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LETTER

Confronting a biome crisis: global disparities of habitat loss and protection

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Abstract

Human impacts on the natural environment have reached such proportions that in addition to an 'extinction crisis', we now also face a broader 'biome crisis'. Here we identify the world's terrestrial biomes and, at a finer spatial scale, ecoregions in which biodiversity and ecological function are at greatest risk because of extensive habitat conversion and limited habitat protection. Habitat conversion exceeds habitat protection by a ratio of 8 : 1 in temperate grasslands and Mediterranean biomes, and 10 : 1 in more than 140 ecoregions. These regions include some of the most biologically distinctive, species rich ecosystems on Earth, as well as the last home of many threatened and endangered species. Confronting the biome crisis requires a concerted and comprehensive response aimed at protecting not only species, but the variety of landscapes, ecological interactions, and evolutionary pressures that sustain biodiversity, generate ecosystem services, and evolve new species in the future.

Keywords

Biodiversity conservation, ecosystem services, extinction crisis, habitat loss, protected areas.

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INTRODUCTION

There is no question that the loss of individual species is a cause of great concern to conservationists, but we can now appreciate that these extinctions are symptomatic of a global-scale 'biome crisis' that threatens biodiversity loss, ecological dysfunction and consequent impacts to human lives and economies. Confronting this crisis demands that the scope of global conservation priorities expand beyond 'hotspots' of species diversity to emphasize protection of entire at-risk ecosystems. This shift in perspective is a matter of vigorous debate about how global conservation priorities should be set (compare Kareiva & Marvier 2003 and Myers *et al.* 2000), and of practical importance for the conservation of biodiversity.

Here we identify those terrestrial biomes and ecoregions in which biodiversity and ecosystem services are at greatest risk because of disparities in the extent of habitat loss and protection. As humans convert natural habitats, the world's biomes and ecoregions are degraded, and biodiversity and the benefits we derive from it are put at risk. Habitat protection can mitigate this risk, but only if protected areas are distributed in a way that represents the ecosystems at risk, and helps to sustain ecological function.

Biomes are global-scale biogeographic regions, such as tundra or tropical grasslands and savannas, shaped by climate and distinguished from one another by the unique collections of ecosystems and species assemblages that have evolved there. Olson *et al.* (2001) delineated the world's terrestrial biomes and subdivided them into finer-scale ecoregions to define a hierarchy of biogeographic organization from global to regional scales. Nested within biomes, ecoregions reflect finer regional-scale patterns of ecological organization that are shaped by local geography and climate, and are distinguished from one another by the unique assemblages of species and ecosystems found within them. Examples include the Orinoco Delta swamp forests in Venezuela and Australia's Great Victoria desert.

The ecological diversity of species and ecosystems across biomes and ecoregions reflects the remarkable outcomes of biodiversity's evolutionary history and sets the stage for its future (Wilson 1991, Myers & Knoll 2001). In tropical forest biomes and other centres of endemism, evolution yielded extraordinary taxonomic diversity, while in desert ecosystems, it selected for organisms uniquely able to live through extreme heat and drought. In each of the world's biomes and ecoregions, natural ecosystems continue to sustain essential ecological functions that support biodiversity

(Bazzaz 1996). They also provide valuable ecosystem services such as erosion control and water retention that help sustain agriculture and human populations (Daily 1997). The value of these ecosystem services has been estimated at $33 trillion US per year (Costanza *et al.* 1997), and may total as much as 4.5 times the value of the Gross World Product (Boumans *et al.* 2003).

As human activity degrades the world's biomes, we not only shorten the list of species that inhabit the world, but we diminish the variety of landscapes, ecological interactions, and evolutionary pressures that sustain biodiversity (Bazzaz 1996), evolve new species in the future (Myers & Knoll 2001), and generate ecosystem services that benefit people (Daily 1997). The first step in confronting this biome crisis is to identify the biomes and ecoregions where biodiversity and ecological function are at greatest risk so that needed conservation efforts can be directed there.

Our analysis advances on previous assessments by combining globally comprehensive datasets to make consistent comparisons of habitat loss and protection among biomes and ecoregions. Previous analyses were limited to only a subset of the world's biomes (e.g. White *et al.* 2000, FAO 2003), and often focused on habitat loss and protection separately (e.g. compare Hannah *et al.* 1995 and Chape *et al.* 2003), thus obscuring a broader perspective on the magnitude of the biome crisis.

MATERIALS AND METHODS

To identify biomes and ecoregions at greatest risk, we estimated the extent of habitat loss and protection at two spatial scales: first within each of 13 terrestrial biomes, and then within the 810 ecoregions they comprise. We used the classification and mapping of biomes and ecoregions by Olson *et al.* (2001) to define boundaries for our analyses. Olson *et al.* originally defined 14 biomes and 847 ecoregions, but we excluded the mangrove biome and its constituent ecoregions because of spatial mismatches with land cover and protected area data layers used to estimate habitat loss and protection. We also excluded the ecoregions of Antarctica because they were not covered by our land cover data.

The global extent and distribution of habitat loss was evaluated by summarizing a modified version of the Global Land Cover 2000 dataset (GLC 2000) (European Commission Joint Research Centre, Institute for Environment and Sustainability (ECJRC) 2002) to calculate per cent area converted in each biome and ecoregion. The GLC 2000 is a compilation of continental land cover maps that together classify land cover at 1 km resolution for all land masses except Antarctica. We replaced the GLC data for North America and Central America to correct obvious inconsistencies and to more accurately reflect habitat status (Vogelmann *et al.* 2001; USGS 2000; MODLAND 2000; World Bank 2001; DeFries *et al.* 1999). Per cent area converted was calculated as the per cent of land area classified as cultivated and managed areas, and artificial surfaces and associated areas in the modified GLC. We assumed that historically the per cent area converted in each biome and ecoregion was zero.

The global extent and distribution of habitat protection were evaluated by summarizing the 2004 World Database on Protected Areas (WDPA) (WDPA Consortium 2004) to calculate the per cent area of each biome and ecoregion covered by a designated protected area. The WDPA is the most comprehensive global catalogue of protected areas, and includes data about their sizes, locations and World Conservation Union (IUCN) classifications of management designation. Protected areas in categories I–IV were explicitly designated for biodiversity protection while those in categories V and VI were designated with multiple-management objectives (IUCN 1994). We included all categories of protected areas in our estimates. The WDPA was assembled by a broad alliance of organizations who aim to maintain a freely available, accurate and current database that is accepted as a global standard by all stakeholders. In calculating per cent area protected in each terrestrial biome and ecoregion, we excluded records from the WDPA that were identified as marine protected areas, lacked location data, or had non-permanent status. Protected areas with only point location and area data were mapped as circles with appropriate radii. Portions of protected areas that extended into marine environments were clipped out. Overlapping protected areas were combined to avoid double-counting errors.

RESULTS

Biomes at risk

Globally, 21.8% of land area has been converted to human-dominated uses. Habitat loss has been most extensive in tropical dry forests (69% converted in SE Asia), temperate broadleaf and mixed forests, temperate grasslands and savannas (> 50% lost in North America), and Mediterranean forests, woodlands and scrub. Meanwhile, tundra and boreal forest biomes remain almost entirely intact (Fig. 1). These statistics do not factor in sub-kilometre land conversion or non-converting habitat degradation (e.g. grazing, selective logging), and so represent minimum estimates of the extent of habitat loss. Such additional modes of habitat degradation have not been comprehensively or consistently evaluated, so their extent cannot be directly compared. However, we expect that these factors will generally correlate positively with habitat conversion such that per cent converted is a reasonable indicator at the scale of this analysis.

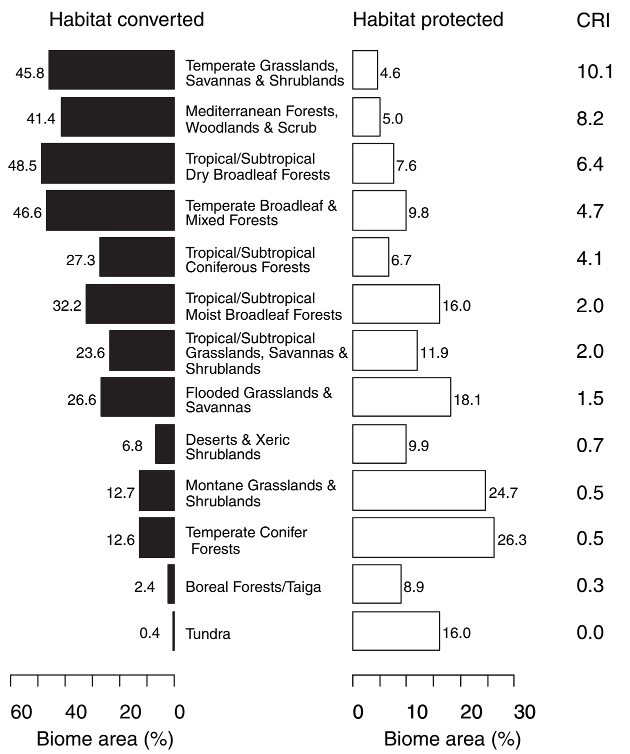

Figure 1 Habitat conversion and protection in the world's 13 terrestrial biomes. Biomes are ordered by their Conservation Risk Index (CRI). CRI was calculated as the ratio of per cent area converted to per cent area protected as an index of relative risk of biome-wide biodiversity loss.

The world's network of protected areas covers 11.9% of all terrestrial land area, although those designated explicitly for biodiversity protection (IUCN categories I–IV, IUCN 1994) only span 5.1% of land area. Habitat protection is most concentrated in temperate conifer forests and montane grasslands and shrublands. Tundra and the flooded grasslands and savannas (e.g. the Everglades) are also relatively well protected. Temperate grasslands and savannas, and Mediterranean forests, woodlands and scrub are the least protected biomes (Fig. 1). We did not consider management effectiveness in this analysis because consistent and comprehensive data were not available.

Biomes with intermediate levels of habitat conversion appear to have greater habitat protection, while those with very low and very high levels of land conversion have only limited protection (Fig. 2a, adj. $R^2 = 0.6$). It is reasonable to assume that biomes with negligible habitat loss have not prompted the designation of protected areas. However, it is disturbing that so little habitat has been protected in biomes in which 30–50% of habitat area has already been lost. Certainly, as more habitat is converted, there is less habitat left to protect. But this inherent trade-off is only a partial explanation for the observed pattern. It persists even after recalculating the per cent area protected relative to non-converted habitat area (Fig. 2b).

Two biomes stand out as being at greatest risk because of extensive habitat loss and under-protection: temperate grasslands and savannas, and Mediterranean forests, woodlands and scrub. In these biomes, the extent of habitat conversion exceeds that of habitat protection by a factor greater than 8. We refer to this conversion-to-protection ratio as the 'Conservation Risk Index' (CRI). Temperate broadleaf and mixed forests, tropical dry forests, and tropical conifer forests are at intermediate risk with CRI > 4. In all other biomes, CRI ≤ 2 (Fig. 1).

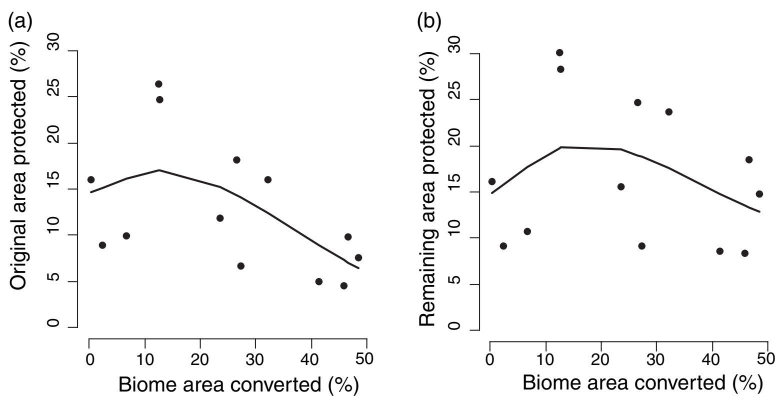

Figure 2 (a) Cubic spline (3 d.f.) fit to relationship between per cent area converted and per cent area protected for the 13 terrestrial biomes of the world. Adj. $R^2 = 0.6$ from general additive model (GAM). (b) Cubic spline (3 d.f.) fit to relationship between per cent area converted and per cent of remaining area protected data for each terrestrial biome. Adj. $R^2 = 0.10$ from GAM. Estimates of per cent of remaining area protected were calculated by dividing the total protected area in each biome by the area of non-converted land cover in each biome. Although this relationship appears less pronounced, biomes with intermediate levels of habitat conversion still have greater levels of habitat protection, while biomes with very low or very high habitat conversion have less.

Ecoregions at risk

Within biomes, the biome crisis is playing out ecoregion by ecoregion. The extent of habitat conversion ranges from less than 1% in 167 of 810 terrestrial ecoregions, to more than 50% in 202 ecoregions. Habitat protection exceeds 25% in 162 ecoregions, but remains less than 2% in 158 others. The relationship between habitat conversion and protection among ecoregions is negative (slope = −0.18, $P < 0.001$, $R^2 = 0.06$), suggesting a general tendency for protection efforts to decline as larger and larger proportions of ecoregions are converted to human-dominated uses.

To identify at-risk, or crisis ecoregions, we calculated the CRI in every ecoregion, and categorized 305 as Vulnerable, Endangered, or Critically Endangered based on their CRI. Ecoregions in which habitat conversion > 20% and CRI > 2 were classified as Vulnerable ($n = 161$); those in which conversion > 40% and CRI > 10 were classified as Endangered ($n = 80$); and those with conversion > 50% and CRI > 25 were classified as Critically Endangered ($n = 64$) (Fig. 3). The categories were defined to be analogous to those established for IUCN Red List species (IUCN 2001).

Crisis ecoregions are found on every continent (except Antarctica which was excluded from this analysis) and represent every biome except tundra and boreal forests (Fig. 4). Many of these ecoregions have also been prioritized for conservation on the basis of their biological distinctiveness and exceptional species richness – 134 (44%) are included in the WWF Global 200 (Olson & Dinerstein 1998) and 153 (50%) overlap with CI biodiversity hotspots (Myers *et al.* 2000). The crisis ecoregions are also home to 249 of 595 (42%) IUCN Red-listed vertebrate species known from only single locations (Alliance for Zero Extinction, unpublished data).

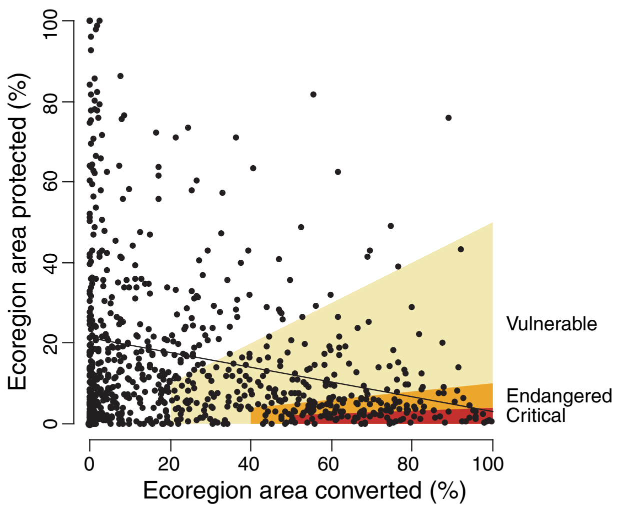

Figure 3 Classification of crisis ecoregions as Vulnerable, Endangered, and Critically endangered. Scatterplot shows relationship between per cent area converted and per cent area protected in each of 810 terrestrial ecoregions (slope = −0.18, $R^2 = 0.06$). Ecoregions with > 50% habitat conversion and Conservation Risk Index (CRI) > 25 are classified as Critically endangered (red); ecoregions with > 40% conversion and CRI > 10 are classified as endangered (orange); and those with > 20% conversion and CRI > 2 are classified as Vulnerable (yellow). CRI for each ecoregion was calculated as the ratio of per cent area converted to per cent area protected.

DISCUSSION

Our analysis reveals a biome crisis emerging from substantial and widespread disparities between habitat loss and protection across ecoregions and, at a global scale, across entire biomes. These disparities are especially stark for temperate grassland and Mediterranean scrub biomes (Fig. 1), and for crisis ecoregions classified as Vulnerable, Endangered and Critically Endangered (Fig. 4). Just recognizing the biome crisis is not sufficient, though.

The risks of loss of biodiversity and ecological dysfunction call for a concerted conservation response that is commensurately global in scope. Identification of biomes at risk – e.g. temperate grasslands and Mediterranean scrub – underscores the global magnitude of the biome crisis and points to high-level priorities around which international funding agencies, governments and conservation organizations can coordinate. The map of crisis ecoregions yields a more specific perspective on where biodiversity and ecological function are at greatest risk, and identifies regions within which on-the-ground conservation action should be focused. Within these regions, effective management of existing protected areas, and strategic designation of additional areas can maximize representation of biodiversity, and ensure that ecological function is not further eroded. Methods for conservation planning within ecoregions and at individual sites have been developed to promote these objectives (Margules & Pressey 2000; Groves 2003). By improving the degree and distribution of habitat protection both within and among biomes and ecoregions, we will capture the greatest breadth of ecological diversity of both species and ecosystems (Olson & Dinerstein 1998). This sort of approach has already been implemented by Australia to inform development of a comprehensive National Reserve System (Commonwealth of Australia 1999).

For years now, we have been alerted to the crisis of species loss (Wilson 1991, Pimm *et al.* 1995, Myers & Knoll 2001), especially in tropical rainforests and other species-rich 'hotspots'. But, our analysis suggests that the tropical rainforest biome is at relatively lower risk (CRI = 2) compared to at-risk biomes such as Mediterranean forests, woodlands and scrub (CRI = 8) that also contains hotspots

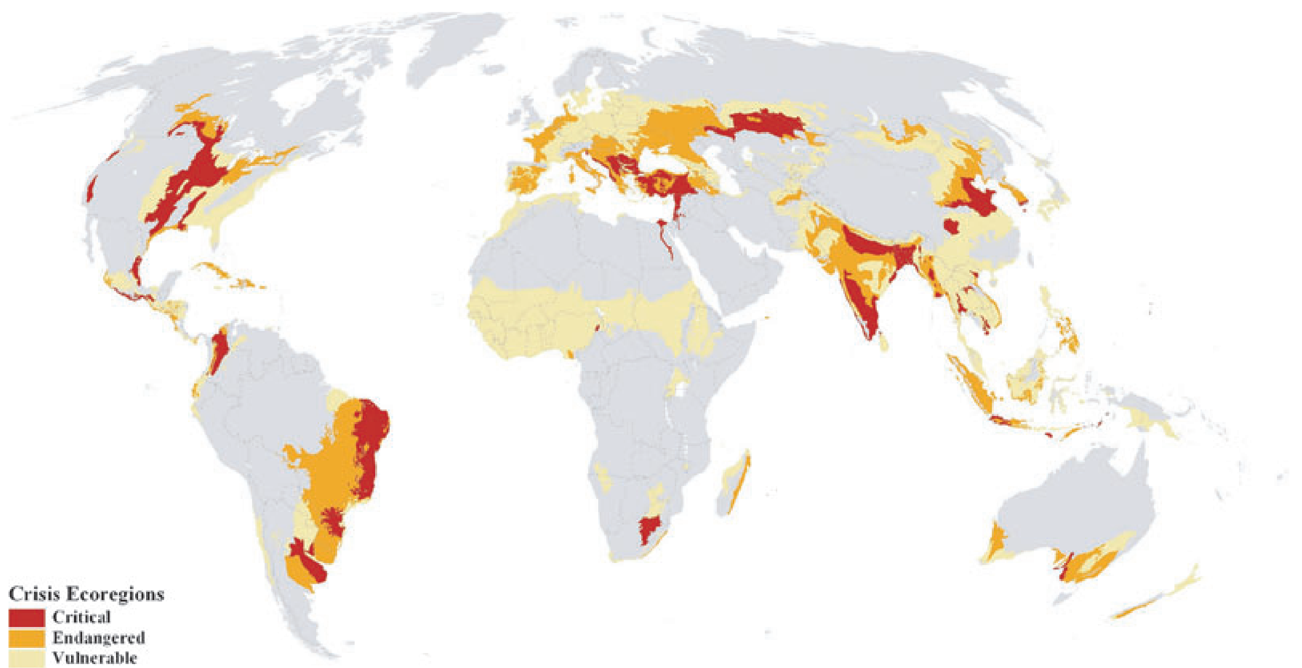

Figure 4 Map of crisis ecoregions. Vulnerable, Endangered, and Critically endangered, ecoregions were classified as described in text and shown in Fig. 3.

of species diversity and endemism (Myers *et al.* 2000). Furthermore, the regional disparities between habitat loss and protection, especially within the 144 Endangered and Critically Endangered ecoregions with CRI > 10, represent a much starker and potentially more serious conservation gap than that suggested by a recent assessment that reported the world's current protected area network to already cover nearly 88% of vertebrate species included in that analysis (Rodrigues *et al.* 2004).

Surely, we should strive to represent the full diversity of threatened species within the world's protected area network, and conservation efforts should continue in tropical biomes and other species-rich ecoregions where large numbers of species could face extinction. But such efforts would only assure protection to the small and taxonomically biased percentage of threatened species that have been named (Gewin 2002), and would represent only a fraction of the world's ecological diversity. Our analysis clearly shows that the scope of global conservation priorities needs to reflect a much broader perspective on biodiversity and risk. We need to be equally, perhaps even more vigilant about protecting threatened ecosystems if we hope to avert the biome crisis. Otherwise, we may succeed at conserving examples of the taxonomic diversity of life on Earth, but fail to maintain the ecosystems and ecological function that sustain those species and the valuable ecosystem services we derive from each of the world's biomes and ecoregions.

This perspective on where biodiversity is at greatest risk around the world goes to the heart of a vigorous discussion about how global conservation priorities should be set. Prioritization of biodiversity 'hotspots' (e.g. Myers *et al.* 2000) has been enormously influential, but has come under repeated criticism for being too narrowly focused on concentrations of species diversity in the tropics without adequate regard for the importance of ecological representation (e.g. Olson & Dinerstein 1998) or ecological function and ecosystem services (e.g. Jepson & Canney 2001, Kareiva & Marvier 2003). Our analysis draws particular attention to biomes and ecoregions where species, communities and ecosystems are all at risk because of disparities in habitat loss and protection. We do not presume our analysis to singularly redefine global conservation priorities, but we do assert that the urgency of the looming biome crisis should weigh heavily alongside considerations of representation of ecological diversity (Olson & Dinerstein 1998) and the vulnerability and irreplaceability of unique species (IUCN 2003, Rodrigues *et al.* 2004).

Fortunately, momentum for confronting the biome crisis is building. In 2003, the Vth IUCN World Parks Congress celebrated expansion of the world's protected area network over the last decade, while highlighting the need for better representation of the world's biomes and ecoregions (IUCN World Parks Congress 2003). Shortly thereafter, in 2004, parties to the Convention on Biological Diversity affirmed their commitment to complete designation of comprehensive national networks of protected areas by 2010 (COP-7 2004). At the same time, a consortium of private conservation organizations (including those of the authors) pledged their support for conducting necessary gap analyses, completing systematic conservation plans, and enhancing management effectiveness of protected areas (Birdlife International, Conservation International, Greenpeace, The Nature Conservancy, Wildlife Conservation Society, WWF, World Resources Institute 2003). These public–private partnerships promise to advance comprehensive conservation efforts at the global scale necessary for confronting the biome crisis.

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SUPPLEMENTARY MATERIAL

All of the data used in these analyses are freely available on the internet. Map files of biomes and ecoregions are available at http://www.worldwildlife.org/science/data/terreco.cfm. The GLC 2000 land cover data are available at http://www.gvm.sai.jrc.it/glc2000. The 2004 World Database on Protected Areas is available at http://maps.geog.umd.edu/WDPA/index.html.

The following material is available from http://www.blackwellpublishing.com/products/journals/suppmat/ELE/ELE686/ELE686sm.htm

Appendix S1 Output from modified version of the GLC2000 database used in analysis (0.4 Mb, jpg file).

Appendix S2 Modified version of the GLC2000 database used in analysis (35 Mb, zipped GIS database file).

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