Wilderness and biodiversity conservation

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Human pressure threatens many species and ecosystems, so conservation efforts necessarily prioritize saving them. However, conservation should clearly be proactive wherever possible. In this article, we assess the biodiversity conservation value, and specifically the irreplaceability in terms of species endemism, of those of the planet's ecosystems that remain intact. We find that 24 wilderness areas, all ≥1 million hectares, are ≥70% intact and have human densities of less than or equal to five people per km². This wilderness covers 44% of all land but is inhabited by only 3% of people. Given this sparse population, wilderness conservation is cost-effective, especially if ecosystem service value is incorporated. Soberingly, however, most wilderness is not speciose: only 18% of plants and 10% of terrestrial vertebrates are endemic to individual wildernesses, the majority restricted to Amazonia, Congo, New Guinea, the Miombo–Mopane woodlands, and the North American deserts. Global conservation strategy must target these five wildernesses while continuing to prioritize threatened biodiversity hotspots.

The concept of wilderness is ancient. The word itself is derived from the Norse *will* (uncontrolled) and *deor* (animal), evolving to its biblical use as "uncultivated" (1). The term began to gain positive connotations through the Romantic and Transcendentalist writers and Hudson River School of landscape painters in the 19th century, fledging into a conservation movement with the writings of Muir, Audubon, and others. The concept first entered a regulatory context in 1929, building up to the U.S. Wilderness Act of 1964, which established the standards for protection of wilderness on federal lands. Countries as diverse as Australia, Canada, Finland, and South Africa now have similar wilderness legislation. A wilderness area is defined in The World Conservation Union (IUCN) Framework for Protected Areas as "a large area of unmodified or slightly modified land and/or sea, retaining its natural character and influence, which is protected and managed so as to preserve its natural condition" (2). Building from "good news areas" (3) and "major tropical wilderness areas" (4), we now expand the focus of the wilderness concept beyond specific protected areas to inform global conservation strategies.

The units of analysis for this study were based largely on the world's terrestrial ecoregions (5). Where these ecoregions could be combined into broader biogeographic units, such as Amazonia, we aggregated them into single units. To select only ecosystems of global significance, we set a minimum size for inclusion in the analysis as 10,000 km². As a preliminary assessment of ecoregions for inclusion as wilderness areas, we overlaid a binary classification of human population density data (6) outside of urban areas as greater than and less than five people per km² (rounding down), retaining only the latter for subsequent analysis (we subsequently also identified areas with approximately one person or less per km²). We then conducted an extensive literature search and contacted >200 specialists on these potential wilderness areas, compiling data on intactness, biodiversity, human populations, threats, and existing conservation initiatives. We used intactness (7) as a further criterion for inclusion, stipulating that an area must retain at least 70% of its historical habitat extent (500 years ago) to be considered a wilderness area. These data are less precise than the other data used here, with sources ranging from detailed remote sensing assessments through to the opinion of regional specialists, and so we use only one significant figure for intactness throughout.

In total, this analysis identified 24 wilderness areas (Fig. 1). These fall into nine terrestrial biome types (8): Tropical Humid Forest (three areas, 12% of total area); Tropical Dry Forests and Tropical Grasslands (three areas, 4% of total area); Warm Deserts/Semideserts and Cold-Winter Deserts (seven areas, 30% of total area); Mixed Mountain Systems, Temperate Rainforests, and Temperate Needleleaf Forests (five areas, 23% of total area); and Tundra Communities and Arctic Desert (two areas, 30% of total area); plus four relatively small wetland wildernesses (1% of total area). Six additional regions (the Appalachians, the European mountains, the Sudd swamp, the Serengeti, the Brazilian Caatinga, and the Peruvian and Chilean coastal deserts) came close to but failed to meet the thresholds. The total historical area of the 24 wildernesses was 76 million km², 52% of the Earth's land area, of which 65 million km² remains intact, covering 44% of the planet (Table 1, and see Table 3, which is published as supporting information on the PNAS web site, www.pnas.org). The total human population of these areas is 204 million (3% of the global total), which is reduced to 83 million (1.4%) when urban areas are excluded (Table 1 and see Table 3), giving an average rural population density of 1.1 people per km².

Considering only those 16 wilderness areas with rural human population densities of less than approximately one person per km², the results are even more striking. Together, these areas covered 66 million km² (45% of the land's surface), of which ~90% remains intact, accounting for 57 million km² (39% of the land's surface), an area equivalent to the world's six largest countries combined. A third of this area is under permanent ice, making habitation impossible; in total, this vast area holds just 43 million people, or 0.7% of Earth's human population.

This study provides an assessment of the biodiversity value of remaining wilderness areas. About 55,000 vascular plant species (18% of the global total) and 2,800 terrestrial vertebrate species (10%) are endemic to the wilderness areas (Table 2, and see Table 4, which is published as supporting information on the PNAS web site). The disparity between the plant and the vertebrate percentages is probably explained by the much smaller mean range size of plants (9). However, even for plants, and even given that many wilderness areas are poorly studied (10), this percentage is clearly far lower than would be expected were endemic species distributed across ecoregions in proportion to land area. Further, the vast majority of these species are concentrated into just five high-biodiversity wilderness areas: Amazonia, the Congo forests of Central Africa, New Guinea, the Miombo–Mopane woodlands of Southern Africa (including the Okavango Delta), and the North American desert complex of northern Mexico and the southwestern U.S. The intact portion of these five wildernesses covers 8,981,000 km² (76% of their

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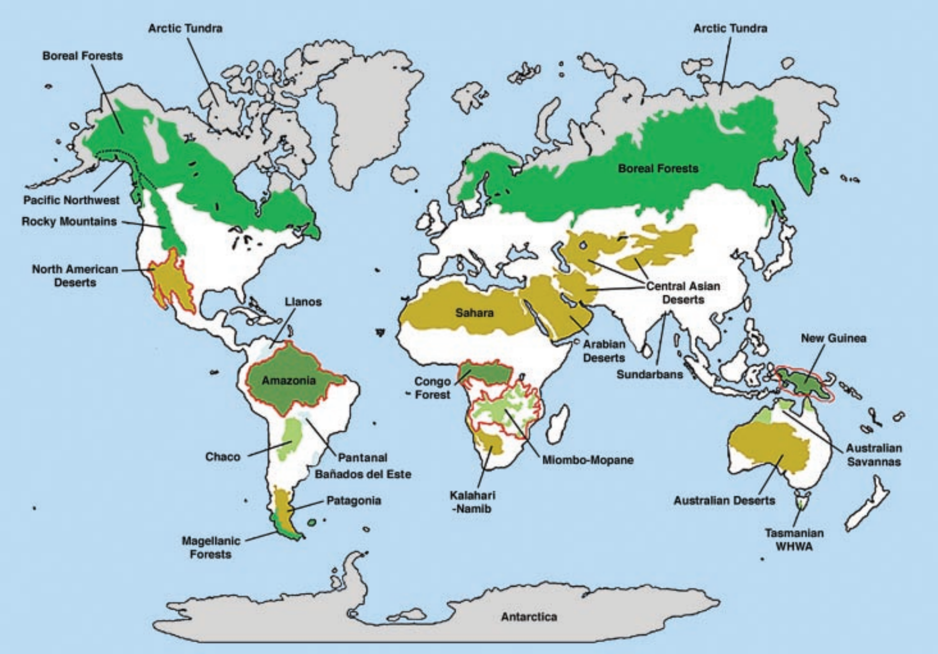

Fig. 1. Overall map showing wilderness areas, human population density less than or equal to five people per km^2, with biomes shaded, and the five high-biodiversity wilderness areas outlined in red.

Table 1. Extents of the 24 wilderness areas, their human populations, and their levels of protection

			Population†			
Biome and wilderness	Area,* km^2	Intact,* %	Total	Minus urban	People per km^2†	Protected areas,‡ %
Tropical humid forest						
Amazonia	6,683,926	80	21,430,115	7,355,126	1.1	8.3
Congo forest	1,725,221	70	16,000,000	10,000,000	5.8	8.1
New Guinea	828,818	70	6,000,000	4,197,200	5.1	11
Tropical dry forests and grasslands						
Chaco	996,600	70	2,810,000	648,693	0.65	7.5
Miombo–Mopane	1,176,000	90	5,839,000	3,816,000	3.2	36
Australian savannas	585,239	100	60,730	24,188	0.041	11
Mixed mountain, temperate rain, and temperate needleleaf forest						
Rocky Mountains	570,500	70	1,574,986	1,035,174	1.8	17
Pacific Northwest	315,000	80	770,000	597,095	1.9	48
Magellanic forests	147,200	100	253,264	34,501	0.23	72
Tasmanian WHWA	13,836	90	8	8	0.000058	100
Boreal forests	16,179,500	80	30,337,925	15,438,546	0.95	3.8
Wetland						
Llanos	451,474	80	4,444,243	1,065,956	2.4	15
Pantanal	210,000	80	1,125,200	81,200	0.38	2.7
Bañados del Este	38,500	80	200,000	40,000	1.0	2.8
Sundarbans	10,000	80	3,000	3,000	0.30	31
Warm and cold-winter deserts						
North American deserts	1,416,134	80	15,348,342	4,509,403	3.2	23
Patagonia	550,400	70	800,000	200,000	0.36	4.1
Sahara	7,780,544	90	35,187,620	10,273,595	1.3	2.8
Kalahari–Namib	714,700	80	1,422,700	425,900	0.60	25
Arabian deserts	3,250,000	90	47,000,000	15,000,000	4.6	8.3
Central Asian deserts	5,943,000	80	9,000,000	5,500,000	0.93	2.8
Australian deserts	3,572,209	90	400,000	285,000	0.080	9.4
Tundra						
Arctic tundra	8,850,000	90	4,288,613	2,385,713	0.27	20
Antarctic	13,900,000	100	1,000	1,000	0.000072	0.025
Total	75,908,801	90	204,296,746	82,917,298	1.1	7.5

WHWA, World Heritage Wilderness Area.

*Area of each of wilderness area and percentage intactness (one significant figure). Areas must exceed 10,000 km^2 and 70% intactness to qualify as wildernesses.

†Human population, human population outside of urban areas, and human population density (two significant figures) of each wilderness area.

‡Percentage (two significant figures) of each wilderness area under protected area status (IUCN categories I–IV).

Table 2. Biodiversity of the 24 wilderness areas, in terms of species richness (*R*) and endemism (*E*) for vascular plants, mammals, birds, reptiles, and amphibians

	Plants		Mammals		Birds		Reptiles		Amphibians	
Biome and wilderness	*R*	*E*	*R*	*E*	*R*	*E*	*R*	*E*	*R*	*E*
Tropical humid forest										
Amazonia	40,000	30,000	425	172	1,300	263	371	260	427	366
Congo forest	9,750	3,300	275	39	698	8	142	15	139	28
New Guinea	17,000	10,200	233	146	650	334	275	159	237	215
Tropical dry forests and grasslands										
Chaco	2,000	90	150	12	500	7	117	17	60	8
Miombo–Mopane	8,500	4,600	336	14	938	54	301	69	138	33
Australian savannas	3,176	594	219	13	343	4	214	66	44	15
Mixed mountain, temperate rain, and temperate needleleaf forest										
Rocky Mountains	1,414	22	92	1	264	0	14	0	14	2
Pacific Northwest	1,088	7	80	3	227	0	8	0	10	0
Magellanic forests	450	35	42	2	121	0	2	1	11	2
Tasmanian WHWA	924	62	32	2	121	0	13	2	7	1
Boreal forests	2,000	200	196	0	650	0	16	0	36	0
Wetland										
Llanos	3,424	40	198	3	475	1	107	1	48	6
Pantanal	3,500	0	124	0	423	0	177	0	41	0
Bañados del Este	1,300	5	79	0	311	0	33	0	31	0
Sundarbans	334	0	54	0	174	0	14	0	3	0
Warm and cold-winter deserts										
North American deserts	5,740	3,240	197	32	248	4	225	93	53	7
Patagonia	1,221	296	60	4	211	10	47	19	12	5
Sahara	1,600	188	124	14	360	0	82	7	12	0
Kalahari–Namib	1,200	80	103	2	341	3	105	18	19	0
Arabian deserts	3,300	340	102	10	213	2	108	52	8	4
Central Asian deserts	2,500	750	82	27	90	6	100	20	6	0
Australian deserts	3,000	150	98	14	346	3	340	83	34	5
Tundra										
Arctic tundra	1,125	100	115	10	379	1	3	0	10	0
Antarctic	60	0	6	0	49	1	0	0	0	0
Total	—	54,299	—	520	—	701	—	882	—	697

original extent), 6.1% of the planet's land area. Between them they hold >51,000 vascular plants (17% of the global total) and 2,300 terrestrial vertebrates (8% of the global total) as endemics. Even for these five areas, the concentration of biodiversity pales in comparison to that of the 25 biodiversity hotspots (11), which hold nearly 3 times as many endemics in an area one-fourth as large.

Of the 76 million km^2 covered by the wilderness areas, <6 million km^2 (7%) fall within protected areas of the IUCN categories I–IV. Coverage varies enormously (Tables 1 and 3), from minimal (e.g., Antarctica, 0.025%) to total (Tasmanian World Heritage Wilderness Area, 100%) but is generally inadequate given the threats facing these regions. Of 15 nonmutually exclusive threat categories (Fig. 2), agriculture, grazing, hunting, invasive species, logging, and mining are the most pervasive, each affecting more than half of the wilderness areas. Disconcertingly, all but grazing affect four or more of the high-biodiversity wilderness areas. Several threats are concentrated into particular biome types: logging and fire disproportionately affect forest; grazing, drainage, pollution, and dams disproportionately affect wetlands and deserts. Although these threats are pervasive in scope, as demonstrated by the presence of DDT residues in Adelie penguins (*Pygoscelis adeliae*), for example (12), they are currently minor in severity compared with those facing the rest of the planet (13).

Our results clearly depend on the ecoregions on which our units of analysis are based, which, although not universally accepted, constitute the most up-to-date global land classification available (14). The only global assessments of wilderness to date have used the alternative approach of measuring continuous variables: infrastructure across 4,000-km^2 cells (15); or a combined score of population, urbanization, transport networks, and power infrastructure (16). However, analysis of such continuous variables requires use of weighted scoring no less arbitrary than the threshold approach used here. Further, reliance on population data and infrastructure surrogates such nocturnal lights (17) will inevitably miss the large areas heavily transformed by agriculture and grazing (18). Nevertheless, both of these studies (15, 16) produced wilderness maps remarkably similar to ours, although with lower overall areas of wilderness because of their use of more severe thresholds, for example, <1 person per km^2 (16). The earlier study (15) was subsequently refined by overlaying habitat data, which suggested that only 22% of the planet's original forest cover remains as undisturbed "frontier forests" (19), including much of the eight forest wildernesses identified by us. Further, synthetic studies suggest that >40% of net primary productivity is appropriated by humans (20, 21), which is also broadly consistent with our finding that just under half of the planet remains wild.

What other biases might influence our results? Our definition of intactness as the proportion of historical habitat remaining clearly gives a temporal threshold, in the same way as ecoregions frame the study with spatial thresholds. Much of the world was heavily modified by prehistoric human activity through the Pleistocene (22). This is most notable, perhaps, in Australia, where the extent of anthropogenic megafaunal extinction was such that none of the continent can be considered in any way "pristine" (23). Another obvious important limitation is our

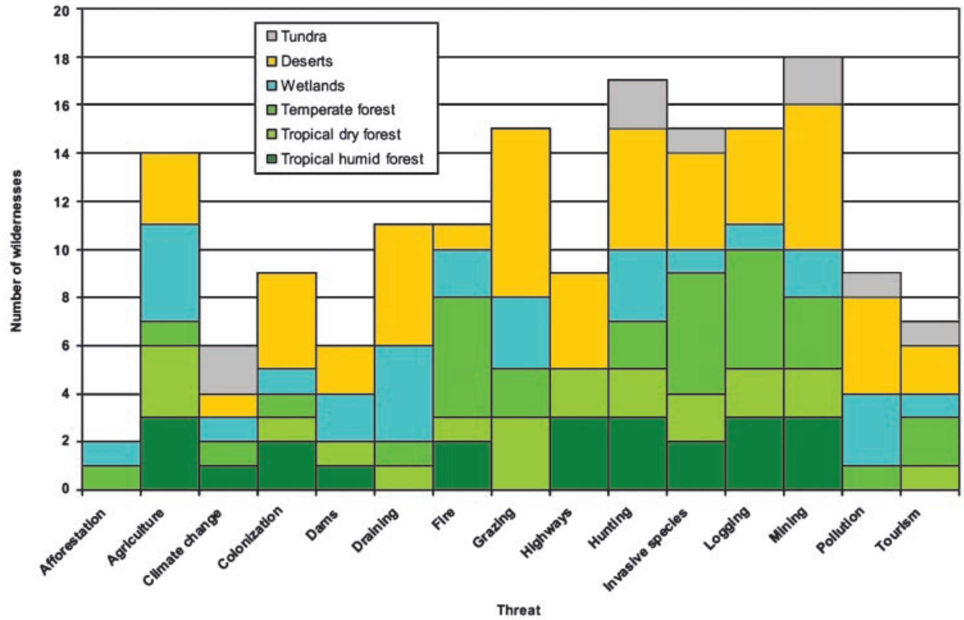

Fig. 2. Threats to the wilderness areas (categories are not mutually exclusive), shaded by biome.

concentration in the terrestrial realm, although human appropriation of 60% of freshwater (24) and 35% of ocean shelf productivity (25) suggests that the intact proportion of these realms is comparable to that of land.

With the exception of the five high-biodiversity wilderness areas, this study reveals that the targets of biodiversity conservation and of wilderness conservation are generally different (26). Although they surely hold the bulk of the planet's biomass and also the last remaining intact megafaunal assemblages, the wilderness areas hold many fewer species than expected. This is unsurprising, given the correlation between human population density and biodiversity (27). However, these areas are of great importance for numerous other reasons (28). The ecosystem services they provide have enormous value (29), for example, through hydrological control, nitrogen fixation, pollination, and carbon sequestration, in addition to providing destinations for ecotourism and adventure tourism. The wilderness areas serve as valuable controls against which to measure the health of the planet (30). The coincidence between areas of biological and cultural diversity, at least in Africa (31), also means that the high-biodiversity wilderness areas provide the last strongholds for many of the world's languages (32). Finally, there are strong aesthetic, moral, and spiritual values of wilderness, permeating all cultures and religions, and providing a firm imperative for its conservation (33).

The value of wilderness can be further put into perspective if the cost of its conservation is considered. The low population densities of wilderness areas suggest that land values and hence costs of endowing conservation and management will be relatively inexpensive, maybe \$10/hectare in the high-biodiversity wilderness areas, for example (34). Thus, these five areas could be protected with an investment of ~\$10 billion. To conserve wilderness globally might cost 5 times this, given that the rest of the planet's wilderness is 6 times larger but less productive for agriculture, and so presumably cheaper per hectare. Estimated globally, the cost-to-benefit ratio of conserving wild nature is estimated as 1:100 (35). Given the opportunity costs of not undertaking conservation (and hence investing in marginal development) we suspect that this disparity will increase markedly in the wilderness areas. Conservation of the remaining wild half of the planet, through an integrated strategy of protection, zoning, and carefully implemented best practices in industry and agriculture, would be a strikingly good bargain.

Of course, this is not to suggest that the wilderness areas are *terra nullius*, empty lands (36), but rather that they lie at one end of a continuum of human impact (13). Further, the unfortunate coincidence among biodiversity, threat, and human populations (37) means that most conservation should remain concentrated at the other end of this continuum, in the hotspots of biodiversity (11). Thus, the low cost and great value to humanity of the world's remaining wildernesses better justify their conservation than does their biodiversity. However, efficient global biodiversity conservation should focus on a two-pronged strategy targeting the 6.1% of the land's surface covered by the five high-biodiversity wilderness areas as well as the 1.4% covered by the hotspots. Such a strategy could conserve more than one-sixth of species as endemic to the high-biodiversity wildernesses and more than one-third to the hotspots, and the biodiversity conservation community would be wise to allocate their scarce resources accordingly.

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