 highly irreplaceable PAs highlighted in this study is inscribed as WHS under criterion (x) (table S2). We thus encourage the respective nations and the World Heritage Committee to consider extending World Heritage recognition to the remaining highly irreplaceable territory, either through the nomination of new WHS or the extension of existing sites (see the figure and fig. S1) (*16*). Given that WHS must, as a prerequisite to inscription, meet rigorous standards of integrity, protection, and management, the process to achieve and maintain recognition under the WHC would be a powerful mechanism to ensure effective protection of the exceptionally irreplaceable areas identified in this study.

Furthermore, these areas vary in the urgency of their conservation needs (tables S1 and S2). In areas of high irreplaceability for species at risk of extinction, there is no time to lose in establishing effective management necessary to prevent extinctions.

Highly irreplaceable PAs whose uniqueness is driven by nonthreatened species can afford proactive conservation actions that anticipate future threats.

Strategic Management Within PAs
Ensuring that highly irreplaceable PAs are managed as effectively as possible is crucial to the collective performance of the global network of PAs, but in order to be effective, local management must be strategically tailored to the specific biodiversity features of each site. Local management plans often focus on charismatic species, and management decisions favoring these (e.g., habitat protection) will often benefit a whole set of species. However, management objectives established for particular species sometimes deliver no benefits to, or can even jeopardize the persistence of, other species [e.g., (*17*)]. In such cases, we propose that species for which a PA has the highest conservation responsibility should be the first consideration for management and monitoring.

The percentage of each species' global distribution that overlaps each PA can be used as a simple indicator of responsibility (complemented by better data when available; e.g., on population abundance). This percentage can be estimated from global distribution maps already available for some taxonomic groups and being compiled for others (*10*, *18*), but given the coarse nature of such maps, it is only informative for relatively high percentages of overlap (see SM). We provide, for each PA, the list of species for which >5% of their range overlaps the PA, and the extent of such overlap (*19*). For example, Gunung Lorentz National Park, Indonesia, overlaps >5% of the range of 46 mammal species, including two that occur nowhere else, and eight that have more than half their range inside the park, which should be high priorities for management.

Data compiled in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (*10*) can help guide conservation strategies, particularly in high-biodiversity, poorly known regions (*20*). In Gunung Lorentz National Park, for example, both the Alpine Woolly Rat (*Mallomys gunung*, endangered, 95% overlap) and the Dingiso (*Dendrolagus mbaiso*, endangered, 59% overlap) are montane species threatened by hunting, which suggests that regulating hunting in high-altitude ecosystems should be a management priority within this PA.

Data that we provide are derived from extensive global data sets on species and PAs that are already freely available (SM). Turning these data sets into information useful for the management of individual PAs requires processing and resources that are often not easily available to park managers and decision-makers. We make our results available in an easily accessible format (table S1) (*19*), to complement other information needed for effective protected area management (e.g., on the costs of conservation actions and the value of sites for conservation of biodiversity at levels other than species, such as genes and ecosystems).

PAs are our main hope for meeting ambitious global conservation targets, such as preventing species extinctions (*3*), but the costs of ensuring their effective management are substantial, albeit affordable (*21*). We hope that the conceptual guidance and specific data provided here will support strategic reinforcement of the world's existing PAs, to improve their individual and collective effectiveness for conserving global biodiversity.

References and Notes

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ENVIRONMENTAL SCIENCE

What Does Zero Deforestation Mean?

Ambiguous definitions and metrics create risks for forest conservation and accountability.

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Since 2005, negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) have focused considerable attention on the role that reducing emissions from deforestation and forest degradation (REDD+) can play in climate change mitigation. As global interest in reducing deforestation has grown, numerous governments, corporate groups, and civil society organizations have set time-bound targets for achieving "zero deforestation." Some targets specify "net deforestation," some "gross deforestation," and some do not specify at all (see the table). Public- and private-sector policy-makers who commit to deforestation reduction targets, and those who advocate for them, are often unclear about their implications. This lack of clarity may lead to perverse outcomes, including governments celebrating reductions of deforestation when large areas of native forest have been cut down and "zero deforestation" certification of agricultural commodities produced on land recently cleared of native forest cover. Progress toward goals of forest conservation, climate change mitigation, and associated cobenefits would be better served and more readily monitored by setting separate time-bound targets for reductions in the clearing of native forests (gross deforestation) and increases in the establishment of new forests on previously cleared lands (reforestation). Net deforestation targets, inherently and erroneously, equate the value of protecting native forests with that of planting new ones.

Net Versus Gross Deforestation

The most commonly used source of data on global deforestation is the United Nations Food and Agriculture Organization's Forest Resource Assessment (FAO-FRA) program, which publishes reports at 5-year intervals (*1*). A key metric in the FAO-FRA reports is the annualized net change in forest area. This "net deforestation" is estimated as the difference in forest area between two points in time, taking into account both losses from deforestation and gains from forest regeneration and/or tree plantations, divided by the number of years between the two time periods (*1*, *2*). For most tropical countries, this metric is generally estimated from tabular data, provided to the FAO-FRA by the countries, which are based on periodic forest inventories, land-use surveys, and/or forest area maps but rarely from interpretation of multiyear remote sensing imagery due to the lack of capacity and resources to acquire and process the imagery. Because losses in forest area generally exceed gains due to secondary forest regeneration and tree plantings in tropical countries, the FAO-FRA "net deforestation" metric for those countries is often reported simply as "tropical deforestation" (*3*).

Meanwhile, since 1988, the Brazilian Space Agency (INPE) has monitored

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