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Global protected areas and IUCN designations: Do the categories match the conditions?

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ABSTRACT

Protected areas are considered fundamental to the preservation of nature. The International Union for Conservation of Nature (IUCN) has standardized categories for protected areas designation, which are intended to represent varying levels of regulatory protection. We evaluate whether the present assignment of protected areas to IUCN categories corresponds to the expected gradient of naturalness in a globally consistent manner. Our proxy of naturalness was a global map of human influence known as Human Footprint (HF). Higher HF values represent less intact natural areas. Our final sample of protected areas included 21,186 IUCN-designated sites that were $\geqslant 1$ km^2. We used multiple linear regression to test for the effect of IUCN categories on mean HF while accounting for biome and protected area size.

The present assignment of protected areas to IUCN categories does not correspond to the expected gradient of naturalness. We observed that IUCN Category Ia areas have higher HF than expected and Category VI protected areas have unexpectedly low HF; Category VI protected areas also are generally larger than protected areas of other categories. Reporting of area protected in different IUCN categories is one measure of progress towards meeting commitments under the Convention on Biological Diversity, yet because IUCN categories are not interpreted consistently across the globe, this is not a reliable metric. Further, despite the social, economic and ecological importance of protected areas with a very low HF, our results suggest that the availability of such areas within the global protected areas network is very limited.

1. Introduction

Human activities including agriculture, forestry, and urbanization, have impacted terrestrial ecosystems such that few natural areas remain globally (Cardillo et al., 2006; Imhoff et al., 2004; Mittermeier et al., 2003). Consequently, protected areas are now considered fundamental to preserving and conserving natural areas, and reducing biodiversity loss (Bruner et al., 2001; Ehrlich and Pringle, 2008; Rodrigues et al., 2004). Protecting natural areas is a useful endeavor for many reasons: natural areas may retain their biodiversity autonomously (i.e. without need for management interventions), provide many ecosystem services such as nitrogen fixation, and carbon sequestration (Daily, 1997), and they can be controls to assess the health of ecosystems (Arcese and Sinclair, 1997; Lindenmayer and Franklin, 2002). There are also aesthetic and spiritual reasons for protecting them (Cronon, 1996). Globally, the number of protected areas has increased rapidly in recent decades (Bishop et al., 2004; Chape et al., 2005). The World Database on Protected Areas (WDPA) now recognizes 102,290 areas (Chape et al., 2008), covering 12.9% of the Earth's land surface (Jenkins and Joppa, 2009), as being under some form of protection. Given the increasing global reliance on protected areas as cornerstones of conservation, it is important to ask whether the assignment of lands to various levels of protection can be interpreted consistently relative to conservation objectives (Boitani et al., 2008). Here, we focus on one conservation objective, namely the protection of natural or intact ecosystems.

The International Union for Conservation of Nature (IUCN) has been instrumental in coordinating global protected areas through their World Commission on Protected Areas. In 1994, the IUCN

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developed standardized guidelines for protected areas designation, based on six categories (Ia, Ib, II, III, IV, V, and VI) that were intended to represent levels of legislative or regulatory protection, and the nature and intensity of permissible land uses (IUCN, 1994, Table 1). Since then, many countries have adopted these categories for their national protected areas plans (Chape et al., 2005). Despite their widespread application, the conservation effectiveness of the IUCN categories has been disputed (Joppa et al., 2008; Locke and Dearden, 2005). For example, in a recent analysis of tropical moist forests, Joppa et al. (2008) concluded that the IUCN categories did not discriminate differences in the relative forest cover inside and outside of protected areas, suggesting a mismatch between IUCN designations and the condition of protected areas. More broadly, the categories have been criticized because they were defined largely in terms of management objectives rather than quantitative conservation goals (Bishop et al., 2004; Boitani et al., 2008; Locke and Dearden, 2005).

In response to these criticisms, the IUCN recently released a comprehensive guide to applying their categories, which clearly identifies the conservation of nature as the primary management objective of protected areas (Dudley, 2008). The IUCN guide identifies goals common across all IUCN categories, including the conservation of genetic, species, community, ecosystem, and landscape diversity, and the processes that link these different elements (Dudley, 2008). Although protected areas from all IUCN categories share broad conservation objectives, the categories describe different management approaches for achieving these. One reflection of the IUCN's qualitative goal of nature conservation is an expressed gradient of naturalness among protected area categories (Dudley, 2008). The gradient, from most natural to least natural, follows categories Ia = Ib > II = III > IV = VI > V (Bishop et al., 2004; Chape et al., 2005; Dudley, 2008). Natural is defined relative to both ecosystem structure and human activity (IUCN, 1994), whereby natural areas are "those that still retain a complete or almost complete complement of species native to the area, within a more-or-less naturally functioning ecosystem" (Dudley, 2008, 12). Accordingly, IUCN Category Ia mandates "strictly controlled and limited" human visitation, use and impacts (Dudley, 2008, 13), whereas IUCN Category V protected areas aim to maintain "values created by interactions with humans through traditional management practices" (Dudley, 2008, 20). While naturalness is an important criterion in the IUCN categories, there has been no quantitative evaluation that determines whether the present assignment of protected areas to these categories corresponds to the expected gradient of naturalness in a globally consistent manner.

There are several ways to quantify naturalness (Anderson, 1991; Karr, 1990; Lackey, 2001), many involving the use of a proxy measure related to human disturbance. Haines et al. (2008) recently argued for the use of human footprint data (i.e. maps of anthropogenic features) to monitor landscape level conservation efforts, of which protected areas are an important component. Several spatial representations of measures of human disturbance exist at a global scale (e.g. Bryant et al., 1997; Imhoff et al., 2004; Sanderson et al., 2002; UNEP, 2001). Bryant et al. (1997) mapped the world's remaining frontier forests (i.e. the remaining large, intact, natural forest systems) while Imhoff et al. (2004) derived a map which compares the amount of net primary production required by humans to the total amount generated. GLOBIO, part of the United Nations Environment Programme, is developing a global model for exploring the impact of environmental change on biodiversity (UNEP, 2001). At smaller scales, Global Forest Watch has produced maps that quantify the intactness of Canada and Russia's boreal forest systems using coarse filter indicators (Aksenov et al., 2002; Lee et al., 2006). The Human Footprint index of Sanderson et al. (2002) represents a continuum of expected human influence on the intactness, naturalness, and function of natural communities based on population density, land transformation, accessibility, and electrical power infrastructures. The Human Footprint index is global, incorporates a range of human activities, and may therefore be used as a reasonable global proxy of naturalness *sensu* Dudley (2008).

Our main research objective was to determine whether IUCN categories are interpreted consistently across the globe with

Table 1
The IUCN definitions for categories of protected areas, after Dudley (2008), where the degree of naturalness, ranging from most natural to least natural conditions is Ia = Ib > II = III > IV = VI > V.

Category	Title	Description
Ia	Strict nature Reserve	• Strictly protected • Set aside to protect biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of conservation values • Can serve as indispensable reference areas for scientific research and monitoring
Ib	Wilderness area	• Large unmodified or slightly modified areas, retaining natural character and influence, without permanent or significant human habitation • Protected and managed so as to preserve natural condition
II	National park	• Large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area • Provide a foundation for environmentally and culturally compatible spiritual, scientific, education, recreational and visitor opportunities
III	Natural monument or feature	• Set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove • Generally quite small areas and often have high visitor value
IV	Habitat/species management area	• Protect particular species or habitats, and management reflects this priority • May need regular, active interventions to address requirements of particular species or to maintain habitats
V	Protected landscape/seascape	• Interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value • Safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values
VI	Protected area with sustainable use of natural resources	• Conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems • Generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area

respect to the expected gradient of naturalness, as one measure of whether protected areas categories can be interpreted consistently relative to conservation objectives, in particular, the conservation of natural ecosystems. Specifically, we tested whether protected areas followed the expected naturalness gradient, from most to least natural, of IUCN categories Ia = Ib > II = III > IV = VI > V (Bishop et al., 2004; Chape et al., 2005; Dudley, 2008). Our secondary objective was to determine the availability of relatively large and natural protected areas in the current global protected area network. To achieve these objectives, we calculated mean Human Footprint values for an extensive sample of the world's protected areas and used the distribution of these areal means to quantify the relationship between Human Footprint, as a measure of naturalness, and IUCN protected area category within and among terrestrial biomes.

2. Methods

Our proxy of naturalness was Sanderson et al.'s (2002) Human Footprint dataset. The Human Footprint index is a composite of nine global datasets that represent four aspects of direct or potential anthropogenic impact: (1) population density, (2) land transformation, (3) accessibility, and (4) electrical power infrastructure. Within-cell footprint scores range from 0 (low) to 100 (high) and are standardized within terrestrial biomes, as delineated by Olson et al. (2001). Human Footprint and naturalness are inversely related; a low Human Footprint score indicates a relatively natural area.

The Human Footprint index is reported at a spatial resolution of 1 km^2, based on buffering, interpolation or modelling of the component datasets, some of which are of lower spatial resolution than the final product. For example, population density for each Human Footprint cell is modeled from regionalized census data. Consequently, population density estimates may not be reliable in areas with poor or low-spatial resolution census data. The four aspects of direct or potential anthropogenic impacts included in the Human Footprint may not be positively correlated to each other and as such, different regions of the world may be influenced by one aspect (e.g. land transformation) more than another (e.g. population index). The developers of this index (Sanderson et al., 2002) acknowledge these limitations.

We identified 37,455 protected areas in the 2007 WDPA with IUCN designations and spatial boundaries falling entirely within terrestrial biomes (WDPA, 2007). We recalculated the extent of each protected area to correctly treat component areas of multipart protected areas in the original WDPA (e.g. St. Lawrence Islands National Park of Canada which is composed of 20 islands and 90 islets scattered on the St. Lawrence River, Canada). We excluded all protected areas <1 km^2 as being clearly below the spatial resolution of the Human Footprint dataset. However, the estimated Human Footprint might also be biased upwards for small intact protected areas embedded within otherwise densely populated or intensively used areas. Accordingly, we performed a supplementary analysis using only protected areas $\geqslant$10 km^2 to determine whether our results were unduly influenced by the apparent footprints of smaller protected areas due to sampling resolution. It might also be the case that there exist a large number of very small Category Ia protected areas with low Human Footprint, embedded within highly modified landscapes. If so, their absence from our data set might have biased our findings.

Protected areas were assigned to biomes by centroid location. The "Lakes" and "Rock & Ice" biomes contained very few protected areas and were therefore excluded from further analyses. The final sample included 21,186 protected areas $\geqslant$1 km^2 (11,702 protected areas $\geqslant$10 km^2 for supplementary analysis) in 14 terrestrial biomes (see Table 2 for biome names). The mean size of protected areas $\geqslant$1 km^2 and $\geqslant$10 km^2 was 598 km^2 and 1079 km^2, respectively. We used ArcGIS' v9.2 Zonal Statistics (ESRI, 2005) and Hawth's Analysis Tools (Beyer, 2004) to calculate the mean Human Footprint per protected area. Fig. 1 illustrates the global distribution of these protected areas and their associated mean Human Footprint. To minimise edge effects, these calculations included only 1 km^2 cells whose centroids fell within protected area boundaries. Human Footprint cells whose centroids fell outside protected area boundaries were excluded. There is evidence that the land adjacent to protected areas tends to have relatively high Human Footprint compared to the land inside protected areas (Wittermyer et al., 2008), particularly in densely populated regions such as Europe. We assumed that our centroid-based criterion would yield a conservative estimate of Human Footprint per protected area, in the sense that edge effects would be minimized. However, the effect of orientation and shape of individual protected areas on the validity of this assumption should be tested in future studies. For example, Human Footprint statistics for small protected areas may be more sensitive to the removal of a few peripheral cells than large protected areas.

Our main goal was to determine if the mean Human Footprint of protected areas differed significantly among IUCN categories. We used a multiple linear regression approach with mean Human Footprint per protected area as the response variable. We use the term "grand mean" to refer to means calculated at higher levels such as for biomes or IUCN categories: a grand mean is a mean of cell-level means among protected areas in a given group. We included IUCN category in the model as an unordered factor. The amount of human activity varies among biomes as a legacy of historical settlement patterns, current population size, and level of economic development, so we also included a factor for biome. The sizes of protected areas within our dataset spanned more than five orders of magnitude (from 1 to 425,967 km^2). Because we expected that larger areas might be relatively remote from human influence within their biome, we also included protected area size as a continuous covariate, $\log_{10}$ transformed to stabilize variances. Coefficients for IUCN category and biome were estimated using treatment contrasts, as recommended for unbalanced designs (Venables and Ripley, 2002, Section 6.2). This requires that a reference level be specified for each factor. The ordering of the parameter estimates and estimated

Table 2
Frequency and proportional abundance within biomes of protected areas (PAs) having low Human Footprint.

Biome	Mean Human Footprint		% of PAs		Total PAs
	$\leqslant$ 5	$\leqslant$ 10	$\leqslant$ 5	$\leqslant$ 10	
Tropical & Subtropical Moist Broadleaf Forests	184	294	8.2	13.1	2 240
Tropical & Subtropical Dry Broadleaf Forests	15	22	4.3	6.4	346
Tropical & Subtropical Coniferous Forests	1	5	0.7	3.3	152
Temperate Broadleaf & Mixed Forests	168	473	1.5	4.2	11 150
Temperate Conifer Forests	152	434	10.7	30.5	1 422
Boreal Forests/Taiga	352	762	21.2	45.9	1 660
Tropical & Subtropical Grasslands, Savannas & Shrublands	38	105	5.8	16.0	655
Temperate Grasslands, Savannas & Shrublands	19	162	1.6	13.9	1 163
Flooded Grasslands & Savannas	6	12	8.1	16.2	74
Montane Grasslands & Shrublands	20	52	4.4	11.5	453
Tundra	103	164	48.6	77.4	212
Mediterranean Forests, Woodlands & Scrub	20	62	3.1	9.7	637
Deserts & Xeric Shrublands	41	216	6.1	32.2	671
Mangroves	12	23	7.9	15.2	151

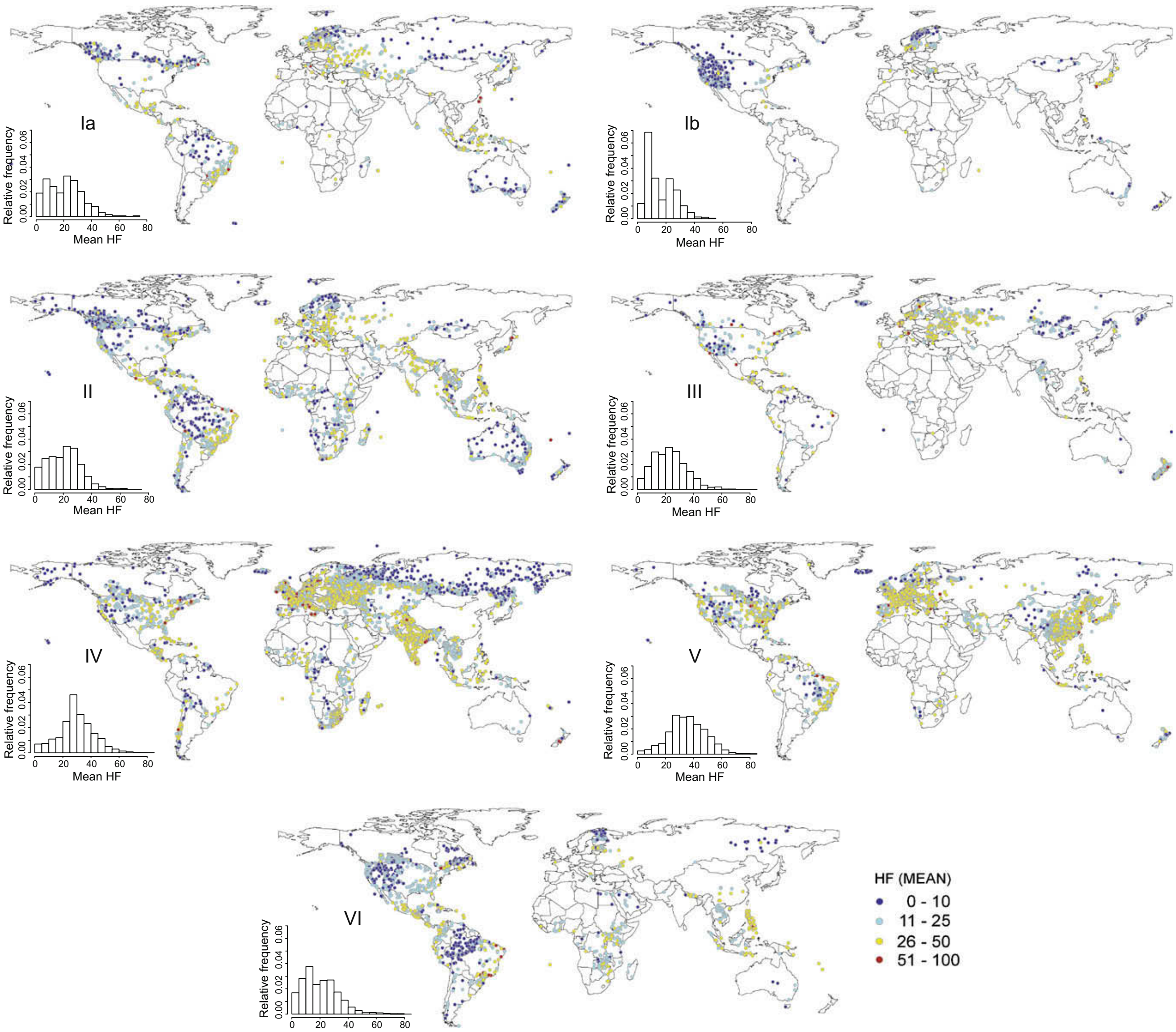

Fig. 1. Geographic distribution of protected areas by IUCN category and Human Footprint intensity, with histograms of mean Human Footprint (HF) distribution within category.

relative effect sizes are insensitive to the choice of reference level. We chose Category Ia for IUCN reference category because protected areas in this category are defined as strict nature reserves. As these would be expected to have the highest degree of naturalness, it seems reasonable to evaluate category-level effects relative to them. We chose Temperate Grasslands, Savannas and Shrublands as the reference biome.

To evaluate the consistency of IUCN-category naturalness rankings across biomes we compared the distributions of the response variable by IUCN category within biomes. For each biome, we also compared the number of protected areas with mean Human Footprint $\leqslant$ 5 and $\leqslant$ 10, to identify biomes having the greater proportions of protected areas with high degrees of apparent naturalness. We used R v 2.5.0 (R Development Core Team, 2006) for statistical analyses and presentation graphics.

3. Results

In general, protected areas with low mean Human Footprint are in regions with low human population density like the boreal region, Amazon forest and central Australia (Fig. 1). Only 3/14 biomes have >10% of their protected areas with mean Human Footprint $\leqslant$5: Tundra (48.6%); Boreal Forest/Taiga (21.2%); and Temperate Conifer Forest (10.7%). Ten of 14 biomes have >10% of their protected areas with mean Human Footprint $\leqslant$10 (Table 2).

The multiple linear regression model with covariates for IUCN category, terrestrial biome and size explained 43% of the variance in mean Human Footprint per protected area (Table 3). IUCN protected area categories departed from the expected mean Human Footprint gradient of Ia = Ib < II = III < IV = VI < V. Instead, the distributions of mean Human Footprint per protected area within IUCN categories (Fig. 2A) and coefficients from the regression analysis (Table 3) showed that IUCN designated areas were ordered as Ib = III < Ia < II = VI < IV < V. We obtained identical results when the index of Human Footprint per protected area was calculated from the median, rather than the mean, of cell-level values.

Category Ia protected areas are defined as strict nature reserves and thus were expected to be mostly free of human influence, but their grand mean Human Footprint was 20.19 (on a scale of 0–100). After accounting for biome and size effects, the mean Human

Table 3
Results of multiple linear regression model of mean protected area (PA) Human Footprint against IUCN PA category, controlling for terrestrial biome and PA size. Category Ia and Temperate Grasslands, Savannas and Shrublands are used as the reference levels for the IUCN category and biome factors, respectively. All coefficients were significant at $P \leqslant 0.001$ except for the factor for the Deserts and Xeric Shrublands biome ($P = 0.45$). $R^2 = 0.43$.

	Estimate	Std error	*t*-Value
Intercept	25.47	0.45	56.74
IUCN PA category			
Ib	−2.30	0.50	−4.57
II	2.30	0.39	5.96
III	−2.07	0.39	−5.31
IV	5.96	0.34	17.77
V	11.14	0.35	32.21
VI	2.30	0.40	5.69
Biome			
Tropical and Subtropical Moist Broadleaf Forests	5.68	0.38	14.77
Tropical and Subtropical Dry Broadleaf Forests	8.80	0.65	13.52
Tropical and Subtropical Coniferous Forests	8.38	0.91	9.17
Temperate Broadleaf and Mixed Forests	5.59	0.33	16.73
Temperate Conifer Forests	−1.59	0.43	−3.73
Boreal Forests/Taiga	−7.46	0.41	−18.37
Tropical and Subtropical Grasslands, Savannas and Shrublands	4.79	0.53	9.09
Flooded Grasslands and Savannas	5.24	1.27	4.12
Montane Grasslands and Shrublands	4.62	0.59	7.83
Tundra	−7.61	0.80	−9.53
Mediterranean Forests, Woodlands and Scrub	6.85	0.52	13.06
Deserts and Xeric Shrublands	0.39	0.52	0.76
Mangroves	4.21	0.92	4.60
$\log_{10}$ (PA size (km^2))	−4.97	0.09	−58.73

Footprint of Category Ia protected areas was significantly higher than for Categories Ib and III (Table 3).

The ordering of IUCN protected areas by mean Human Footprint was not entirely consistent among biomes, but some regularity is evident (Fig. 3). Within biomes, the grand mean Category Ia Human Footprint varied from 10.86 to 29.77, and was greater than for Category Ib in 10/14 biomes, and for Categories II and VI in 9/14 biomes. Conversely, multi-management Category VI protected areas had a relatively low grand mean Human Footprint of 19.63, varying from 3.09 to 30.43 among terrestrial biomes. Grand mean Human Footprint for Category VI protected areas was lower than for Category IV in 11/14 biomes, and for Categories III and V in 10/14 biomes. This trend was consistent with that found in the supplementary analysis of protected areas $\geqslant 10\ km^2$ (Appendix A). This supplementary analysis yielded a partial ordering of IUCN designated areas by mean Human Footprint as Ib = III < Ia = II = VI < IV < V, which was consistent with results for the complete dataset described above.

Mean Human Footprint decreased markedly with protected area size (Fig. 2B), as indicated by the significant negative coefficient for size in the regression model (Table 3). The grand mean Human Footprint of the smallest protected areas, size class 0 (1–9.9 km^2) and 1 (10–99.9 km^2; Fig. 2B), was 33.28 and 26.15, respectively and for the largest protected areas, size class 4 (10,000–99,999.9 km^2) and 5 (100,000 km^2+), was 7.77 and 4.50, respectively. Protected area size varied among IUCN categories, with II and VI having the largest protected areas on average; 1377.81 km^2 and 1998.32 km^2, respectively (Fig. 2C; ANOVA: $F = 565.95$, $df = 6$, $p < 0.001$). Protected area size also varied among biomes (ANOVA: $F = 606.24$, $df = 13$, $p < 0.001$). The three biomes with the greatest grand mean protected area size were the Tundra (6357 km^2), Deserts and Xeric Shrublands (2887 km^2), and Montane Grasslands and Shrublands (2686 km^2).

4. Discussion

The IUCN category definitions imply a gradient in naturalness, such that Category Ia protected areas should exhibit the highest degree of naturalness. We operationalised the attribute of naturalness by calculating the areal mean Human Footprint (Sanderson et al., 2002) for a large sample of terrestrial protected areas with assigned IUCN categories and having mapped areas larger than 1 km^2. The Human Footprint index is a surrogate for naturalness, therefore, we expected that IUCN Category Ia protected areas, characterized by strict conservation goals, would have the lowest mean Human Footprint among all categories. However, our analysis suggests otherwise. Globally, over all biomes and protected area sizes, the grand mean Human Footprint of IUCN Category Ia areas is higher than for Category Ib, and is roughly equivalent to Categories II, III, and VI. Our multiple regression models control for the mean effects of protected area size and terrestrial biome. Consequently, it follows that within or between biomes, a randomly chosen protected area of Category Ia would, with high probability, have a higher mean Human Footprint than a randomly chosen protected area of equal size in Categories Ib or III. The exact probability of this outcome can be estimated from the model regression coefficients and standard errors. These findings are robust to the choice of minimum protected area size (1 km^2 or 10 km^2) and metric of Human Footprint per protected area (mean or median of cell-level values). We conclude that the present assignment of protected areas to IUCN categories does not correspond to the expected gradient of naturalness in a globally consistent manner. Although our analysis

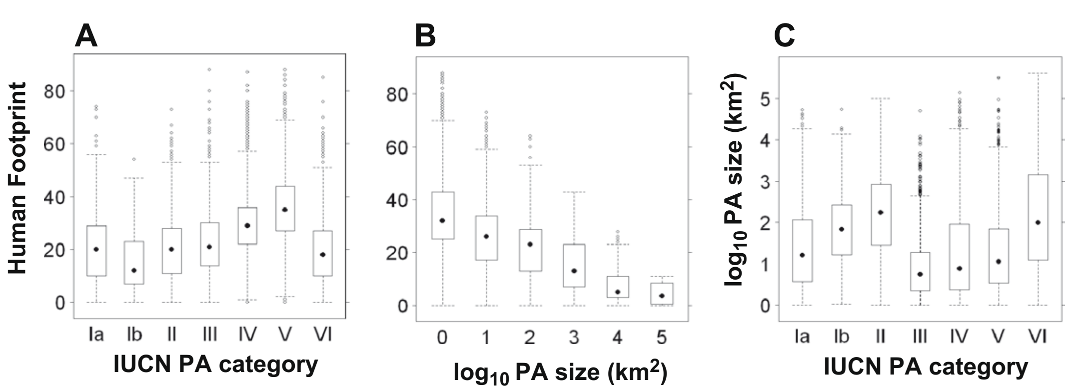

Fig. 2. Distributions of Human Footprint within protected areas (PA) and of PA sizes. (A) Mean Human Footprint of PAs by IUCN category, (B) Human Footprint by PA size class, (C) PA size distributions by IUCN category.

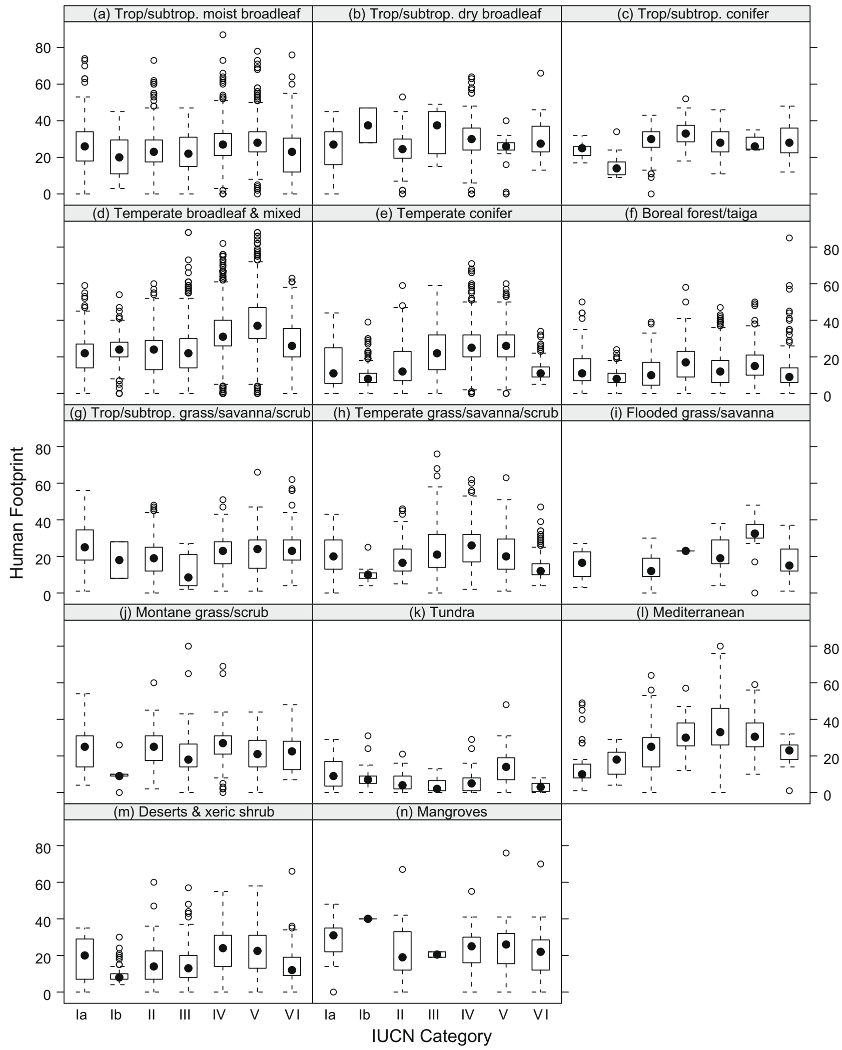

Fig. 3. Distributions of Protected Areas mean Human Footprint indices by IUCN category within terrestrial biomes.

cannot determine the reasons for the observed discrepancy, we can suggest three possible explanations.

First, the IUCN categories may not, in fact, be applied according to the IUCN guidelines. IUCN category designation is administered by local or national governments and there is no standardized central body that evaluates their category designations. This may explain, for example, the striking patterns in the relative distributions of Categories Ia and Ib protected areas shown in Fig. 1. Dudley's (2008) comprehensive guide to applying protected area management categories may lead to more globally consistent category designations in the future. Other methods, such as the development of a protected area certification program may also achieve this goal (Dudley et al., 2004). Secondly, protected areas may be designated based on intended future use rather than present condition. In that case, differences in the timing of establishment among IUCN categories might account for some of the variation we observed. Thirdly, some protected areas may not be managed according to the objectives of their designations, which refer to intended rather than to realized objectives. The first global analysis of the effectiveness of protected area management reports that overall management performance is at a "barely acceptable" level (Leverington et al., 2008), which tends to support this last explanation for our findings.

Ideally, it should be possible to identify actions to help protected areas better meet their primary management objectives. In some cases, this might involve restoration to reduce human impact (e.g. in some Category Ia protected areas). In other instances, strategies to restore historical human activities may be required to meet management objectives (Dudley, 2008). Recent developments in methods for measuring conservation progress (e.g. Gaston et al., 2006; McDonald-Madden et al., 2009; Timko and Innes, 2009) and the effectiveness of protected areas' management (e.g. Hockings et al., 2004; Leverington et al., 2008) may lead to directly measurable indices that could explain some of the discrepancies we observed.

Though the Human Footprint (Sanderson et al., 2002) does not directly measure human behaviors and activities, we speculate that the patterns we document indicate that IUCN Category Ia protected areas do not consistently respect the criteria of "strictly controlled and limited" human access (Dudley, 2008). This raises the possibility that many such areas do not qualify as strict nature reserves. A high degree of naturalness is not a necessary condition to satisfy every conservation value, but areas with a very low Human Footprint have many social, economic, and ecological values, including retention of biodiversity, production of ecosystem services, and detection of ecosystem change and associated biodiversity loss due to human activity. Unfortunately, in many biomes, only a small proportion of protected areas, among all categories, exhibit a low mean Human Footprint. We suggest that the global protected area network needs to identify and acquire more natural areas, specifically those with lower Human Footprint.

Most of the recent increases in protected areas have been in multi-management IUCN Categories V and VI (Locke and Dearden, 2005), where sustainable levels of human activities are allowed (Dudley, 2008). The relatively low mean Human Footprint in multi-management Category VI protected areas represented a surprising departure from the rank order of naturalness described by the IUCN (Dudley, 2008). This departure may simply be a result of the relatively recent establishment of most Category VI protected areas, and the success of these protected areas should be monitored through time. Conversely, this departure may occur because the Category VI definition allows for sustainable economic activity, and such areas provide incentives for local populations to protect natural resources while potentially enabling large tracts of land to be set aside. In that respect, we note also that existing Category VI protected areas are among the largest on average, among all categories. Others have identified the value of multi-management protected areas involving local communities (Ehrlich and Pringle, 2008; Ostrom and Nagendra, 2006; Tallis et al., 2008). Ostrom and Nagendra (2006) suggested that multi-management protected areas also may be more cost-effective than the creation of strictly protected parks. It should be emphasized that the term "local communities" includes any resource-dependent communities in relatively undeveloped regions whether in economically developed or developing countries (e.g. in the boreal forests of Canada and in Brazilian Amazonia). In areas where the risk of losing relatively natural ecosystems is high and increasing due to pressures for economic development (e.g. South America; Azevedo-Ramos et al., 2006; Nepstad et al., 1999), Category VI protected areas managed with the conservation of natural structure and function as the goal have unique potential to support economic and social benefits while also contributing to ecological objectives (Ostrom and Nagendra, 2006).

In densely populated regions or biomes, large areas with low Human Footprint may no longer be available for designation as new protected areas of any category. Small protected areas in these regions, whether existing or to-be-established, may be of high conservation value (e.g. Laguna et al., 2004) even if they depart markedly from a natural state. Likewise, protected areas are not the only mechanism for conservation; the lands outside protected areas may make significant contributions to conservation goals (e.g. Gove et al., 2005). A full suite of protected areas from different categories and with different sizes and levels of human activity may be necessary to provide the full range of social, economic and ecological values expected of protected areas. However, because present Category VI protected areas have a low Human Footprint and also tend to be large, we believe these areas have a significant and unrealized potential for global conservation. In some biomes, these areas may also represent the best option for establishing new large protected areas.

The Convention on Biological Diversity requires signatories to report on the effectiveness of protected areas in meeting conservation goals (UNEP, 1992). Most studies that assess effectiveness restrict evaluation to IUCN Categories I–IV because these have strict management goals (e.g. Bruner et al., 2001; DeFries et al., 2005; Loucks et al., 2008; Rodrigues et al., 2004; Wittermyer et al., 2008, but see Schmitt et al., 2009). Future assessments of the effectiveness of protected areas should include all IUCN categories in order to determine the contribution of large multi-management protected areas to biodiversity conservation.

The Human Footprint dataset is a conservative estimate of current human influence. The global population has increased by nearly 1 billion people since the census data used in the Human Footprint (UNPD, 2007). The underlying access and land transformation data included only the largest roads and rivers. There is evidence, however, that even narrow and vegetated linear features may influence the behaviour of local fauna (e.g. Dyer et al., 2002; Whittington et al., 2005). Moreover, the Human Footprint dataset, and our analysis, provides only a snapshot of the level of human impact on protected areas. Ideally, time-series data on Human Footprint or a similar metric would be used to assess effectiveness of protected areas' management and conservation outcomes through time.

Finally, we note that the WDPA itself may contain errors and biases (Bishop et al., 2004; Chape et al., 2005; Joppa et al., 2008). We selected our sample in an effort to minimize the effects of such errors. Despite the potential limitations of both these datasets, these data are the best currently available at the global scale and have been used and advocated by many recent studies (e.g. Haines et al., 2008; Joppa et al., 2008). On these grounds, we think our use of these data is well-supported.

5. Conclusions

We derive three main conclusions from our analyses. First, existing IUCN designated areas do not correspond to their expected degrees of naturalness, as measured by Human Footprint, and IUCN categories do not appear to be interpreted consistently across the globe with respect to this characteristic. Second, the global protected areas network lacks large, strictly-protected areas with very low Human Footprint (i.e. a high degree of intactness). While large, natural, and strictly-protected areas will not achieve all conservation goals alone, they do provide many social, economic, and ecological values (Mittermeier et al., 2003) and are important controls for detecting the effects of natural and human disturbances. Finally, given their present condition, IUCN Category VI protected areas should not be discounted with respect to their conservation potential, and should be evaluated along with other designated sites based on measurable criteria.

The global expansion of protected areas is fueled by commitments under the Convention on Biological Diversity to reduce the rate of biodiversity loss by 2010 (Chape et al., 2005; Mace and Baillie, 2007). Setting aside new land for protection is one way to achieve this goal, and reporting areas protected in different IUCN categories is one measure of progress under the Convention. Without a clear and globally consistent alignment between the IUCN categories and their application, protected areas cannot be interpreted consistently relative to conservation objectives and reporting under the Convention may be ineffective or misleading. This issue could be resolved by establishing quantitative criteria for protected-area condition in association with each IUCN category, and by evaluating existing protected area designations (Boitani et al., 2008). While this will not be a trivial exercise, it would ultimately provide a consistent assessment of protective status based on measurable ecological parameters.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2009.11.018.

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