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The global distribution of protected areas management strategies and their complementarity for biodiversity conservation

R. Vimal, L. Navarro, Y. Jones, F. Wolf, G. Le Moguec, M. Réjou-Méchain

ABSTRACT

5 Over the last decades, massive efforts have been made to both assess and increase the amount of land dedicated to biodiversity conservation. Less is known, however, about the diversity of management strategies implemented across the network of protected areas. In this study, we used a large database of more than 175,000 global terrestrial protected areas and the distributional data of non-marine mammals, amphibians and birds to assess both the relative proportion of land
10 covered by different IUCN management categories across regions and their potential contribution to protecting biodiversity. We show that, although at least 41% of the terrestrial protected land is managed via a strict control of human activities to conserve wild areas, 13% is dedicated to particular species or habitats often requiring active management and 25% preserves both natural and cultural values and promotes the sustainable use of resources. Our analysis
15 further suggests that protected areas associated with a more “human friendly” management are potentially as important as strictly-protected areas for the preservation of mammals, amphibians and birds. We argue that integrating the diversity of management strategies into conservation planning is a crucial step towards the successful preservation of the earth’s biosphere.

20 **Keywords:** Protected areas, Biodiversity, Irreplaceability, IUCN management categories

1 INTRODUCTION

The global network of protected areas (PAs) is the cornerstone of conservation policies for the reduction of biodiversity loss (Bruner et al., 2001; Gray et al., 2016a; Rodrigues et al., 2004a).

25 However, despite sharing this common objective, PAs vary considerably within and among regions in terms of governance, ownership, and management and can thus contribute to various alternative goals including tourism and community development, climate change mitigation, poverty alleviation, the preservation of indigenous cultures and the sustainable use of resources (Cabral et al., 2020; Leroux et al., 2010; Shafer, 2015). Protected areas encompass designations
30 as diverse as for instance national park, indigenous reserve, game refuge, wildlife sanctuary or voluntary conservation area, to name a few.

The Convention on Biological Diversity (CBD) and its Parties have engaged in increasing the PAs coverage to at least 17 % of the world terrestrial land by 2020 (CBD, 2011) and this effort is very likely to be maintained – and potentially intensified - in the post-2020 global biodiversity
35 framework as well (CBD, 2020). For the last 20 years, under the framework of Systematic Conservation Planning, researchers have investigated gaps in the existing global network of PAs and identified spatial priorities for its extension (Margules and Pressey, 2000a; Rodrigues, 2006; Wilson et al., 2009). Thus, they predominantly focused on *what* and *where* to protect (e.g. Brum et al., 2017; Butchart et al., 2010; Dinerstein et al., 2017; Oliveira et al., 2017; Runge et al.,
40 2015) and less on *how* to achieve this goal (e.g. Geldmann et al., 2018; Leverington et al., 2010).

The priority should now shift from considering a landscape as binary, *i.e.* protected or not (Wilson et al., 2010), towards highlighting the full diversity of existing protected areas.

Over the last decades, the prevailing views of nature, its relationship with humans and their activities, and the resulting approaches to conservation have changed from a focus on species
45 and wilderness that excludes humans to a focus on ecosystem functions and services that

integrates both people and nature (Mace, 2014). Accordingly, the concept of PA itself has evolved (Palomo et al., 2014). The dominant view of pristine, central state-controlled PAs began to change into what researchers referred to a paradigm shift (Hulme and Murphree, 1999; Locke and Dearden, 2005). This is illustrated for instance by the establishment in the 1970s of the Man and the Biosphere Programme of the UNESCO and the implementation of Biosphere Reserves (Coetzer et al., 2014). Protected areas have been increasingly expected to provide benefits to local people as well to integrate local activities into their management. Nowadays, the global network of PAs reflects this evolution and management regimes range from “fortress” to community conservation (Galvin and Haller, 2008), from strict to multi-use approach (Nelson and Chomitz, 2011) or from exclusionary protection to sustainable utilization (Andrade and Rhodes, 2012). The most recent definition of PAs adopted by the IUCN is meant to embrace this plurality. A protected area is a “clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Dudley, 2008; Dudley et al., 2010).

In response to a need for a common nomenclature allowing assessment and comparison between PAs within and across regions, the IUCN proposed a classification according to their management objectives into six categories. The IUCN categories give information on the specific objectives of a PA and the approach intended and needed to achieve those. They reflect a gradient towards an increased tolerance for human activities and range from strict nature reserves and wilderness areas (categories Ia and Ib) to protected areas with sustainable use of natural resources (category VI).

Such categorization of PAs coupled with the establishment of the World Database of Protected Areas (WDPA) paved the way for numerous studies that explored the relationship between

management and human pressure (e.g. Geldmann et al., 2014; Jones et al., 2018; Leberger et al.,
70 2020; Nagendra, 2008), between management and biodiversity trends (e.g. Coetzee et al., 2014;
Gray et al., 2016b), or between management and human livelihood (Naughton-Treves et al.,
2005; Oldekop et al., 2015). Interestingly, those studies tend to show that there is no linear
relationship (if any) between the degree of strictness in the management of PAs and the measured
outcomes. For instance, Leroux et al. (2010) established that there was a global mismatch
75 between the IUCN category and the degree of human impact, measured by the human footprint
indicator within PAs: categories Ib and III were less impacted than categories Ia and II, and
category VI was less impacted than categories IV and V. Gray et al. (2016b) found no significant
differences between the IUCN categories according to four local biodiversity metrics (i.e. species
richness, abundance, endemism and rarefied richness). Nevertheless, a correlation exists
80 between the biophysical properties of an area and its management, with stricter protection
typically designated in areas of higher altitude, lower accessibility and steeper slopes when
compared to other categories (Joppa and Pfaff, 2009).

Surprisingly, however, little has been said regarding the complementarity of different
management categories or more broadly of different types of protected areas (Leménager et al.,
85 2014). Complementarity is a core concept in systematic conservation planning and highlights the
need to consider the extent to which an area contributes to adding unrepresented features to
another area (Kukkala and Moilanen, 2013; Margules and Pressey, 2000a). The recent “protected
planet reports” (UNEP-WCMC et al., 2018; UNEP-WCMC and IUCN, 2016) briefly mentions
the relative distribution of PAs within the different IUCN categories but does not provide a
90 detailed analysis of the potential of these categories to contribute to conservation goals.

In this paper, we assess the complementarity of different management strategies of PAs based on their spatial distribution and their relative importance for the biodiversity that they are meant to protect. Rather than trying to explain their effectiveness or to provide normative views regarding how PAs should best be managed, we highlight their shared responsibility at different scales.

95

2 METHODS

2.1 Data used

Information on 221,503 polygons and multi-polygons considered as PAs were extracted from the World Database on Protected Areas (IUCN and UNEP WCMC, 2019). For the purpose of this study, we focused on terrestrial PAs for which the designation types were “National” and the status “Designated” and excluded all PAs associated with “International” or “Regional” designation types and “Proposed” status. We also removed duplicates, fixed some of the geometries and did not consider PAs entirely overlapping with other (see supplementary information). After these operations, we obtained a total of 176,904 terrestrial PAs (Fig. 1, Table S1).

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Data on species' distribution were obtained from the IUCN Red List of Threatened Species (IUCN, 2017) and BirdLife International (BirdLife International and Handbook of the Birds of the World, 2018). For the purpose of this study, we focused on non-marine mammals (n=5424), amphibians (n=6564) and birds (n=10936) that are neither extinct (EX) nor extinct in the wild (EW) (Table 1).

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Following Saout et al. (2013), we included only the ranges of species considered as “extant” or “probably extant” (presence codes 1 and 2) and as native (origin codes 1 and 2). Furthermore, for

birds, only areas where species occur as “resident”, “breeding”, or “non-breeding” were included (seasonality codes 1 to 3).

115 2.2 Protected areas management categories

Since 2002, the attribution of IUCN categories to the PAs is strictly provided by national agencies. IUCN management categories differ from each other in relation to their management focus and accordingly with regard to both the human activities allowed inside the PA (e.g. resource extraction, tourism) and the degree of intervention authorized to restore or to maintain the habitats within the PA (i.e. from active to passive) (Chape et al., 2005; Dudley, 2008, see Table 2).

In this study, we clustered the IUCN management categories into three classes (Table 2).

Categories I-III PAs (n=32,959) promote nature conservation via a strict control of human activities. Such PAs aim at preserving the structure, composition and functions of ecosystems or natural monuments. They mostly target high levels of naturalness but also consider spiritual and cultural values. The level of human intervention is typically null to minimal. Human activities are prohibited, with the exception of those associated with the subsistence of local and indigenous communities, and with traditional lifestyles. Tourism requires strict control to avoid any degradation. These areas are also valuable in terms of recreation, education and scientific research.

Category IV PAs (n=53,595) aim to preserve and restore fragments of ecosystems often in relation with cultural land uses. They are usually small-sized and focus on maintaining and conserving designated natural and semi-natural habitats or populations of specific species and their requirements. Protected areas in category IV often require proactive management of the

135 semi-natural habitats associated with cultural landscapes. Tourism is allowed and resource
extraction might occur. Those PAs can also serve for education, research and recreation.
Categories V-VI PAs (n=49,356) promote sustainable development and the co-existence of
human activities and nature conservation. Such PAs aim to implement conservation while
allowing the sustainable use of natural resources, following traditional and cultural land and sea
140 uses. The main objective of PAs of categories V-VI is to maintain a balance between nature
conservation, human well-being and economic development. Resource extraction such as
forestry, farming, mining and fishing is allowed, and ecotourism is often highly promoted.
An additional category “Not Reported” (n=40,994) combines all PAs for which none of the
IUCN categories was informed.

145 Combining the six IUCN categories into three broader classes allowed us to mitigate the fact that
different countries may allocate different categories to similarly managed PAs, and, inversely,
that PAs labeled under the same category might be managed slightly differently from one country
to the other (see supplementary information for detailed description of the potential limits of our
approach).

150 2.3 Irreplaceability

The irreplaceability reflects the relative importance of an area regarding its contribution to nature
preservation. Originally, irreplaceability was used in Systematic Conservation Planning as “the
potential contribution of a site to a reservation goal” (Margules and Pressey, 2000b) in order to
identify and select new sites to be included in a PAs network. Using the same principle, Saout et
155 al., (2013) proposed an alternative version of the irreplaceability as the measure of the actual
contribution to biodiversity conservation of an area that is already designated as protected. Here
we calculated an irreplaceability index inspired by the one developed by Saout et al. (2013) but

correcting for some limitations (see supplementary information) and giving higher weights to threatened species and to species poorly represented in the global PAs network. The

160 irreplaceability index for a given protected area, I_p , is of the form:

$$I_p = \sum_i \Lambda_{i,p} \times \sigma_i$$

Where σ_i is a coefficient varying according to the IUCN threat category of species i (i.e. from “Data Deficient” to “Critically Endangered”, see supplementary information) and $\Lambda_{i,p}$ represents the irreplaceability of species i in protected area p calculated as follows:

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$$\Lambda_{i,p} = (\omega_{i,p} \times c_1) + (\tau_{i,p} \times c_2)$$

Where $\omega_{i,p}$ represents the proportion of the distribution of species i covered by protected area p and $\tau_{i,p}$ represents the proportion of the “protected” distribution (i.e. the global distribution of the species that falls within the global PAs network) of species i covered by protected area p . The use of $\tau_{i,p}$ thus gives more weight to species mostly protected by a single PA.

170 Finally, the coefficients c_1 and c_2 were here both set to 0.5 in order to give the same weight to $\omega_{i,p}$ and $\tau_{i,p}$ and so that $\Lambda_{i,p}$ ranges from 0 to 1. Note that the alternative multiplicative form $\Lambda_{i,p} = \omega_{i,p}^{c_1} \times \tau_{i,p}^{c_2}$ gave similar results (not shown). The final index I_p was calculated for all taxa combined and for each taxonomic group (mammals, amphibians and birds), separately.

2.4 Analysis

175 In this paper, the complementarity between different management categories was assessed following two approaches. First, we calculated basic statistics for each PA such as the average surface and human footprint (Venter et al., 2016) as well as the distribution of the PAs within the different management categories globally and per subcontinent (Table 3 and Fig. S2). Following

the approach of Watson et al. (2014), we calculated and mapped the proportion of each ecoregion covered by the different management categories (Fig. 3 and Table S2 for detailed statistics on each ecoregion).

Second, we compared the irreplaceability score between different management categories. Given that the purpose of this study was to understand the differences in irreplaceability between PAs of different management categories in similar geographical conditions, we stratified our statistical tests by ecoregions and subcontinents (see Fig. S2 for the delimitation of subcontinents). This stratification resulted in 797 spatial units worldwide corresponding to unique combinations between subcontinents and ecoregions where PAs were found (note that few ecoregions can overlap with more than one subcontinent). We fitted simple linear models, independently within each spatial unit. The model was built as follows:

$$\log(I(p)) = \alpha + \beta \cdot \log(A_p) + \gamma(Cat_p) + \varepsilon_p$$

where p is a protected area, I_p its irreplaceability, A_p its area, and Cat_p its management category (I-III, IV, V-VI). We arbitrarily considered the category I-III as the reference in the ANalysis Of VAriance (i.e. the parameter γ_{I-III} was set to zero) so that the parameters to be estimated are hence γ_{IV} and γ_{V-VI} and express the deviation of irreplaceability values in categories IV and V-VI relative to categories I-III while differences between categories IV and V-VI remain directly interpretable. The residual ε_p corresponds to the residual of the model following the usual hypotheses of a classical linear model. We fitted the model using a log-transformation for I_p because its distribution was highly skewed, with a few very large values that led to a non-gaussian form of the residuals. We also considered the effect of the area (A) in a log scale as to control the fact that I_p is expected to increase with A only through a larger

sampling effect. Protected areas of category “Not Reported” were excluded in this part of the analysis.

The analysis was conducted for all species and for each taxonomic group separately (Fig. S3). To ensure the robustness of our results, we also compared our results with those obtained when
205 using other forms of the irreplaceability index (i.e the index of Saout et al (2013) as well as an alternative form where the threat coefficients σ was set to 1 for all species) (Fig. S4).

RESULTS

After processing the WDPA, we estimated that terrestrial nationally designated PAs represent 17,424,082 km², hence 13,3% of the world land surface.

210 As of 2019, we identified 20% of PAs as categories I-III, covering 41% of the PAs network. PAs of categories I-III cover a wide range of sizes but most often target pristine locations with lower levels of human activities as measured by the human footprint (Table 3). They are still the cornerstone of wildlife conservation, especially in North America, Central and Western Europe and South East Asia where they represent 64%, 66% and 56% of the total protected area respectively.

215 As a symbol of such pristine nature, the “Kahuzi-Biega National Park” (category II) in the Democratic Republic of Congo (Fig. 2) is listed in the top 200 most irreplaceable PAs in the world (Table S1) and hosts the endemic and critically endangered eastern lowland gorilla (*Gorilla beringei graueri*).

In contrast, by focusing on specific species and/or habitats, the implementation of PAs of
220 category IV allows the protection of generally smaller areas often distributed among fragmented landscapes (Table 3). Within such PAs, human activities might be either highly regulated, tolerated or promoted, depending on the requirement of the targeted ecosystem. Although they represent only 13% of the global protected surface, their number is quite high, particularly in

Central and West Asia and in Eastern Europe where they represent more than 60% of the total
225 number of PAs (Table 3).

Finally, the co-existence between human and nature promoted by PAs of categories V-VI
explains their ability to cover large areas often in human dominated landscapes with a relatively
higher human footprint (Table 3). In 2019, PAs of categories V-VI represented 25% of the global
protected surface and more than 40% in Central America and Oceania.

230 In addition to areas that drastically limit human activities, PAs such as the “Hula Nature
Reserve” in Israel (category IV) and “Los Tuxtlas” in Mexico (category VI) also represent
flagship areas of conservation worldwide (Fig. 2 and Table S1). The Hula Nature Reserve was
created to restore and protect the wetlands that were drained for the expansion of farmland in the
1950s. These wetlands are an important stopover for migrating birds and are also home to the
235 critically endangered Hula painted frog (*Latonia nigriventer*). Los Tuxtlas is an exemplar of
category VI, where aside from the conservation of emblematic and endangered species such as
the endemic long-tailed sabrewing (*Campylopterus excellens*), the Biosphere Reserve also
preserves indigenous traditions and promotes sustainable uses of resources (e.g. fishing,
agroforestry) by local communities.

240 Management categories are not distributed uniformly across the sub-continental regions and also
show disparities among ecoregions (Fig.3). For instance, some ecoregions within part of Europe
and of Oceania are poorly covered by categories I-III and IV in contrast with categories V-VI.
However, despite such patterns, our results show that, overall, different management categories
largely co-exist within each ecoregion. Over the 266 ecoregions (out of 814) for which the area
245 protected is superior or equal to 17% (Table S2, Fig 3), most encompass a balance of

management categories and only a few (n=30) are exclusively protected by one category type (categories I-III n=27, category IV n=1, categories V-VI n=2).

Furthermore, our results show that PAs with strict protection and those allowing more active management and/or human activities have a similar responsibility in terms of the biodiversity they host per unit area. Indeed, across most ecoregions, when the effect of the area of PAs is controlled for, the irreplaceability of categories IV and V-VI is not overall different from the irreplaceability of categories I-III (Fig. 4, Table S3). Nonetheless, our study also reveals different patterns at both the ecoregion and sub-continental levels with the irreplaceability of categories IV and V-VI being either lower or higher than categories I-III. For instance, in the “Humid Chaco transboundary” ecoregion of Argentina, PAs of categories IV and V-VI have a significantly lower irreplaceability than PAs of categories I-III (Table S3). In contrast, in the “Azores temperate mixed forests” in Europe, the irreplaceability is higher for categories IV and V-VI than for categories I-III. At the sub-continental level, categories V-VI have a lower irreplaceability than categories I-III in Africa and in South-East Asia, while in the latter, category IV has a higher irreplaceability than categories I-III (Fig. 4).

The analyses conducted per taxonomic group also reveals spatial disparities between management categories of PAs and their irreplaceability for mammal, amphibian and bird species (Fig. S3). For instance, in South-East Asia, PAs of category IV have a higher irreplaceability than PAs of categories I-III for mammals and birds but not for amphibians. PAs of category V-VI in Africa and in Eastern Europe seem to be of lower importance than other categories for the preservation of birds. Similarly, in Africa, PAs of category IV have a lower importance for amphibians than PAs of other categories.

DISCUSSION

Our study highlights the complementarity and the shared responsibility of different management
270 strategies of PAs in terms of both the proportion of land they cover and the biodiversity they
host.

While previous studies have focused on the extent to which the current network of PAs is on
track to reach the CBD target of 17% of terrestrial land under protection status by 2020 (e.g.
Watson et al., 2014), here we highlight how different management categories contribute to this
275 goal. Overall, our results suggest that both the number and surface of PAs arise from the
complementarity between different management strategies at both the ecoregion and sub-
continental levels. For instance, leaving aside the non-reported PAs, PAs with the strictest
protection tend to be on average larger in area, in contrast with PAs of category IV whose
management type allow to establish more areas, albeit smaller, included in closer vicinity to
280 human populations and activities (Table 3). In accordance with the results of Zimmerer et al.
(2004), we show that the categories are not distributed uniformly across the global PAs network.
Regional differences might be driven by complex combinations of factors related to historical,
geographical, social or economic contexts (Jones-Walters and Čivić, 2013; Joppa and Pfaff,
2009). For instance, the presence of large, undisturbed and wild areas in North America might
285 have facilitated the emergence of categories I-III PAs under the concept of “wilderness” while in
contrast, the high level of human density and of fragmented landscapes in Europe might explain
its high number of category IV PAs. The prevalence of strictly protected areas in South-East Asia
might be partly related to its colonial history (Déry and Vanhooren, 2011; Domínguez and
Luoma, 2020) while in Central America, the spatial congruences between indigenous territories
290 and biodiversity hotspots (Berkes, 2009; Stevens, 2014) probably influenced the implementation
of categories V-VI PAs.

Different studies focused on analyzing the efficiency of different management categories in preserving biodiversity (e.g Coetzee et al., 2014; Nolte et al., 2013). Here, we rather demonstrate the shared responsibility and the complementarity of those categories towards protecting
295 irreplaceable sites for birds, mammals and amphibians. We show that overall, in most regions of the world, the irreplaceability of PAs does not considerably vary from one management category to another one (Fig. 4). This result does not mean that biodiversity is equally preserved in all categories but that given the actual distribution range of animal species, all categories, if well managed, have the potential to preserve important biodiversity areas. Nonetheless, our results
300 also reveal spatial patterns at both the ecoregion and continental levels with different management categories having different irreplaceability, including for different taxonomic groups (Fig. 4 and Fig. S3). Such result contributes to highlight the fact that no global hierarchy can be made between the different management categories regarding their potential role for for biodiversity conservation. Rather, their relative contribution to conservation must be assessed
305 according to each taxonomic group in each geographical context.

Although it is widely accepted that the world's protected surface must increase to face global environmental changes, understanding the complementary between different management strategies is still a major issue. Nature conservation policies are implemented through complex combinations of ecological, social, economic, political and cultural issues (Brechin et al., 2010; Gavin et al., 2018; West et al., 2006). It is now crucial to understand how, across distinct
310 geographical contexts, different factors shape the choice of different management strategies, and how in return different management strategies perform and respond to different objectives. While PAs dedicated to strict nature protection must remain at the forefront of conservation strategies, we showed that alternatively managed areas, more embedded with human activities,

315 do have a high potential for protecting biodiversity as illustrated by both their spatial extent and
their comparable irreplaceability (Fig. 3 and Fig. 4). Such PAs of categories IV to VI could offer
relevant alternatives to protect fragmented and/or human dominated landscapes and increase the
network's robustness towards maintaining key ecological processes. Although their efficiency in
maintaining biodiversity on the long term still needs to be demonstrated, we argue that such
320 performance is entirely related to our capacity to fully acknowledge and support the management
strategies that these PAs rely on (Corrigan et al., 2018). This is particularly true in regions where
such strategies, as shown in our results, cover a high proportion of the protected land and/or have
a higher responsibility than others.

CONCLUSION

325 Over the last decades, the assessment of the world protected areas network has been
multipurposed (Maxwell et al., 2020; Rodrigues and Cazalis, 2020) and included not only the
evaluation of the design (e.g. coverage of species and ecoregions, PAs connectivity) but also the
evaluation of the input (e.g budget or capacity shortfalls), of the threat reduction (e.g. change in
human pressures, pollution), and of the outcome (e.g. change in species abundance, socio-
330 economic benefits). We argue that such evaluations should now be conducted in light of the
diversity of management strategies implemented across the protected areas network.

The CBD has invited decision makers, scientists and practitioners to reflect on and propose the
scope and content of the post-2020 global biodiversity framework (CBD, 2020). In this context,
new targets directly addressing spatial planning and the expansion of the protected area network
335 should explicitly integrate the importance of the diversity of management strategies. The
successful combination of these strategies will be critical to both operate the balance and find
synergies between effective biodiversity conservation and human well-being.

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Table 1. Number of species considered and their IUCN status for each taxonomic group used in the analysis.

IUCN Status	Amphibians	Mammals	Birds
DD	1399	735	52
LC	2737	3185	8405
NT	380	337	1012
VU	637	521	799
EN	903	466	469
CR	508	180	199

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Table 2. Categories' main characteristics (adapted from Chape et al. (2005) and Dudley (2008) Note that Categories Ia and Ib differ mostly due to the size of the areas (Ia being potentially much smaller than Ib) and the conditions in which a limited number of visitors is allowed.

IUCN Category	Name	Objectives	Management	Human activities allowed	Category as defined in this study
Ia	Strict nature reserve	Conservation of natural ecosystem, species, and geological features. Scientific research and/or environmental monitoring	Minimum intervention for restoration	Research and visit in the case of sacred sites (limited)	I-III
Ib	Wilderness area	Wilderness protection (i.e. large unmodified areas) and recreation (secondary)	Minimum to no intervention	Recreation, traditional wilderness based activities, research, education	
II	National park	Ecosystem protection (i.e. maintenance of large scale ecological processes) and recreation	Minimum intervention. Those areas are subject to zoning and a higher tolerance to human use can be observed in the surrounding buffer zones	Tourism, recreation, education, research, subsistence resource use for indigenous and local communities	
III	Natural monument or feature	Conservation of specific natural features (e.g. landform, submarine cavern, ancient grove) and the associated species and habitats	Intervention targeted to particular natural features (overall similar to the management of category II, although at a smaller scale)	Tourism, recreation, education, research	
IV	Habitat/species management area	Conservation of specific habitats or species populations of natural or cultural value	From low intervention to regular, active (traditional) interventions to maintain or restore specific (semi-)natural habitats or species requirements	Tourism, recreation, education, research	IV
V	Protected landscape/seascape	Conservation of areas shaped and maintained by human activities and recreation	Management, including by the local communities, by active intervention, maintenance or restoration of the (traditional) human activities that defined the landscape/seascape. Note that this category can act as buffers of stricter protection areas	Agriculture, forestry, fishery, development, tourism, recreation, education, research	V-VI
VI	Protected area with sustainable use of natural resources	Conservation of ecosystems, ecosystem services and associated cultural values, and (traditional) sustainable use of its natural resources	Management to allow the maintenance of natural ecosystems and resources to support their sustainable use	Sustainable extraction of natural resources (including hunting, grazing), development, tourism, recreation, education, research	

Table 3. Descriptive statistics for each management category.

Subcontinent	Category	Percentage of the total Number of PAs in the Region	Percentage of the total Area covered by PAs in the Region	Average Human Footprint in PAs	Average Area of PAs (km ²)
Africa	I-III	5	29	7,0	2930,4
	IV	4	16	9,5	2166,3
	V-VI	3	14	7,2	2568,5
	Not Reported	88	41	10,3	246,8
Central and Western Europe	I-III	12	66	12,0	113,9
	IV	39	5	20,0	3,0
	V-VI	15	20	21,7	28,0
	Not Reported	33	9	10,6	6,2
Eastern Europe	I-III	25	33	8,7	560,0
	IV	66	48	8,8	312,5
	V-VI	6	18	5,2	1224,8
	Not Reported	3	2	7,3	335,3
North America	I-III	17	64	9,1	214,5
	IV	9	17	3,9	105,3
	V-VI	72	18	16,6	13,7
	Not Reported	2	0	23,8	13,6
Central America	I-III	16	39	12,5	637,1
	IV	18	3	15,5	46,0
	V-VI	36	42	11,2	314,4
	Not Reported	30	16	14,9	143,9
South America	I-III	18	24	8,7	1335,7
	IV	12	2	9,2	158,9
	V-VI	27	31	10,4	1139,5
	Not Reported	44	43	9,8	963,6
Central and West Asia	I-III	10	42	11,3	572,8
	IV	68	23	21,3	46,8
	V-VI	19	27	18,5	204,7
	Not Reported	3	8	15,3	417,3
South East Asia	I-III	44	56	9,9	510,1
	IV	12	18	9,0	640,9
	V-VI	28	16	13,9	236,3
	Not Reported	16	10	11,5	246,5
Oceania	I-III	64	45	9,7	66,5
	IV	23	2	10,7	6,5
	V-VI	10	50	7,9	460,8
	Not Reported	2	3	10,0	129,5
Global	I-III	19	41	10,4	214,4
	IV	30	13	17,7	42,7
	V-VI	28	25	17,5	87,8
	Not Reported	23	21	10,8	91,1

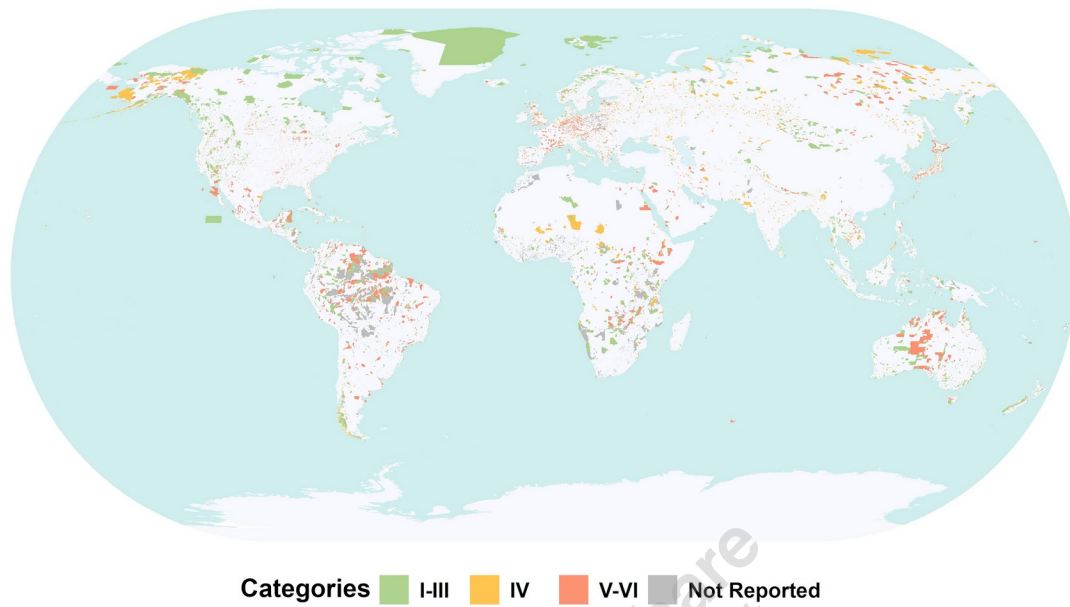


Fig. 1. The distribution of the 176,904 protected areas used in this study and their IUCN management categories.

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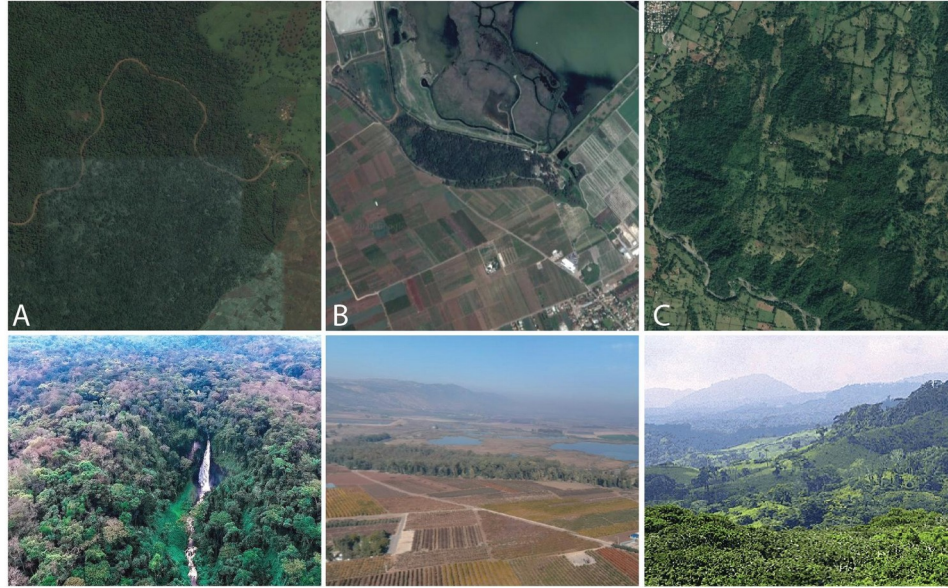


Fig. 2. Examples of protected areas from the top 200 most irreplaceable sites identified in this study : A- Kahuzi-Biega National Park in Republic Democratic of Congo (IUCN Category II); B- Hula Nature Reserve in Israel (IUCN Category IV); C- Los Tuxtlas (Zona de Amortiguamiento) in Mexico (IUCN Category VI). Copyright : Forest Service/ USDA (public domain), Google Earth, Semarnat (<https://www.gob.mx/semarnat>).

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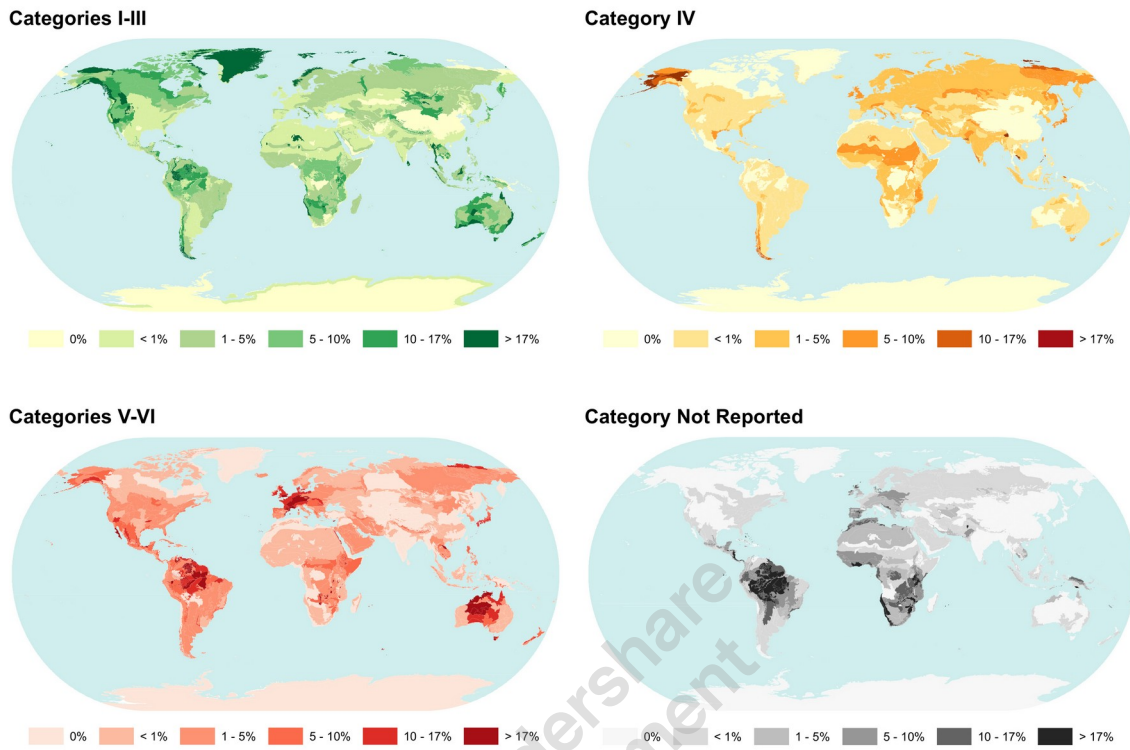


Fig. 3. Proportion of each ecoregion covered by different management categories of protected areas. The highest threshold of 17% was chosen in reference to Aichi Target 11 (CBD, 2011).

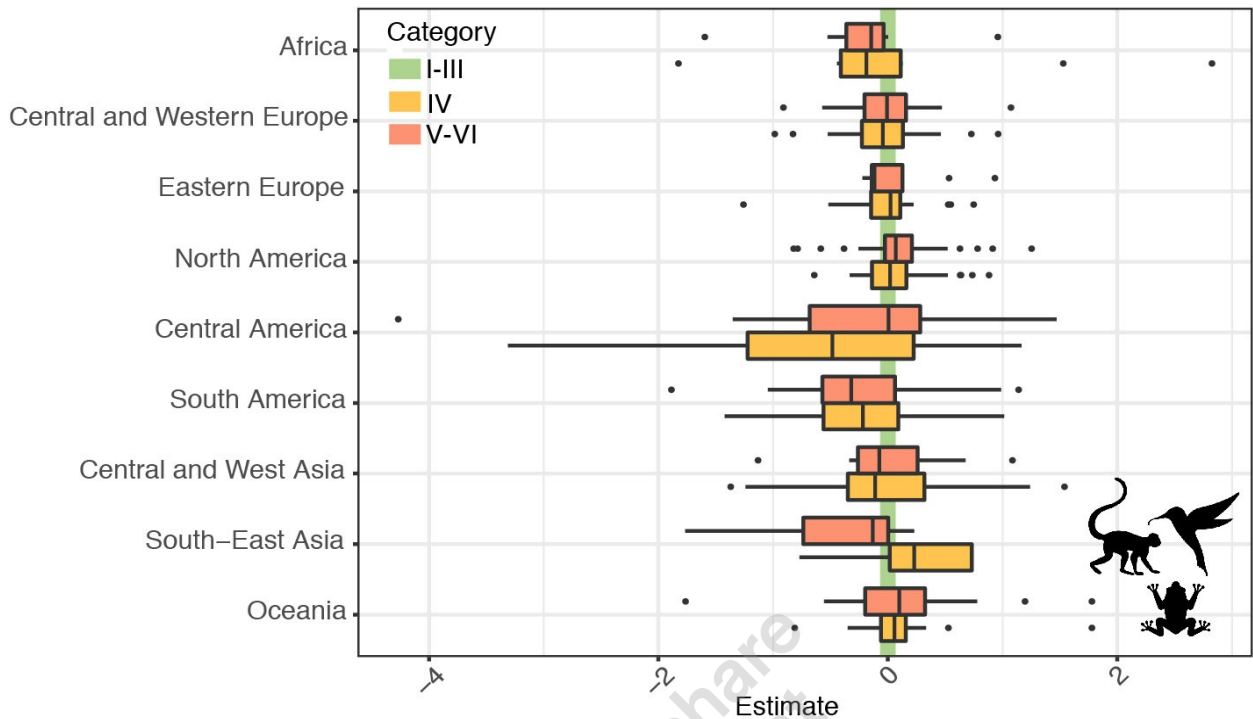


Fig. 4. Comparison of the irreplaceability of protected areas of different management categories for mammals, amphibians and birds. Linear models were fitted separately within each ecoregion controlling for the surface of protected areas. Boxplots represent the distribution, at the subcontinental level, of the model coefficients (Estimates) associated with categories IV and V-VI, (categories I-III being considered as the reference).

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